The Encyclopaedia of Radio and Television

THE ENCYCLOPAEDIA OF RADIO AND TELEVISION

768 PAGES

Over 750 Special Drawings

Over 3,000 Entries

THIS completely new, up-to-date and authoritative illustrated reference book for everyone connected with radio, radar and television today is the work of thirteen distinguished experts.

Arranged in A-Z order are over 3,000 detailed entries, a complete guide to all terms used in the theory and practice of modern telecommunication techniques. This encyclopaedia is a reliable source of "refresher" information for practising engineers and experienced amateurs, while the student and apprentice will find it a thorough, comprehensive guide to modern terminology and practice.

Definitions are in language understandable to the reader with no prior knowledge of radio. Complex mathematical explanations are avoided. The work is cross-referenced with exceptional thoroughness.

It is illustrated with over 750 line drawings, especially commissioned for this volume.

The hundreds of subjects covered include :—

Aerials . . . Amplification . . . Audio-frequency transmission . . . Broadcasting . . . Communication systems . . . Detection . . . Direction-finding . . . Distortion . . . Electrical Machinery . . . Fundamentals . . . Interference . . . Measuring instruments . . . Modulation . . . Oscillators . . . Power distribution . . . Power supply . . . Radio components . . . Receivers . . . Senders . . . Speech and hearing . . . Symbols, abbreviations, prefixes . . . Transmission (general) . . . Units . . . Valves . . . Vision- frequency Transmission . . . Wave progagation.

CONTRIBUTORS.

S. W. Amos, B.Sc. (Hons.), Grad. I.E.E.
E. J. Clayton P. P. Eckersley, M.I.E.E.
C. F. Ellis, B.Sc. (En.)
E. T. G. Emery, A.M.I.E.E., A.M.I.Mech.E.
G. P. Kendall, B.Sc. J. W. Godfrey
G. A. Graham, Assoc. I.E.E.
L. F. Ostler, Assoc. I.E.E.
H. H. Reyner, A.C.G.I., B.Sc. (Hon.), D.I.C., M.I.E.E., M.Inst.R.E.
J. Rogers K. Rogers
M. G. Scroggie, B.Sc., A.M.I.E.E.

THE ENCYCLOPAEDIA OF RADIO AND TELEVISION

A COMPLETE ALPHABETICAL
REFERENCE TO ALL ASPECTS
OF MODERN
RADIO TECHNOLOGY

ODHAMS PRESS LIMITED
LONG ACRE, LONDON

TECHNICAL CONSULTANT

J. H. REYNER,
A.C.G.I., B.Sc.(Hons.), D.I.C., M.I.E.E., M.Inst.R.E.

PRINCIPAL CONTRIBUTORS

And Main Subjects Covered

S. W. AMOS, B.Sc.(Hons.), Grad.I.E.E.
Appreciation of Sound; Negative Feedback.

E. J. CLAYTON
Measuring Instruments.

P. P. ECKERSLEY, M.I.E.E.
Broadcasting; Frequency-changing; Modulation; Power Supply; R.F. Transmission; Valves.

C. F. ELLIS, B.Sc.(Eng.)
Radio Components.

E. T. G. EMERY, A.M.I.E.E., A.M.I.Mech.E.
Electrical Machinery.

G. P. KENDALL, B.Sc.
Aerials and Feeders; Direction-finding; Radio Fundamentals; Receivers.

J. W. GODFREY
A.F. Transmission; Communication Systems.

G. A. GRAHAM, Assoc.I.E.E.
Wave Propagation.

L. F. OSTLER, Assoc.I.E.E.
Testing and Fault-tracing.

J. H. REYNER, A.C.G.I., B.Sc.(Hons.), D.I.C., M.I.E.E., M.Inst.R.E.
Detection.

J. ROGERS
Oscillators and Senders.

K. ROGERS
Radar; Television Transmission and Reception.

M. G. SCROGGIE, B.Sc., A.M.I.E.E.
Distortion in Receivers and Amplifiers; Radio Interference.

First Published 1950

Made and Printed in Great Britain by
ODHAMS (WATFORD) LTD., WATFORD

THE
ENCYCLOPAEDIA
OF RADIO
AND TELEVISION

HOW TO USE
THIS ENCYCLOPAEDIA

THIS ENCYCLOPAEDIA has been produced primarily to provide easy reference to all the major aspects of modern radio and television. It will meet the requirements of students and practising engineers, as well as those of all radio amateurs. The treatment is simple but, at the same time, completely authoritative; accuracy has not been sacrificed on the altar of simplicity.

Entries are arranged in strict alphabetical order, irrespective of hyphenation and whether two or more words comprise a term. Adequate cross-references are given throughout; where it is useful or necessary to refer to other entries for further information, suitable references are printed, for clarity, in small capital letters.

Wherever it has been considered helpful, the text has been illustrated by pictures and diagrams. All illustrations are given Fig. numbers, commencing at 1 for each separate alphabetical section, and are appropriately referred to in the text.

Much thought has been given to the choice of terms included, bearing in mind that some of those employed in the early days of radio were ill-chosen and have since lost their original meaning. In general, definitions are confined to terms accepted or given preference by responsible bodies, and to those in regular use by qualified radio engineers. Certain obsolescent and deprecated terms still in use have been entered, however, but with a cross-reference to their preferred counterparts. For example, under *radio transmitter* the reader is referred to *sender*, under *coil* to *inductor*, under *condenser* to *capacitor*. . . . These accord with recommendations of the British Standards Institution.

Despite the fact that mathematics often enters largely into the present-day study of radio and allied subjects, it has been reduced to a minimum in the body of the encyclopaedia so as to ensure that readers who are not mathematically inclined may take full advantage of the definitions and practical information. In the Reference Section at the back of the book, however, a selection of useful formulae is given, along with worked examples.

The Reference Section will be of particular value to those readers who are interested in a quantitative treatment of the subject, for it includes Abacs and formulae relating to inductance, capacitance, resonant circuits, stage gain, amplification, transformer ratios, negative feedback, oscillators, aerials, and feeders. There are also logarithm tables and copper-wire data.

THE EDITOR.

ABBREVIATIONS

The following common and technical abbreviations have been employed in the compilation of this encyclopaedia:

A.C.	alternating current
A.F.	audio frequency
A.G.C.	automatic gain-control
Ah.	ampere-hour(s)
amp.	ampere(s)
approx.	approximately
B.S.S.	British Standard Specification
B.Th.U.	British Thermal Unit
C.	Centigrade
c.c.	cubic centimetre(s)
cm.	centimetre(s)
cos	cosine
C.R.T.	cathode-ray tube
c/s	cycle(s) per second
C.W.	continuous waves
cwt.	hundredweight
db.	decibel(s)
D.C.	direct current
D.C.C.	double-cotton covered
deg.	degree(s)
D.F.	direction-finding
dia.	diameter
D.S. & enam.	double-silk and enamel
D.S.C.	double-silk covered
e.g.	for example
e.m.f.	electromotive force
etc.	*et cetera*, and the rest
F.	Fahrenheit
F	farad(s)
g.	gramme(s)
G.B.	grid bias
H	henry(s)
h.p.	horse power
H.T.	high tension
I.C.W.	interrupted continuous waves
i.e.	that is
I.F.	intermediate frequency
in.	inch(es)
K.	Kelvin
kc/s	kilocycle(s) per second
kg.	kilogramme(s)
kV	kilovolt(s)
kW	kilowatt(s)
lb.	pound(s)
log	logarithm
L.S.	loudspeaker
L.T.	low tension
m.	metre(s)
mA	milliampere(s)
mA/V	milliampere(s) per volt
M.C.	moving coil
Mc/s.	megacycle(s) per second
M.C.W.	modulated continuous waves
μF	microfarad(s)
min.	minute(s)
mm.	millimetre(s)
μμF	micromicrofarad(s)
m.p.h.	miles per hour
μV/m.	microvolt(s) per metre
mW	milliwatt(s)
MW	megawatt(s)
Ω	ohm(s)
oz.	ounce(s)
p.d.	potential difference
pF	picofarad(s)
Q.P.P.	quiescent push-pull
q.v.	which see
rev.	revolution(s)
R.F.	radio frequency
r.m.s.	root mean square
r.p.m.	revolutions per minute
R.T.	radio telegraphy
S.C.C.	single-cotton covered
sec.	second(s)
S.G.	screen grid
sin	sine
sp.gr.	specific gravity
sq.	square
S.S.C.	single-silk covered
S.W.G.	Standard Wire Gauge
sync.	synchronizing
tan	tangent
temp.	temperature
T.R.F.	tuned radio-frequency
V	volt(s)
VA	volt-ampere(s)
V.F.	voice frequency
V.H.F.	very high frequency
W	watt(s)
Wh.	watt-hour(s)
yd.	yard(s)

A

A. Abbreviation for AMPERE(S).

A-AMPLIFIER. Synonym for MICROPHONE AMPLIFIER.

A-BATTERY. American term for LOW-TENSION BATTERY.

ABNORMALLY POLARIZED WAVE. Radio-wave polarized in a plane which is neither horizontal nor vertical. In practice, such waves are usually found to have circular or elliptical polarization. See CIRCULAR POLARIZATION, ELLIPTICALLY POLARIZED WAVE, POLARIZATION.

ABSOLUTE UNITS. System of units which can be defined in relation to, and is derived from, the basic units of time, length and mass.

ABSORBER CIRCUIT. In a sender, a circuit, usually employing a valve, which absorbs the power from the sender when a break occurs in a certain part of the circuit. Without an absorber circuit, a break in an oscillatory circuit could cause a surge across the points at which the break occurs, producing an arc and causing damage to the apparatus.

ABSORPTION. Loss of energy by a radio-wave due to absorption by the ionosphere in the case of an ionospheric wave, and absorption by the ground, hills, buildings, forests and so forth, in the case of ground waves.

When the electrons in an ionized layer are set in motion by a wave, collisions will occur between the electrons and the ionized gas molecules. At high frequencies, the average time between collisions is long compared with the period of the wave, so that the effect of the collisions is not very important, and the effect of these collisions can be regarded as providing a damping-force proportional to the velocity of the electrons but tending to impede their motion. When the frequency is high, the damping-force is small and the energy-loss while the wave is in the layer is small.

As the frequency is reduced, however, the damping-force increases and the absorption becomes greater, until the frequency of the wave corresponds to the average time of collisions in the layer. At this frequency a resonance effect takes place and the absorption of energy from the wave becomes enormous. The frequency at which this heavy, absorption takes place varies according to the state of ionization of the layer, each layer having a critical wave band in which the absorption is so high as to make reception by means of the ionospheric wave completely unreliable.

The critical wave band of the E-LAYER (q.v.) is approximately 150–350 metres, and that of the F-LAYER (q.v.) is 8–12 metres. It is thus evident that the best results are obtainable with the higher frequencies, provided that they are outside the limits of the critical wave bands.

Absorption or attenuation of the ground wave depends, in a rather complex way, on the conductivity of the earth's surface and on its relative permittivity, both of which vary for different kinds of soil and for different weather conditions. For the lower frequencies, it is the conductivity which is more important; the higher this is, the lower is the attenuation. For high- and very high-frequency waves, the relative permittivity becomes more important; the higher it is, the less the attenuation. Thus for all frequencies the ground wave is attenuated less over sea than over land, and the attenuation increases with frequency. For example, the ground-wave range of the G.P.O. station at Rugby, operating on a frequency of 16 kc/s, is several thousand miles; whereas a station using a frequency of 75 Mc/s will have a ground wave of only a few miles. The ground wave undergoes attenuation because it induces alternating e.m.f.s in the earth and, as the earth has a finite resistance, there must be a loss of power and current, energy thus dissipated being supplied by the wave itself. See CONDUCTIVITY, GROUND RAY, IONOSPHERE, IONOSPHERIC RAY, RELATIVE PERMITTIVITY.

ABSORPTION MODULATION. Amplitude modulation in which the amplitude of a carrier wave is varied according to the power absorbed from it in a variable resistance, the value of the resistance being controlled by the modulating wave. See ABSORPTION MODULATOR, LINEAR MODULATION, VARIABLE-RESISTANCE MODULATION.

ABSORPTION MODULATOR. Modulator in which the anode slope-resistance of a valve is varied by the modulating wave and absorbs more or less power from the carrier wave. As the voltage applied to the grid of a valve is varied by the modulating wave, the valve absorbs more or less power from the carrier source connected between anode and cathode. Thus the amplitude of the carrier wave is varied by the modulating wave. The method is obsolescent, however, because, with deep modulation, modulation distortion is intolerable for most purposes. See MODULATION DEPTH, MODULATION DISTORTION.

A.C. Abbreviation for ALTERNATING CURRENT.

ACCELERATOR. Electrode in a cathode-ray tube, and sometimes referred to as the "anode," which is normally at a positive potential with respect to the cathode. Successive accelerators are employed to provide not only successive accelerations of the electrons leaving the cathode, but also to provide a method of focusing the electrons into a narrow beam which will form a sharply defined spot at the screen.

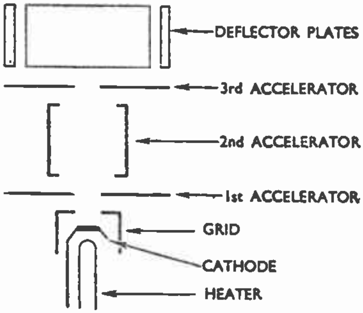


Fig. 1. Diagrammatic representation of the electrodes of a cathode-ray tube, showing arrangement of accelerators.

The so-called gun assembly of the modern cathode-ray tube usually consists of the cathode, the grid and three accelerators, as shown in Fig. 1, the potential differences between the cathode and the other electrodes being approximately:

Grid, 15–50 volts negative;
1st Acc., 300 volts positive;
2nd Acc., 1,000 volts positive;
3rd Acc., 2,000–5,000 volts positive.

There is thus a difference of potential between the first and second accelerators of about 700 volts, and between the second and third of several thousand volts.

The electrons are, therefore, speeded up on each stage of their journey as they come under the influence of the increasing positive potentials. This succession of potential increases has, however, a further effect whereby the electron beam is focused. See ELECTRON LENS.

ACCELERATOR GRID. See SCREEN GRID.

ACCEPTOR CIRCUIT. Series-tuned circuit so connected in relation to other parts of a circuit that it reduces a voltage to a low value at a particular frequency at a particular point in the circuit (Fig. 2). A series-tuned circuit has its lowest impedance at a certain frequency. This is the frequency at which the inductive reactance of the inductor has the same numerical value as the capacitive reactance of the capacitor. Thus the acceptor circuit, having a relatively low resistance at a certain frequency, reduces the amplitude of a wave having that frequency to a low value. See RESONANCE, TUNED CIRCUIT, TUNING.

ACCUMULATOR BATTERY. Battery of accumulator cells. See BATTERY.

ACCUMULATOR CELL. Voltaic cell which may be recharged after it is discharged. The e.m.f. produced by voltaic cells is the result of a chemical process which takes place in them. Discharging a cell gradually uses up the chemicals necessary to produce the e.m.f. Thus, depending upon the discharge current and the period for which it flows, there is a limited time during which the cell can produce an e.m.f. at its terminals.

The unique property of the accumulator cell is that the chemical conditions necessary to produce the e.m.f. may be restored without structural alterations to the cell. The cell may be recharged by passing a current through it in the reverse direction to that of the discharging current.

The usefulness of a cell is judged by:

1. Its internal resistance, which should be small.

2. The discharge current that may be taken from the cell without damaging the cell; it should be large.

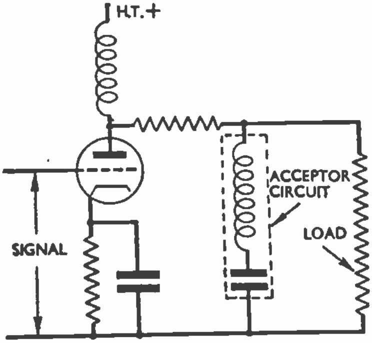


Fig. 2. If the frequency of the wave applied to the grid of the valve is equal to the series-resonant frequency of an acceptor circuit, the voltage across the load is reduced because the circuit has, at this one specific frequency, a comparatively small resistance.

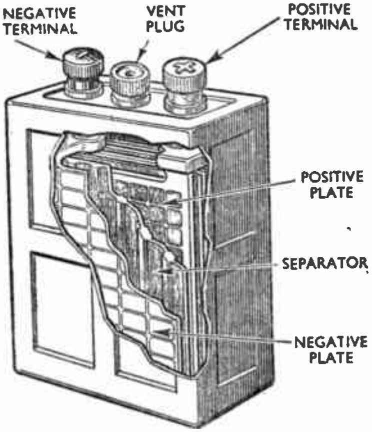


Fig. 3. View of a cut-away small lead-acid type of accumulator cell.

3. The weight of the cell, which should be low, for a given ampere-hour capacity.

4. The changes in the voltage of the cell during discharge, which should be small.

5. The possibility of restoring the charge without structural alterations to the cell.

6. Ease of installation and maintenance in all sorts of conditions.

The accumulator cell scores in all the above particulars except 3 and 6; its drawbacks are excessive weight and the fact that it contains acid liable to spill out of the containers. Also, it requires a good deal of attention, for example, the addition of distilled water to the acid from time to time, the greasing of terminals to prevent sulphating, and care that it is not left discharged for long periods.

There are two types of cell. That most commonly used consists of lead plates covered with a weak sulphuric-acid solution; the other type (the Edison cell) uses nickel-hydroxide and iron plates in an alkaline solution.

A small accumulator cell in part

section is shown in Fig. 3. The negative plate is made of lead and the electrolyte is sulphuric acid diluted with pure water. The specific gravity of the electrolyte is 1·24 when the cell is fully charged and has its least internal resistance.

The internal resistance of a cell depends, among other things, upon the area of the plates. In typical construction, the positive and negative plates are interleaved but insulated from one another.

After being fully charged, an accumulator cell of the lead-acid type has a voltage of 2·5 volts, but very soon after a substantial discharge takes place, the voltage falls to 2·0 volts and then remains almost constant during the discharge period. When the cell is discharged, the voltage begins to fall rapidly, and the cell must be charged again to restore its capacity to supply current.

The maximum discharge current that can be taken from an accumulator is limited by the area of the plates and other less important factors. The specified maximum discharge current can be exceeded only at the risk of damaging the cell. Some accumulators are constructed to be able to supply very large currents for short periods. The makers' instructions as they relate to maximum charge and discharge currents should be strictly followed. A cell should never be left in a discharged state for any length of time.

The specific gravity of the accumulator acid varies with the state of charge; it should be at least 1·24 when the cell is fully charged and falls to 1·15 when it is discharged. Some makes of cell have a pointer which moves over a scale marked: "Capacity—full, ¾, ½, ¼, 0." The movement of the pointer is controlled by the specific gravity of the acid.

Lead sulphate tends to form during the discharge period and is recognizable as a white substance liable to coat the plates and the internal connexions. A badly sulphated cell will not give its full rated current, but provided the cell is well looked after and never allowed to remain discharged during long periods, sulphating will not occur. See ACCUMULATOR CHARGING, AMPERE-HOUR CAPACITY, BATTERY CHARGING, HYDROMETER.

ACCUMULATOR CHARGING. Process used to restore the charge in a discharged accumulator battery or cell. The process consists of passing a current through the cell or cells in a direction opposite to that of the discharge current.

If any source from which a direct current can be drawn is used to charge accumulators the positive terminal of this supply must be connected to the positive terminal of the cell to be charged. Moreover, when current flows, a moving-coil ammeter reading the current must show a deflection when the positive terminal of the ammeter is connected to the positive supply terminal and the negative terminal to the positive terminal of the accumulator.

Alternatively, the positive terminal of the ammeter could be connected to the negative terminal of the accumulator and the negative terminal to the negative terminal of the source of supply. If, in either of these conditions,

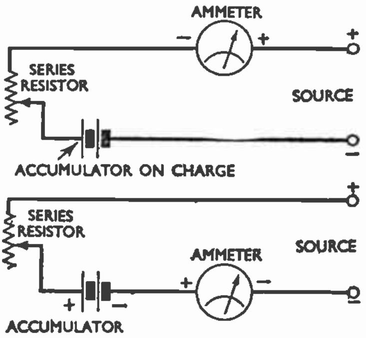


Fig. 4. Basic connexions for accumulator charging. The D.C. source voltage must be greater than the voltage of the fully charged accumulator.

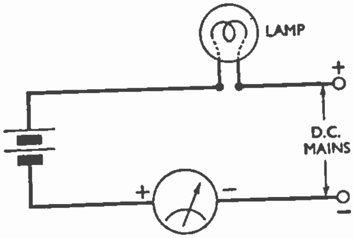


Fig. 5. Connexions for charging a 4-volt accumulator battery of two cells from D.C. mains; charging current is determined by the resistance of the lamp.

the ammeter needle tends to move below the zero, then the voltage of the source is too small and is allowing the battery to discharge a current into the source. Fig. 4 gives the foregoing information in a pictorial form.

Obviously, in order to pass a certain current through a cell in the reverse direction to the discharge current it is necessary to have a supply voltage which is greater than the voltage of the accumulator.

Suppose an accumulator battery of three cells has a voltage of 6 volts and an internal resistance of 0·2 ohm. Suppose also that it is desirable to charge the battery at 5 amp. The source must have a voltage of 6 volts, to overcome the reverse-acting 6 volts of the battery, and sufficient extra voltage to pass 5 amp. through 0·2 ohm. This is 5 amp. × 0·2 ohm = 1·0 volt, so that 6 + 1 = 7 volts are required.

Almost as soon as a charging current flows, the accumulator battery increases its voltage; this may rise, in time, to 2·5 volts per cell, so that a three-cell battery, when on charge, has a reverse voltage of 7·5 volts, and in such a case 8·5 volts will be demanded from the source.

In common practice, as shown in Fig. 4, a resistor is placed in series with the source, and this can be adjusted during charging so that the charging current may be set at a required value. Clearly, power is wasted in this resistance, and this wastage is the greater as the resistance is larger for a certain charging current. The more the source voltage exceeds minimum requirements, the larger the resistance needed.

For instance, using the values given in the foregoing numerical example if only 8·5 volts are required, then if the source volts were 16·5, 8 volts would be dropped in the resistance. The total power required for charging (at 5 amp.) would be 16·5 × 5 = 82·5 watts, or approximately $\frac{1}{12}$ of a unit. At, say, 2d. per unit the cost of charging would be $\frac{1}{6}$d. per hour, or nearly 2d. for a 50-Ah. accumulator.

When 4- or 6-volt accumulators are charged from D.C. mains of the order of 100 to 200 volts, the usual practice is to put lamps in series with the mains and the accumulators (Fig. 5). The lamps must have a voltage rating to match the mains voltage, for example, a 200-volt lamp is used for 200-volt mains. Provided the voltage of the accumulator battery is much less than that of the mains, the charging current in amperes is given by dividing the watt rating of the lamps by the mains voltage in volts. The power taken from the mains is a little less than the power rating of the lamps.

With A.C. mains, it is usual to

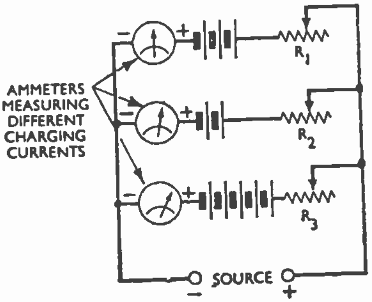


Fig. 6. Method of charging accumulators simultaneously from a single source, but at different rates, by suitable adjustment of R_1, R_2 and R_3.

charge accumulators through a transformer and rectifier; the voltage at the secondary of the transformer is reduced from the mains voltage to a value sufficient to pass current through a rectifier and an accumulator battery of specified voltage. There are many makes of these charging units on the market.

A motor-generator set may also be used to convert the mains power, whether the supply is A.C. or D.C., to a suitable form for the economic charging of accumulators. Fig. 6 shows how several different accumulator batteries, requiring different charging currents, may be simultaneously charged.

Attention should be paid to the following points during the charging of accumulators:

1. If the accumulators are not equipped with some device indicating their state of charge, the fact that they are nearly fully charged will be shown by strong gassing at the plates. The vent plugs should be left undone during charging and naked lights ought not to be brought near the accumulators.

2. Petroleum jelly should be coated over terminals to prevent sulphating.

3. Some of the electrolyte will be lost during the charging period. The loss should be made up by adding distilled water, not dilute acid, provided the specific gravity has the correct value.

4. An hydrometer should be used to test the specific gravity of the liquid if other means of recording it, such as pointers moving over a scale or floats in the acid, are not embodied in the accumulator.

A.C. GENERATOR. Generator for the production of alternating current.

ACORN VALVE. See MINIATURE VALVE.

ACTIVATION. Process in which the cathode of a valve is so treated that it gives the greatest possible emission. Cathodes, whether of the filament or indirectly heated type, are made from tungsten, thoriated tungsten and metallic oxides. The tungsten filament does not require activation, but thoriated tungsten is activated by FLASHING (q.v.). The process of glowing thoriated tungsten consists in keeping it at a temperature of 1,600 deg. K. in a hydrogen atmosphere; this causes carbonizing of the tungsten.

Oxide-coated cathodes are glowed for several minutes at 1,500 deg. K. After glowing, a strong positive anode potential is applied. The emission increases to a fixed limit and then the electrostatic field and temperature are reduced.

Activation is a delicate process subject to many possible variations which cannot be covered in this generalized description. See EMISSION.

ACTIVE AERIAL. Aerial directly connected to a sender or receiver, as distinct from a reflector or director element, which is not so connected. See PASSIVE AERIAL.

ACTIVE COMPONENT. Component which is in phase with a vector used for representing an alternating phenomenon.

In the above graph (Fig. 7) the active component is shown shaded. See ACTIVE CURRENT, ACTIVE VOLT-AMPERES, ACTIVE VOLTAGE.

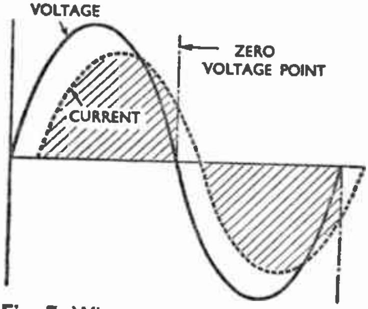


Fig. 7. When current and voltage are "out of step" in an A.C. circuit, that part of the current wave which coincides with the voltage is called the active current or active component (here shown shaded).

ACTIVE CURRENT. Component of the total current in an alternating circuit which is in phase with the alternating voltage. The power in the circuit is found by multiplying these two quantities together. See ACTIVE COMPONENT.

ACTIVE MATERIAL. In an accumulator cell, material the chemical condition of which changes during charging and discharging periods.

ACTIVE VOLTAGE. Component of the voltage in an alternating circuit which is in phase with the current flowing in the circuit. See ACTIVE COMPONENT.

ACTIVE VOLT-AMPERES. Product of the active current and the voltage in an A.C. circuit. In other words, a true measure of the wattage or available power in the circuit, making due allowance for the out-of-phase effects between current and voltage due to the inductive or capacitive nature of the load. See ACTIVE COMPONENT, POWER FACTOR.

ACTUAL LEVEL. Ratio of power at any specified point in a circuit to 1 mW, this ratio being expressed in decibels. Thus, the output from an amplifier might be 100 mW; the ratio of 100 mW to 1 mW is 20 db., and so the actual level in this case is 20 db. If the power is less than 1 mW, the ratio is usually written with a minus sign; thus a power of 0·5 mW is very nearly −6 db., that is to say, the actual level is −6 db. See DECIBEL, POWER, RELATIVE LEVEL, TEST LEVEL.

ADAPTER. Device by whose agency a plug of one size or type may be inserted into a socket of a different size or type, or several plugs may be connected to one socket. Adapters are commonly used as auxiliaries to power-supply plugs and sockets so that several current-using devices can be connected to one socket outlet. They consist of one set of plug contacts in electrical connexion with one or more sets of socket contacts, the whole being mounted in an insulating body. See PLUG AND SOCKET.

ADCOCK DIRECTION-FINDER. Direction-finder employing spaced vertical aerials feeding into a common receiver via a goniometer and provided with some means of reducing the effects of horizontally polarized waves and the errors resulting from them. See SPACED-AERIAL DIRECTION-FINDER, U-TYPE DIRECTION-FINDER.

ADMITTANCE. Quantity which is the reciprocal of impedance, and is thus a measure of the facility with which a current can flow in a circuit under the pressure of a given electromotive force. See IMPEDANCE.

AERIAL. Device from which energy can be radiated in the form of electromagnetic waves; or device by which energy can be picked up from electromagnetic waves. The most familiar type is doubtless the single elevated wire, earthed at one end. If it is suspended vertically, it responds equally to vertically polarized waves reaching it from any direction; this is the classic form of omni-aerial. It resonates in a manner depending on the relation between its physical length and the wavelength of the signal radiated or picked up. If the conductor is earthed at one end it resonates at the frequency for which the aerial length is equal to a quarter wavelength. See QUARTER-WAVE AERIAL.

This is the normal behaviour of such an aerial; in practice, it is customary to use a conductor somewhat shorter than a quarter of the shortest wave likely to be received and to bring it into the resonant condition by loading with inductance and, possibly, capacitance. An exception occurs when an aerial is required to cover a considerable range of frequencies; if made to resonate in the quarter-wave mode at the highest frequency the aerial would be so short that it would be inefficient at the lower frequencies.

In practice, the aerial should be long enough to act as a quarter-wave system over the medium- and lower-frequency range, and to respond at or near one of its harmonics for any higher frequency. Whenever the aerial length is some suitable multiple of a quarter-wave, it can respond in this way. Fig. 8 shows two of the possible voltage distributions in a simple vertical wire which is too long to resonate as a quarter-wave aerial for a particular signal.

To this general class belong such standard types as the inverted-L and inverted-T aerials, in which a horizontal portion is added to provide some localized capacitance high above ground, or endow the aerial with a degree of directivity to suit a specific case. The quarter-wave element, earthed at the foot, is also used as a constituent part of some forms of directive array; here, the massing together of a number of elements produces the required directivity. Such aerials are extensively used for sending purposes on low and medium frequencies.

Another form of aerial which, although earthed, works in a basically different manner, is that sometimes called a wave aerial. A given element of this kind is often several wavelengths long and does not tend to resonate in a fixed pattern of voltage nodes and antinodes. A simple instance is the Beverage aerial, which normally consists of a long single horizontal wire, a few feet above the ground, earthed at one end through a receiver and at the other through a resistor of value equal to the surge impedance of the line, that is, of the wire regarded as a single-wire feeder with earth return.

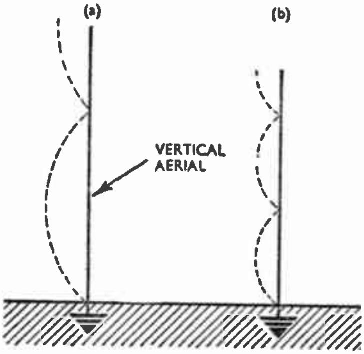


Fig. 8. Possible voltage distributions in a vertical aerial responding to frequencies higher than its fundamental; in *(a)* the aerial height is 3/4 and in *(b)* 5/4 of the wavelength.

Such an aerial delivers large signals to the receiver because, in broad terms, the induced currents travel faster in the wire than in the ground and create a phase difference causing a voltage to be set up between the end and earth. This type of aerial is strongly directive, receiving best from the direction of the end remote from the receiver. In practice, it may be elaborated in numerous ways, as by the addition of extra wires in parallel, or, on a slightly different plan, by the use of a diamond-shaped system of non-resonant elements as in the RHOMBIC AERIAL, V-AERIAL (q.v.).

Another general class of aerials employs elements, singly or grouped in arrays, which are not earthed. In most cases, the elements are arranged to behave as half-wave resonators (see HALF-WAVE AERIAL); hence this form of aerial is mainly used at those higher frequencies at which a half-wave element is of practicable size, and is widely employed for the very high frequencies from, say, 30 Mc/s to 3,000 Mc/s.

These are examples of what is called the open aerial, to distinguish it from the loop, which forms a closed circuit with its associated tuning capacitor. For sending, the open aerial has the obvious advantage that its magnetic and electric fields are spread out to embrace as much space as possible; the closed loop, with its restricted fields, is not, therefore, used for sending. Since the aerial is essentially a reversible device, one can safely argue that what is inefficient for sending is not good for receiving, and, in a sense, this is true of the loop; it is in fact inefficient as a pick-up device, but high-

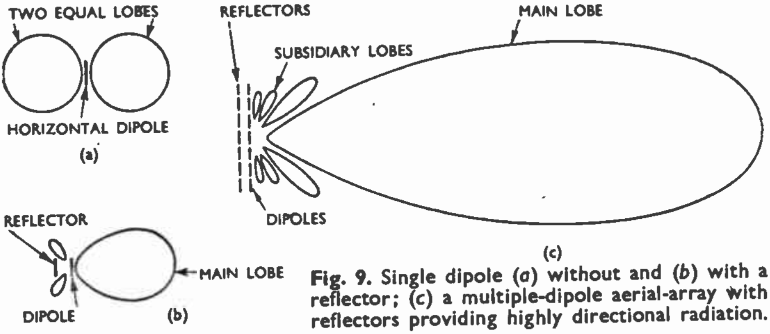


Fig. 9. Single dipole (*a*) without and (*b*) with a reflector; (*c*) a multiple-dipole aerial-array with reflectors providing highly directional radiation.

ly sensitive receivers have made this of little importance.

On the other hand, the loop is highly directive, and this property is often sufficiently valuable to make its use worth while. Moreover, its losses are under the control of the designer and can be made somewhat lower than those of the average open aerial generally used for broadcast reception. The loop therefore gives some improvement in selectivity.

Here, somewhat oddly, its major weakness—low efficiency in extracting energy from passing waves—is indirectly a virtue. Low efficiency as a radiator, and therefore as a pick-up device, implies low radiation resistance; low radiation resistance means very little damping and high selectivity (see AERIAL RADIATION-RESISTANCE).

The directive properties of the loop are employed in the obvious way for direction-finding; but they are also useful in minimizing pick-up of interfering signals or random noise coming from a definite direction. In such circumstances, the loop, correctly used, may give considerable relief. This is due to a simple but often forgotten characteristic: although the setting for maximum signal from a given station is broad and covers a wide swing of the loop, the minimum position is narrow and well defined. If, therefore, a loop is set to pick up the minimum of a particular interfering signal, there is a good prospect that the wanted station will still be heard, since, for this, the loop need not be set accurately to a definite bearing.

These are the basic elements of which nearly all the more elaborate composite aerial systems are composed. The broadside array, for instance, is commonly a collection of half-wave dipole aerials, either in a tier, if it is desired to produce a beam which is compressed in the vertical direction; or a horizontal row, if the beam is to be narrow in the horizontal plane; or a row of tiers, when the beam is to be focused narrowly in both planes.

Again, there are various elaborations of the non-resonant wave aerials such as the rhombic; composites consisting of duplicated or triplicated basic elements are also used, but without change of principle.

More detailed information of specific types may be found under the appropriate headings. See ACTIVE AERIAL, AERIAL-ARRAY, AERIAL GAIN, AERIAL RESISTANCE, BROADSIDE ARRAY, CAGE AERIAL, CONICAL AERIAL, CONICAL-HORN AERIAL, DIAMOND AERIAL, DIRECTIVE AERIAL, FRANKLIN AERIAL, HALF-WAVE AERIAL, INVERTED-L AERIAL, INVERTED-V AERIAL, LOOP-AERIAL, MAST AERIAL, PASSIVE AERIAL, STANDING-WAVE AERIAL, T-AERIAL.

AERIAL-ARRAY. Assembly of aerial elements so arranged and spaced as to produce directional effects. Each element is commonly, though not invariably, a complete aerial in itself, as in an assembly of half-wave dipoles connected to a branching feeder system.

Polar diagrams showing the horizontal patterns of radiation from a dipole with and without a reflector are given in Fig. 9; a figure-of-eight pattern is produced from a normal horizontal dipole (a), whereas a directional lobe is produced by placing a reflector behind the dipole (b).

A more pronounced directional effect is obtained by using an array consisting of several dipoles placed end to end with a corresponding series of reflectors mounted behind them (Fig. 9c). See BROADSIDE ARRAY, CURTAIN ARRAY, END-FIRE ARRAY.

AERIAL CURRENT. Maximum r.m.s. value of radio-frequency current flowing in an aerial when signals are being sent or received.

AERIAL EFFECT. Synonym for ANTENNA EFFECT.

AERIAL FEED-IMPEDANCE. Effective impedance of an aerial as measured at the point where energy is fed into it, or taken from it. For example, the impedance of a half-wave dipole at its open centre point when current-fed. See CURRENT-FED AERIAL.

AERIAL GAIN. Relative term denoting the ratio of the efficiency of a given aerial to that of an assumed standard—usually taken to be a single half-wave dipole. The gain is commonly expressed as the ratio of the powers delivered to a receiver by the two aerials, other factors being kept constant.

AERIAL RADIATION-RESISTANCE. That fraction of the total radio-frequency resistance which arises from the radiation of energy by the aerial. See AERIAL RESISTANCE.

AERIAL RESISTANCE. Equivalent radio-frequency resistance of the complete aerial-system measured at the point where power is put in or taken out. This resistance is made up of two components: the radio-frequency resistance of the conductors, which includes the effect of losses in dielectrics; and another resistance which is postulated as accounting for the energy which in fact is lost as radiation from the aerial. The ratio of radiation resistance to total resistance is some measure of the efficiency of an aerial-system and in a good aerial the radiation resistance may form a substantial fraction of the total.

AERIAL-SYSTEM. Aerial of any type with its masts or other supports and connecting feeders regarded as a complete assembly.

AEROPLANE EFFECT. Direction-finding error due to the presence of a horizontally polarized component in the radiation of an elevated sender, such as an aircraft with a trailing-wire aerial (see AIRCRAFT AERIAL). Similar errors may be produced when waves initially vertically polarized acquire an obliquely or horizontally polarized component during propagation. See POLARIZATION ERROR.

AETHER. Synonym for ETHER.

A.F. Abbreviation for AUDIO FREQUENCY.

AFTER-GLOW. Persistence of luminosity of the screen of a cathode-ray tube after the electrons have stopped striking it; see also PHOSPHOR. The impact of electrons on the substances used to form the screen of a cathode-ray tube causes the particles in the screen to fluoresce. This fluorescence should cease immediately impact ceases, but usually a certain amount of phosphorescence occurs and the screen continues to glow, this phenomenon being termed after-glow.

The period of after-glow varies from a matter of a few milliseconds to several seconds according to the substance used for the screen and the number and speed of the electrons striking it. In some uses of the cathode-ray tube (see RADAR), long after-glow is an advantage, whereas, in an oscilloscope and in television, the period of lag before illumination dies away should be as short as possible.

A.G.C. Abbreviation for AUTOMATIC GAIN-CONTROL.

Ah. Abbreviation for AMPERE-HOUR(S).

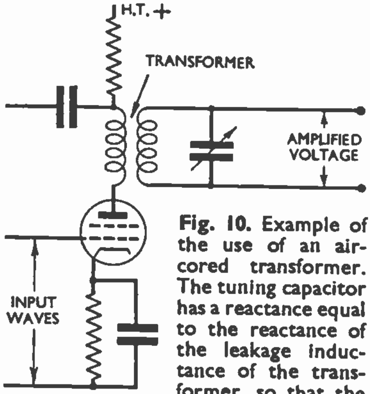


Fig. 10. Example of the use of an air-cored transformer. The tuning capacitor has a reactance equal to the reactance of the leakage inductance of the transformer, so that the voltage across the secondary has a maximum value for a particular frequency applied to the primary winding.

AIR CAPACITOR. Form of capacitor having air as the dielectric. See FIXED CAPACITOR, VARIABLE CAPACITOR, TRIMMER.

AIR CONDENSER. Synonym for AIR CAPACITOR.

AIR-COOLED ANODE. Anode external to the bulb of a valve and surrounded by fins on to which air is blown. See ANODE DISSIPATION, COOLED VALVE, WATER-COOLED VALVE.

AIR-COOLED VALVE. Valve in which the bulb is made of silica glass and which is cooled by air blown on to the glass. Such valves have a rated anode dissipation of from 1 to 3 kW. See AIR-COOLED ANODE, ANODE DISSIPATION, COOLED VALVE, WATER-COOLED VALVE.

AIR-CORED COIL. See AIR-CORED INDUCTOR.

AIR-CORED INDUCTOR. Inductor having a core of non-conducting, non-magnetic material. Many inductors for use at radio frequencies are of this type because, apart from certain dust-cored inductors, the benefits of a high-permeability core which are attainable at low frequencies are far outweighed by the losses introduced at radio frequencies. See FIXED INDUCTOR, INDUCTOR.

AIR-CORED TRANSFORMER. Transformer in which no iron is used to increase the mutual inductance between the windings. Air-cored transformers are used when the waves passing through them are of such a high frequency that the losses in iron cores would be intolerable. Fig. 10 shows an air-cored transformer as used in typical practice; the tuning capacitor is given a value such that it will resonate with the inevitable leakage inductance of the transformer, to give the required voltage gain.

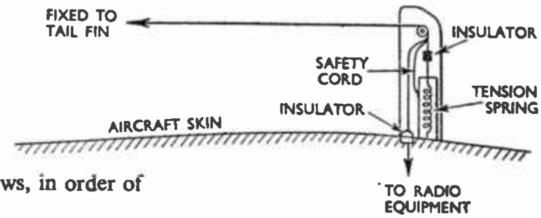
In such a case, the frequency band over which the transformer is efficient is limited, but often suffices in the reception of modulated-wave signals. See IRON LOSS, LEAKAGE INDUCTANCE, MUTUAL INDUCTANCE, TRANSFORMER.

AIRCRAFT AERIAL. Aerial specially adapted to use in the air, either by its construction or its electrical properties. The classic form of aircraft aerial is the long, trailing wire, and this was widely used prior to about 1940. Such an aerial may be up to 250 ft. long, weighted at the end and paid out or wound back with the aid of a winch. This form of aerial has substantial electrical advantages, but the increasing speeds of all aircraft and the need for manoeuvrability in military types have served to emphasize its practical drawbacks.

The present general tendency towards shorter waves has involved the adoption of smaller aerials, mostly dipoles or quarter-wave aerials of rod construction, or of special radiators for centimetric wavelengths. Where medium frequencies are still used, the aerial is most likely to be a stretched wire attached to the structure of the aircraft. For direction-finding purposes, a rotating loop-aerial with remote control may be carried, often in a streamlined casing so that it may be fitted externally. See AIRCRAFT RADIO EQUIPMENT.

AIRCRAFT RADIO EQUIPMENT. Radio apparatus carried in aircraft. The objects of radio in aviation can

Fig. 11. Fixed-aerial installation for aircraft. The aerial is kept taut by a tensioning spring, and a safety cord is incorporated.



be summarized as follows, in order of importance:

1. Navigational service, i.e. direction-finding and approach-landing systems.
2. Giving meteorological information.
3. Passing instructions to the captains of aircraft.
4. Routine messages dealing with organization.
5. Public correspondence (radio-telegrams).

In addition there are, of course, various radar devices, most of which come within category 1 above, e.g., Gee, H_2S, Loran (see PRIMARY RADAR, RADAR).

The frequencies allocated for civilian aviation in Europe are between 255 and 290 kc/s, and between 320 and 365 kc/s in the medium-frequency band. These frequencies are used for traffic between stations, navigation beacons, and for passing meteorological information. Higher-frequency bands are used for passing traffic and meteorological messages at long distance. The very high-frequency (V.H.F.) bands (roughly between 30 and 40, and 100 and 150 Mc/s) are used for landing and approach beacons, as well as for short-range telephony communication.

A suitable frequency coverage for a general-purpose aircraft installation is approximately as follows: 200–500 kc/s (1,500–600 metres); 3–5·5 Mc/s (100–54·5 metres); 5·5–10 Mc/s (54·5–30 metres).

BONDING. The earth on an aeroplane is formed by arranging electrical continuity through all the metal in the structure. This is called bonding. On a modern aeroplane of all-metal construction, this is a simple process, as there are relatively few metal parts electrically discontinuous from the main structure. The control surfaces (ailerons, flaps, elevators and rudder) are bonded across their hinges and, if the engines are mounted on rubber suspension brackets, these are also bonded. An aeroplane of wooden construction obviously presents greater bonding difficulties.

A modern commercial aircraft is fitted with at least six aerials: a fixed aerial, a trailing aerial, a direction-finding (D.F.) loop, a vertical or whip main-beacon aerial for beam approach (B.A.), a horizontal dipole for marker beacons and a second whip aerial for V.H.F. radio telephony.

The fixed aerial, used with the main W.T. (wireless telegraphy) equip-

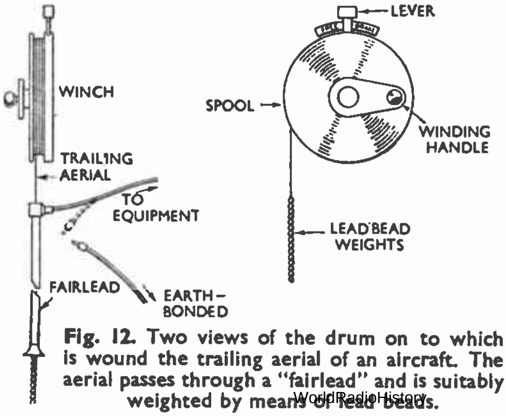


Fig. 12. Two views of the drum on to which is wound the trailing aerial of an aircraft. The aerial passes through a "fairlead" and is suitably weighted by means of lead beads.

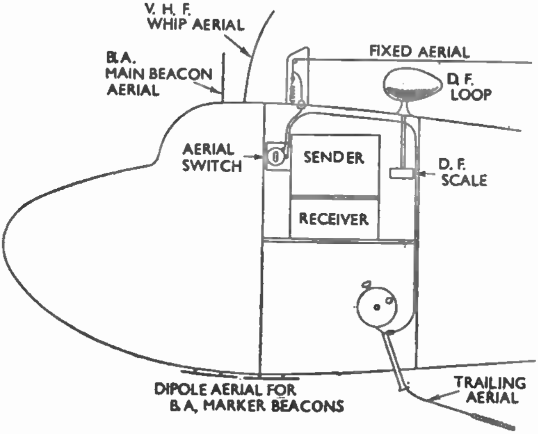


Fig. 14. Example of the lay-out of aerials in a large aircraft. Aerial arrangements are often more complex, however, owing to the number of radio/radar devices used in modern airliners.

ment, is usually made from stainless-steel wire, and is normally 60–70 ft. in length. It is fixed between a stub mast situated above the main equipment and the tail fin of the aircraft. Fig. 11 illustrates a typical fixed-aerial installation and shows the method used to keep the aerial taut by means of a spring, and safeguarded by a check-cord or safety wire.

The trailing aerial, which is now being used to a decreasing extent, has a maximum length of about 250 ft., but the length in use can be increased. It is attached to a moulded plastics drum by means of a cord, and is weighted by means of lead beads (about 1½ lb. in weight). The aerial wire is brought into the aircraft through a "fairlead" which consists of a Paxolin tube passing through the aircraft skin (Fig. 12).

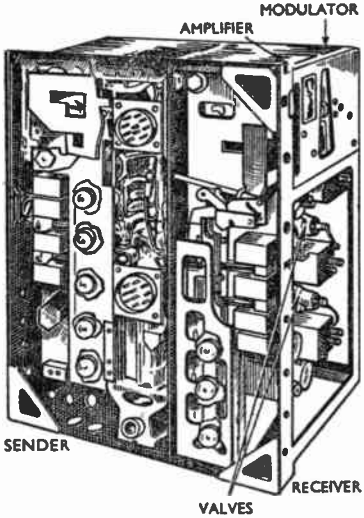


Fig. 13. V.H.F. sender and receiver as used for short-range R.T. communication. The external connexions are made to two ten-point sockets.

There are two B.A. aerials. The main beacon-receiver aerial is usually of the whip type. The marker-beacon aerial is a dipole and is usually mounted beneath the fuselage on small stand-off insulators.

A whip aerial is generally used for the V.H.F. radio-telephony equipment, but this is sometimes replaced by a short, stub aerial. It is usually mounted in close proximity to the V.H.F. sender/receiver.

Fig. 13 shows a V.H.F. sender/receiver unit for short-range radio telephony, and Fig. 14 a typical arrangement of aerials on a large aircraft.

Electrical interference on aircraft is attributable mainly to the ignition system of the engines. The usual method of suppression is to screen all parts of the ignition system completely. This means that the magnetos are enclosed in earthed metal cases, H.T. and L.T. leads are screened cable with the metal braiding earthed, and the sparking-plugs are specially designed with earthed metal screens.

The charging circuits may cause interference if a constant-voltage regulator of the vibrating-contact type is used. Suppression can be achieved by screening or by the use of chokes and capacitors arranged as filter circuits.

Interference may also occur from the electric motors used to operate the retracting undercarriage, flaps, de-icing pumps and windscreen wipers. Filter circuits are normally employed to suppress it.

TYPICAL AIRCRAFT EQUIPMENT. The Marconi AD.87B/8882B aircraft radio equipment (Fig. 15), which is better known as the T.1154/R.1155, is typical of modern practice in large commercial and Service aircraft.

Transmission and reception on both short and medium waves are provided, and continous, or A1, waves (C.W.), modulated continuous, or A2, waves (M.C.W.) or radio telephony can be used. Direction-finding facilities are available on the medium-wave bands of the receiver by the use of a rotating loop-aerial, with facilities for visual and aural D.F. and homing.

The *sender* covers the following four frequency bands:

Range 1, 16·7–8·7 Mc/s.
Range 2, 8·7–4·5 Mc/s.
Range 3, 4·5–2·35 Mc/s.
Range 4, 500–200 kc/s.

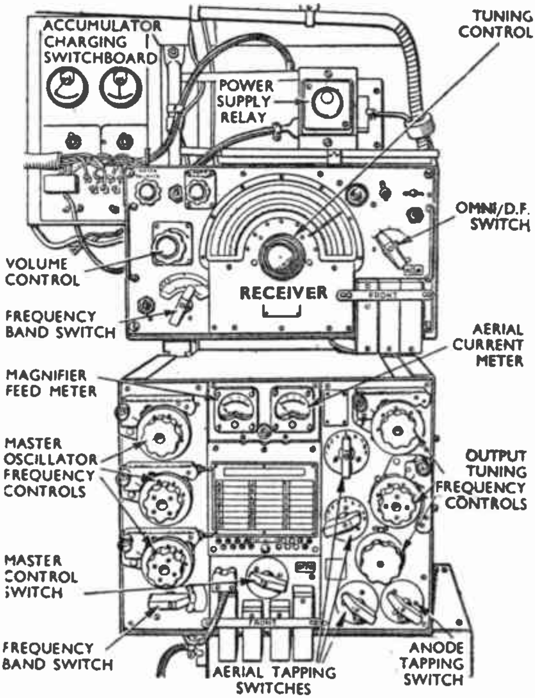


Fig. 15. Marconi sending and receiving installation for general communication and direction-finding. The sender measures 15¾ in. × 16¼ in. × 11 in. and the receiver 10 in. × 16½ in. × 11¼ in. The total weight of the complete installation is approximately 190 lb.

The power supplies for the sender and receiver are obtained from two motor generators which in turn are supplied from an engine-driven generator. The L.T. power unit supplies 6·3 volts for heating all the receiver and sender valves, and approximately 220 volts for the anodes of the receiver valves. The H.T. motor-generator supplies 1,200 volts for the anodes of the sender valves. The starting relay of the H.T. power unit is energized by the L.T. output of the L.T. power unit so that H.T. cannot be applied to the sender before the filaments are alight.

The power consumption of the equipment is approximately 250 watts when in the "receive" and 500 watts in the "send" position. The R.F.

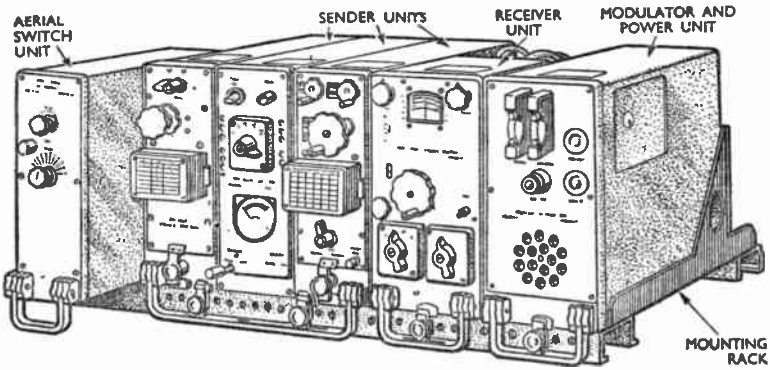


Fig. 16. Lightweight communications equipment mounted on the standard airborne racking. The aerial-switch unit is shown partly withdrawn to indicate the facility with which individual units may be removed or interchanged as required.

output is 50–80 watts on C.W. and a quarter power on R.T. and M.C.W.

A fixed aerial is used for H.F. and a trailing aerial for M.F. These are connected to the sender and receiver by means of a specially designed switch with the following five positions: "normal," "D.F.," "M.F. on fixed aerial," "H.F. on trailing aerial," and "earth."

The sender circuit consists of a master oscillator stage in which an indirectly heated triode is used as a Hartley oscillator, this being capacitance-coupled to a power-amplifier stage which comprises two directly heated pentodes in parallel. A second indirectly heated triode is used as a 1,200-c/s oscillator to provide side-tone on C.W. This valve is used as a modulator for radio telephony and C.W.

A master switch for controlling the sender is positioned centrally at the bottom of the front panel and is marked "off," "STD.BI," "tune," "C.W.," "M.C.W.," "R.T."

The *receiver* is an efficient 10-valve superheterodyne covering the following ranges:

1. 18·5–7·5 Mc/s.
2. 7·5–3·0 Mc/s.
3. 1,500–600 kc/s.
4. 500–200 kc/s.
5. 200–75 kc/s.

The fixed aerial is used for ranges 1 and 2, and the trailing aerial for ranges 3, 4 and 5.

The receiver has a number of special features, some of which can be recognized from the named parts and controls illustrated in Fig. 15.

The valves are (1 and 2) D.F. switching valves, (3) R.F. amplifier, (4) frequency-changer, (5 and 6) I.F. amplifiers, (7) A.G.C. and beat-frequency oscillator, (8) detector, output and visual-meter-switching valve, (9) visual-meter-switching valve, (10) tuning indicator. The I.F. is 560 kc/s.

UNIVERSAL RACK MOUNTING. The British aircraft radio industry has agreed to a scheme for standardizing box sizes and finishes and to a new system for the rack-mounting of the boxes. In a complex radio installation, this enables units of equipment produced by different manufacturers to be engineered into a complete radio station of considerable flexibility. It also simplifies the work of aircraft constructors in installing radio equipment.

In the lightweight aircraft radio equipment produced by the Marconi Company there is a strong, lightweight metal rack in which can be clipped any required combination of receiver, sender, power-supply and other units (Fig. 16). A complete assembly, comprising airborne communication sender and receiver, direction-finding equipment and intercommunication amplifier, can be provided within an over-all weight of 120 lb.

Such an installation (Fig. 17) gives the following facilities: transmission and reception on H.F. and M.F.; automatic direction-finding and homing on M.F.; and crew intercommunication.

The miniaturized and standard boxes or instrument units are all 8 in. high, 9½–12½ in. deep and 3, 4, 5 or 9 in. wide according to the particular unit. Known as radio equipment type AD.97/108/7092 the complete installation may comprise almost any combination of the units described in the following notes.

Transmitter Type AD.97. This has a normal frequency coverage of 2·5–9·1 Mc/s (120–33 metres) and 320–520 kc/s (938–577 metres), but other frequency ranges are available if specially required.

The sender is arranged for direct control by the radio operator and consists of a central structure containing the valves and two plug-in crystal-controlled tuning units. These tuning units may be arranged as one M.F. (medium frequency) and one H.F. (high frequency) per sender, or two M.F. or two H.F. according to the demands of the service for which the sender is required.

The M.F. tuning unit, carrying four crystals, can be adjusted to four pre-set frequencies, any of which can be selected by means of a switch. The H.F. tuning unit, also fitted with four crystals, may be pre-set on one frequency, the other three frequencies being selected by a switch and the output circuits retuned accordingly.

It is designed for operation on C.W., M.C.W. and telephony. The power output to the aerial circuit is 15–30 watts on continuous waves, according to the aerial characteristics.

*Communication Receiver Type A.D.*108. This has a normal frequency coverage of 2–18·5 Mc/s (150–16·2 metres) and 260–510 kc/s (1154–588 metres), but receivers working on other frequencies are supplied to meet special needs.

The communication receiver is a nine-valve superheterodyne, with facilities for the reception of C.W., M.C.W. and telephony signals. It is arranged for both direct and remote operation. Automatic gain control is provided, together with manual control of radio- and audio-frequency gain. The beat-frequency oscillator for C.W. reception is adjustable over ± 1·5 kc/s.

The normal band width of the receiver is 5 kc/s, but when conditions of reception on C.W. are difficult due to heavy traffic, the selectivity of the circuits may be further increased by switching in a crystal filter to reduce the band width to 1,000 c/s. The receiver contains its own anode power unit operated directly from the aircraft 24-volt D.C. supply, the valve heaters being maintained at 18·9 volts through the regulator unit described below.

Modulator and Power Unit. Anode power for the sender is provided by a rotary transformer, fed with 24-volt D.C. (nominal) from the aircraft supply. The modulator section of this unit is designed to amplify the microphone output sufficiently to provide a signal capable of modulating the sender carrier to a depth of 90 per cent on telephony and to provide modulation at 1,000 c/s for M.C.W. working. In addition, this amplifier provides intercommunication.

A low-gain electromagnetic microphone is employed which, together with the modulating circuits incorporated, provides a high-fidelity communication system.

Radio Station Regulator Unit. This unit is designed to provide a regulated 18·9-volt supply for the heaters of all valves. The regulation is maintained with any D.C. input of between 21·5 and 29 volts. Check meters and arrangements for supply adjustments are brought out to the front panel.

Intercommunication System. An intercommunication system is provided for the radio operator and pilot. Station boxes enable either of them to use the various services provided by the equipment. If required, an additional box can be fitted in the steward's compartment enabling him to communicate with the pilot and radio operator. In addition, provision is made for the station boxes to switch the facilities offered by other items of radio apparatus installed in the aircraft, such as a beam-approach receiver and V.H.F. communication equipment.

Aerial Switch Unit. This incorporates the aerial change-over relays, allowing M.F. or H.F. to be used on either a fixed or a trailing aerial. These relays are brought into operation by means of the tuning-unit selector switch mounted on the transmitter panel.

The unit also contains an adjustable inductance for loading the fixed aerial for medium-frequency working. This loading inductance is automatically removed when H.F. is used on the fixed aerial.

Automatic Radio Compass Type AD.7092. This is a navigational aid with a normal frequency coverage of 150–2,000 kc/s (2,000–150 metres).

The receiver is an 18-valve superheterodyne receiver which contains its own power unit and is fully remotely controlled, the remote-control box carrying a tuning scale calibrated in kilocycles per second, with all the necessary switching. The usual manual rotation of the loop aerial is superseded by a system of electronic phase-switching, which actuates a special motor driving the loop, and a position repeater which operates the radio compass-bearing indicator. The normal band-width of the receiver is 3·5 kc/s. Increased selectivity can be obtained by the use of crystal filters.

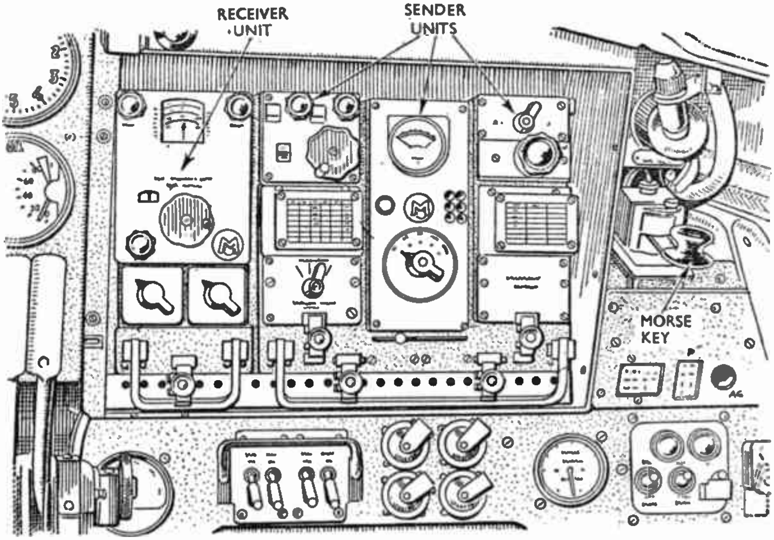


Fig. 17. Equipment, including the Transmitter AD.97, installed in a De Havilland Dove aircraft; it is fitted into the instrument panel on the starboard side.

two additional band-widths of 1,000 c/s and 200 c/s being provided.

While primarily intended for direction-finding and homing, the receiver is also suitable for the normal reception of C.W. and telephony for communication purposes and of radio-range signals.

AIR-GAP. Gap in the magnetic circuit of the core of an inductor. The gap is introduced to prevent saturation of the iron. See INDUCTOR, SMOOTHING CIRCUIT, TRANSFORMER.

AIR-SPACED COIL. Coil for use in an inductor or transformer at radio frequencies, so made that the turns of wire are spaced apart in order to reduce both the self-capacitance of the inductor and the influence of the proximity effect upon its effective resistance and Q-factor. See LATTICE-WOUND INDUCTOR.

ALEXANDERSON ALTERNATOR. Synchronous generator of the inductor type, used for generating high-frequency currents. See SYNCHRONOUS GENERATOR.

ALIGNED GRID. In a valve, a screen grid situated in relation to the control grid so that the wires of the two grids lie on straight lines and perpendicular to the cathode, between cathode and anode. The arrangement ensures that electrons flowing between cathode and anode flow in sheets, with minimum impediment. Moreover, screen-grid current is reduced to a minimum (Fig. 18). The aligned grid is used in the beam tetrode. See BEAM POWER-VALVE, SCREEN GRID.

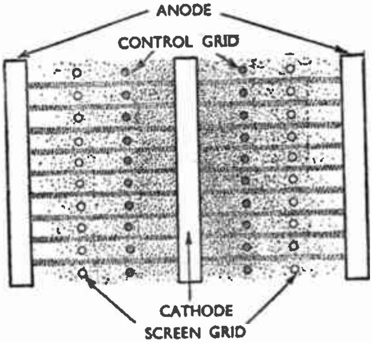


Fig. 18. Diagrammatic illustration of the alignment of the screen grid with the control grid of a valve.

ALL-MAINS RECEIVER. Receiver obtaining all its power supply from the electric mains. The name distinguishes such receivers from the battery-operated type, and, more particularly, from the type wherein anode voltages are derived from the mains, usually via a separate unit containing rectifier and smoothing, while grid bias and filament current are supplied by batteries, a method now less common than formerly.

All-mains receivers intended only for A.C. supplies employ valves with low-voltage heaters taking comparatively large currents, for example, 1 amp. at 4 volts. These are fed from suitable transformer windings, often in paralleled groups.

For D.C. supplies, an all-mains receiver usually embodies special valves whose heaters require a smaller current at a higher voltage, such as 20. These are connected in series, and supplied straight from the mains through a suitable resistor. Such receivers, however, are rare.

A more common type is the universal, designed to work on either A.C. or D.C. mains as required. This uses valves and heater arrangements similar to those just described for D.C. but has, in addition, a rectifier to produce the necessary unidirectional anode voltages when working on A.C. See MAINS UNIT, POWER SUPPLY, RECTIFICATION, SMOOTHING CIRCUIT.

ALL-WAVE RECEIVER. Term somewhat loosely applied to any receiver capable of working on one or more short-wave bands in addition to normal medium- and long-wave broadcast ranges. Typically, such a receiver might cover 10–20 metres, 20–50, 200–550, and 1,000–2,000 metres. This term dates from times when receivers to cover *all* wavelengths in common use were feasible. Recent development of centimetric and millimetric waves has made such designs impracticable, and therefore the term can no longer be taken literally. See BAND SWITCHING.

ALTERNATING CURRENT. Electric current which continually reverses its direction of flow, rising to a maximum in one direction, dropping to zero, then rising to a maximum in the opposite direction. The rapidity with which it does this is called the frequency or "periodicity"; the complete cycle consists of a pulse in one direction followed by a pulse in the other, and the frequency is expressed in cycles per second (c/s).

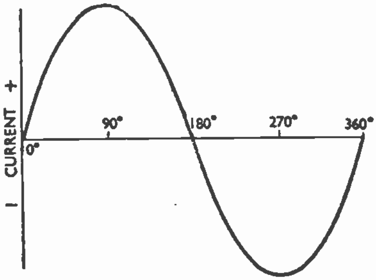


Fig. 19. Graph of one complete cycle of alternating current, showing the usual method of reckoning its timing on an angular scale of 360 deg.

The type of alternating current, or A.C., commonly employed for public supplies in Great Britain has a periodicity of 50 c/s, which means that there are, in fact, 100 pulses of current in each second—50 in one direction and 50 in the other (each pulse is called an alternation; a cycle, therefore, consists of two alternations). For special purposes, alternating currents of higher frequencies, such as 500 and 1,000 c/s are used; the currents involved in the electrical reproduction of speech and music have frequencies ranging from a lower limit of the order of 25 c/s up to an approximate maximum of 10,000 c/s, and those which carry the picture details in television are of still greater frequency range.

The high-frequency currents used in radio communication may alternate as many as a million or a thousand million times every second. All these are alternating currents, but the term is usually reserved for those of comparatively low periodicity which are used for power, lighting and heating purposes.

For an alternating current there is a definite relationship between amplitude (or intensity) and time; the complete cycle is regarded in terms of the 360 deg. of a complete revolution, with the start of the cycle at 0 deg., the halfway point at 180 deg., and the finish at 360 deg. (Fig. 19). Alternating current thus has, at any instant, an intensity proportional to the sine of the angle which corresponds to the particular point in the cycle. This is called the instantaneous value of the current.

To compare a current which is continually changing in value and direction with a steady direct current presents some initial difficulty; for example, to determine the heating effect of an alternating current it is necessary to square its value, as in the case of steady current; but it is difficult to decide what value to take. It is obviously wrong to square the maximum value of the current, because, for a considerable part of the cycle, the current has much smaller values and at times, of course, is zero.

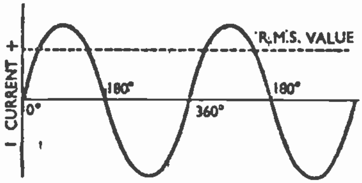


Fig. 20. The value of A.C. at a given instant is equivalent to the sine of the angle corresponding to that instant in the cycle. Heating effect is determined by the r.m.s. value of the current.

The heating effect can be evaluated by taking a number of instantaneous values during a complete cycle, squaring them, determining the average, and finding the square root of the result. The answer gives the value of a steady current which has the same heating effect as the alternating current. It is known as the root-mean-square value of the current (Fig. 20), and whenever a certain value of alternating current is quoted the r.m.s. value is meant. The r.m.s. value of the current or voltage in an alternating circuit is equal to 0·707 of the maximum or peak value; it is sometimes called the "effective" current or voltage. This is only true, however, for currents or voltages of sine wave form.

If the r.m.s. value of an alternating current or voltage is known, it is possible to find the peak value. The peak value is 1·41 times the r.m.s. value. This calculation is often necessary, for example, in determining the peak voltage which will be delivered to the reservoir capacitor of a rectifying circuit. Suppose that a rectifier is to be connected to mains rated at 230 volts; the peak value of the voltage will be 230 × 1·41 or nearly 325 volts, and this is the figure to be considered when choosing a safety rating for the reservoir capacitor which will be connected across the output of the rectifier.

In a D.C. circuit it is simple to work out the power which is being delivered, by multiplying the voltage by the current. But when the supply is alternating, the current and voltage may not be in step (more correctly "in phase"). If the circuit contains inductance, the current will reach its peak value after the peak of voltage has passed, i.e. will "lag." If the circuit contains capacitance the current will "lead" the voltage and will reach its peak value before the voltage.

Thus, to estimate the power in the circuit, the extent of the lag or lead must be taken into account. This is done by multiplying the "apparent" power (the product of r.m.s. current and r.m.s. voltage) by the cosine of the angle of lag or lead. This factor, cos φ, is called the power factor; it is equal to one when there is no lag or lead (that is, when current and voltage are "in phase") and at all other times is less than one. The angle φ of lag or lead is evaluated on the scale of 360 deg. already described.

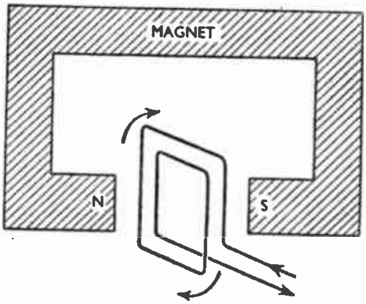


Fig. 21. If a coil of wire is rotated in a magnetic field the voltages induced in the coil rise and fall in the manner of alternating current.

In practical circuits, the power factor is unity only when there is neither capacitance nor inductance in the circuit and the load is pure resistance; or when the values of inductance and capacitance are such as to produce resonance. Extreme cases exist when the circuit contains pure inductance or pure capacitance, without resistance. Voltage and current are then 90 deg. out of phase, cos φ equals zero, and the power is zero. This is the "wattless" condition; it can be approached, but never fully attained in practice. Any physical circuit must contain an amount, however small, of resistance, and if some resistance is present, the 90-deg. phase difference cannot be reached.

Alternating current is simpler to generate than direct current. If a coil of wire is revolved between the poles of a magnet (Fig. 21) the voltages which appear in it by electromagnetic induction are alternating ones; if a direct current is required from the same apparatus, the additional complication of a revolving switching device is needed (this is the commutator of the D.C. generator or dynamo).

Alternating current is more useful than direct current; its great virtue is that its voltage can be varied (changed up or down) by means of a transformer; it can, therefore, be generated at a low voltage, stepped up to a high value for transmission at low loss to some distant point, and there transformed down again to a safe and convenient figure for operating machines, domestic lighting, heating, etc. This process is economical because the transmission of a given amount of power requires a smaller current the higher the voltage is made; a small current needs only a slender conductor to carry it, and a light conductor, insulated to stand high voltages, costs much less than a heavy one insulated for a lower voltage. Insulation is relatively cheap, whereas current-carrying capacity is expensive. Moreover, the power-loss in the case of a small, high-voltage current is less than is economically possible with a large current.

This property of providing any desired voltage by the use of a transformer is one of the most important advantages of alternating current, well exemplified in a radio receiver; here, several different voltages may be needed; for example, to feed valve heaters and for rectification to produce the H.T. supply for the valve-anodes.

Among minor advantages of alternating current are its convenience as a means of synchronizing various devices—the electric clock is an instance—and the ease with which even heavy currents can be broken, that is, switched off by switch-gear. When a large direct current is switched off, it tends to maintain an arc between the separating contact elements of a switch, but when an alternating current is switched off the incipient arc tends to die out as the switch opens, because the current regularly passes through zero value.

ALTERNATOR. Term sometimes used for a synchronous alternating-current generator. See SYNCHRONOUS GENERATOR.

AMMETER. Low-resistance electric-current measuring instrument fitted with a scale calibrated in amperes and multiples or sub-multiples of amperes. Ammeters are of several types: moving-coil, moving-iron, hot-wire, thermo-couple or dynamometer. Ammeters are inserted in series with the circuit, and are frequently shunted by a resistance to permit the measurement of large currents without danger to the instrument.

The basic details of a *moving-coil* ammeter are shown in Fig. 22a. A permanent magnet is fitted with soft-iron pole-pieces. Between the pole-pieces is placed a soft-iron core over which is placed a coil, leaving an air-gap of small dimensions between the core and the pole-faces. A phosphor-bronze spring carries the current to the coil, and a similar coiled spring at the other end of the coil carries the current from the coil. A pointer is pivoted at the centre of the coil and travels over a scale which is calibrated in equidistant divisions.

The coiled springs provide the controlling couple which balances the deflecting couple during the passage of current. When current passes through the coil, the latter tends to rotate about its axis through an angle which is directly proportional to the current flowing through it, owing to the fact that the magnetic field is the same for all positions of the coil.

In the zero position, the springs are not under tension, but, as the coil turns, the springs twist and oppose the motion of the coil, which will come to rest when the torsional pull of the springs exactly balances the electrical torque produced by the current, and the deflection of the pointer is directly proportional, therefore, to the current flowing in the coil.

Moving-coil ammeters can be used for measurement of both D.C. and

A.C., but for A.C. an external rectifier is necessary. Bridge-type copper-oxide rectifiers are generally used.

Moving-iron ammeters, which may be of two types—repulsion and attraction—are more robust but less sensitive than moving-coil ammeters. The basic principle of the repulsion type is illustrated at Fig. 22b. A coil surrounds a pivot which carries both the moving iron and the pointer. When current is passed through the coil the same polarity is induced in both a fixed iron and the moving iron, and repulsion occurs between them, the latter being forced away from the fixed iron, causing the pointer to move.

The movement of the pointer causes the torsion spring to be extended, and this opposes the motion of the pointer, which will come to rest when the tension in the spring exactly counterbalances the electrical torsion set up by the repulsion between the two irons.

In the attraction type of moving-iron ammeter, the fixed and moving elements are replaced by a single soft-iron disc eccentrically pivoted and surrounded by a coil. The disc carries the pointer. Passage of current through the coil causes the disc to become magnetized and move towards the centre of the coil, carrying the pointer with it.

Moving-iron ammeters have scales which are crowded towards the zero, and readings below one-quarter of the maximum tend, therefore, to be inaccurate. These instruments can be used for either D.C. or A.C. work because their action does not depend on direction of current flow. They are liable to be affected by external magnetic fields, but can be safeguarded to some extent by enclosing them in iron cases. Nickel-iron alloy is frequently employed instead of iron as this is less susceptible to hysteresis effects which might otherwise cause inaccuracy in the instrument (see MOVING-IRON INSTRUMENT).

Hot-wire ammeters work on the principle that a stretched wire, usually of platinum silver, will expand if heated. In diagram (c) of Fig. 22 is shown a stretched wire *XYZ* connected at its centre point *Y* to a spring via a pulley. Current passing through the wire causes it to become heated and expand, producing a slackening of the wire. The spring closes to take up the slack, causing a rotation of the pulley, by the movement of the spring wire across it, and a consequent movement of the pointer.

The heat produced in the wire is proportional to the square of the current; the scale is, therefore, not uniform on hot-wire ammeters, the gradations being closer together at the zero end of the scale and well spaced at the other. Such ammeters are somewhat slow in action and their accuracy varies with the temperature of the surrounding air.

They can be used for either A.C. or D.C. work because the heating and expansion of the wire is not dependent upon direction of current flow. They are most frequently employed in radio-frequency A.C. work.

Thermo-couple ammeters depend for their working on the fact that, if the junction of two dissimilar metals in a closed circuit be heated, an e.m.f. is set up between the two metals constituting the thermo-junction.

Fig. 22d shows a loop of wire placed between the poles of a permanent magnet, the lower end of the loop being connected to pieces of steel and Eureka, the junction being heated by the current to be measured which passes through *XY*. The passage of the current heats the junction, and the resultant e.m.f. set up in the loop causes a deflection of the loop between the poles of the magnet and a consequent deflection of the pointer.

Thermo-couple ammeters also can be used for A.C. or D.C. measurements because their action is not dependent upon direction of current flow, but they are most usually employed for radio-frequency A.C. measurements (see THERMO-COUPLE INSTRUMENT).

The basic principle underlying the working of *dynamometer* instruments is that, if current passes through two adjacent wires in the same direction, they will be attracted towards each other. The current to be measured is passed through the two fixed coils, as in Fig. 22e, which are in series with each other and also with a third coil which is free to rotate within the fixed coils. This moving coil carries the pointer and is attached to a spring.

When current is passed through the coils, attraction between them occurs, causing the moving coil to swing towards a horizontal position against the pressure of a spring; the degree of its displacement from the vertical is dependent upon the degree of attraction and, therefore, upon the

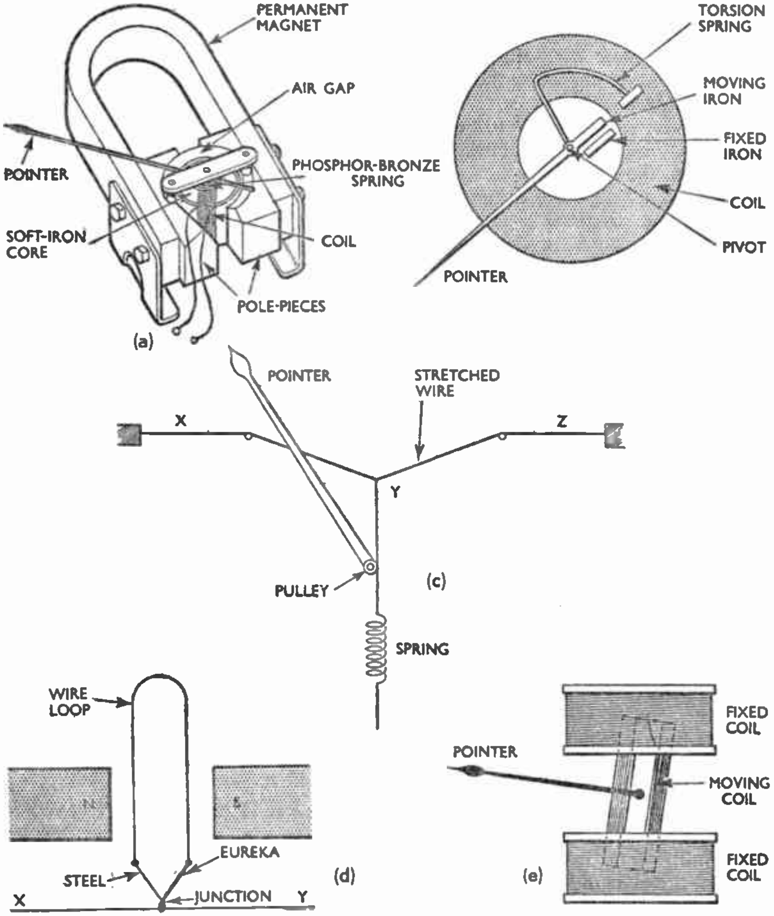


Fig. 22. Principles of operation of various types of ammeter: (*a*) moving-coil; (*b*) repulsion type of moving-iron; (c) hot-wire; (*d*) thermo-couple, and (*e*) dynamometer. All except (*a*) operate equally well on A.C. and D.C.

value of the current that is flowing.

These ammeters can be used for A.C. as well as for D.C. work, for the direction of current flow when A.C. is used will change simultaneously in each coil (see DYNAMOMETER).

AMP. Abbreviation for AMPERE(S).

AMPERE. Unit of volume of electric current, named after a pioneer French physicist. The international ampere is the unit in general use, and this can be defined as the current which will deposit metallic silver at the rate of 0·001118 gramme per second from a solution of silver nitrate by the process of electrolysis. There is also an absolute ampere (see ABSOLUTE UNITS). This is a unit ten times larger, and represents the current which, when passing round a single-turn coil of 1-cm. radius produces a field of 2π gauss at the centre of the coil. See OHM'S LAW, VOLT, WATT.

AMPERE-HOUR. Practical measure of quantity of electricity. It is the amount of electricity delivered by a current of one ampere flowing for one hour. Obviously, the same quantity can be delivered by other combinations having the same product, such as 2 amp. for half an hour.

AMPERE-HOUR CAPACITY. Number giving the current which can be supplied by a cell during a certain time. The number is obtained by multiplying the discharge current in amperes by the time it flows in hours. At the end of the time specified by the ampere-hour capacity, the cell will be discharged. The maximum current that may be taken from the cell must, however, be specified before the ampere-hour capacity can give useful information.

If a cell is said to have a 50-ampere-hour capacity, it might be thought that it could supply 5,000 amp. for one-hundredth of an hour, but a current of this order could not be supplied without damage by a small-capacity cell. If the maximum discharge current were given as 5 amp., then a cell with a 50-ampere-hour capacity would supply 5 amp. for 10 hours or 1 amp. for 50 hours or 100 mA for 500 hours. The maximum discharge current implies a minimum time of discharge; the less the discharge current, the longer the time it flows before the cell is discharged.

The charge taken from a cell is restored by charging. The discharge is expressed in ampere-hours and the charge is similarly expressed, the maximum charging current being specified. Thus, in basic principle, a 50-ampere-hour cell, when fully discharged, can be recharged by passing, say, 5 amp. through it for 10 hours, or 2·5 amp. for 20 hours. In fact, more ampere-hours are used up in charging a cell than can be given up by the cell during discharging. Again, it is essential that the maximum charging current should not be exceeded. The makers always specify maximum charging and discharging currents (see ACCUMULATOR CHARGING).

The ampere-hour capacity unit is applicable to all forms of voltaic cells. A dry cell similarly has a certain ampere-hour capacity, that is, it will supply a certain current for a limited time. Here again, the maximum discharge current must be known before the ampere-hour capacity has any useful meaning.

In some cases, the ampere-hour capacity of a cell is expressed as an ignition rating. This rating is that obtainable when the discharge current is interrupted by a make-and-break system such as is used on internal-combustion engine ignition systems. The ignition rating is naturally greater than the rating which assumes a steady discharge current. See ACCUMULATOR CELL.

AMPERE-TURN. Unit employed in denoting the combined effect of the number of turns in a winding and the density of current flowing therein. Thus if there are 150 turns of wire in a winding and there are 2 amp. flowing round them, the ampere-turn rating of the winding, while thus loaded, is 300.

The magnetizing effect of such a winding is the same as that of one consisting of 100 turns carrying 3 amp., or any other combination having the same ampere-turns.

AMPLIFICATION. Process of increasing the magnitude of an electric current or voltage. Usually, amplification entails the production of a current or voltage which is a magnified copy of another, and is derived from some local source of energy, such as a battery; this local energy is triggered or otherwise controlled by the original current or voltage, but normally flows in a separate and distinct circuit.

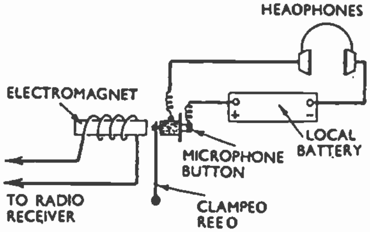


Fig. 23. Principle of the microphone amplifier. Signal currents in the electromagnet vibrate the reed and so cause vibrations in the microphone button.

The process of amplification is fundamental to radio communication; so long as the only energy available in a receiver was the minute amount induced by the incoming signal, reception ranges were severely limited and only headphones could be used.

One of the first attempts to use some kind of relay action to control locally generated energy took the form of a microphone amplifier; a small microphone of special construction was agitated by the movement of an armature, which, in turn, was vibrated by an electromagnet in which the signal currents flowed (Fig. 23).

When the device was correctly adjusted, current taken by the microphone from a battery was modulated in sufficiently close accordance with the signals to yield speech of surprisingly good quality. This amplifier was used extensively during the First World War, but soon after gave place to the triode valve. In one or other of its many forms, the valve is now the universal amplifier in radio communication.

The principle of the valve when used for amplification is basically simple: small variations of voltage on the control grid cause variations of anode current which form, in effect, a magnified replica of the original input (see VALVE). Valves take many forms, but the underlying principle remains the same: the device is a relay in which the only moving parts are electrons.

Methods of using the valve to effect amplification also show some similarity of principle. Consider the case of a valve used to amplify the small signal voltages derived from an aerial circuit and hand them on to a second valve for further amplification; the valve is a voltage-operated device, therefore the input circuits are arranged to apply the maximum voltage to the grid, usually superimposed on the working bias (see GRID BIAS).

It is in the handing-on process that interesting variations appear; here some device is required having a high impedance at the frequencies which are to be amplified. When the incoming signals cause the anode current to vary, a fluctuating voltage is naturally set up across the impedance, and this voltage can be passed on to the grid of the next valve.

The simplest impedance one can use is obviously a suitable amount of resistance, and this method of coupling successive valves is often found in amplifiers intended to work on suitable frequencies. The anode current, in passing through the resistor, produces a drop in the anode voltage, and this drop will vary with changes in anode current; the variations can be passed to the grid of a second valve, and so the signal is handed forward to be amplified still further. Fig. 24 illustrates the essential

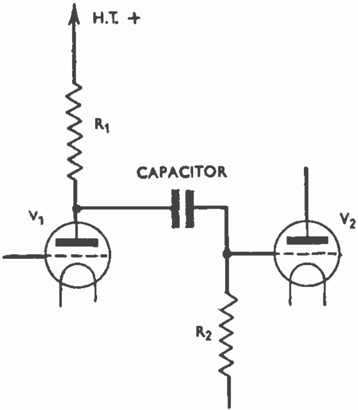


Fig. 24. Essentials of a resistance-capacitance-coupled amplifier. Signal voltages set up across R_1 by variations of anode current are passed through the capacitor to the grid of V_2; R_2 is a grid leak having a very high value.

parts of a resistance-coupled amplifying stage, and there it will be seen that a capacitor is interposed in the wire which carries the signal voltages from the anode of V_1 to the grid of V_2. Its purpose is to block the high positive anode voltage of V_1 and prevent it from reaching the grid of V_2.

This it does effectively so long as its insulation is high, but the varying voltages due to the signals make their effect felt through it, since they are equivalent to an alternating current. Resistor R_1 is the anode load of V_1; R_2 is the grid leak, which permits a suitable bias voltage to reach the grid of V_2.

Resistance coupling is effective at those frequencies for which it is suited, but in dealing with frequencies in the radio range it suffers from a serious weakness; the degree of amplification is reduced by the shunting effect of sundry parallel capacitances, and the higher the frequency the worse the result (see RESISTANCE-CAPACITANCE COUPLING).

For the amplification of signals at radio frequency, therefore, some more effective form of coupling impedance is usual. A tuned circuit is the obvious choice, because it will provide not only a high impedance to the resonant frequency, but will also add to the general selectivity of the receiver by virtue of the resonance effect. The simplest way to use a tuned circuit for intervalve coupling is shown in Fig. 25, where the inductor and capacitor form the conventional tuned-anode coupling to hand the magnified signal on from the anode circuit of V_1 to the grid of V_2.

It will be observed that this circuit shows screen-grid valves: with triodes it would be unstable and would probably oscillate continuously as a result of the feedback effects through the anode-grid capacitances in the valves (see FEEDBACK, SCREEN GRID, VALVE).

The simple tuned anode is not often used in practical receiver designs, because certain benefits, notably in selectivity, can be obtained by loosening the coupling a little. This is usually done by replacing the tuned-anode circuit with a radio-frequency transformer, generally with only its secondary tuned by a variable capacitor. In this way the high-tension voltage is

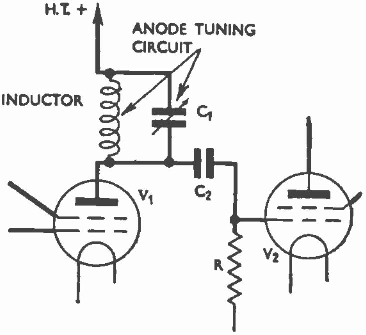


Fig. 25. Tuned-anode R.F. amplifying stage; inductor and variable capacitor C_1 provide the tuned circuit. R.F. voltages set up across it are passed to the grid of V_2 through a blocking capacitor C_2. The grid leak R permits a steady bias voltage to be applied to V_2.

kept off the variable capacitor, with obvious practical advantages, and there is no longer any need for a blocking capacitor in the grid lead of the second valve. Fig. 26 illustrates an elementary form of tuned transformer coupling.

Where the amplifying stage is to work at radio frequency, and must therefore be tunable over a range of wavelengths, it is usual to tune only the secondary. In the I.F. amplifying circuits of a superheterodyne receiver, where only a narrow frequency band is handled, both primary and secondary can be tuned, usually with adjustable, rather then variable, capacitors. It then becomes practical to loosen still further the coupling between primary and secondary, to adjust it for band-pass effects, or otherwise exploit its possibilities for increased selectivity and/or improved fidelity of reproduction.

These are the principal methods of radio- and intermediate-frequency amplification now used. They are comparatively simple, because valves of the screen-grid and R.F. pentode types have substantially solved the problem of stability; when the triode was the only valve available for radio-frequency amplification, many and varied arrangements were devised to achieve stability—bridge circuits, neutrodynes, and the like. These are now used only in high-power senders (see NEUTRALIZATION).

Amplification of frequencies in the audio range calls for different methods. Resonance effects are, in general, undesirable in audio work, where the object is usually to obtain uniform gain at all frequencies within a wide range. An exception occurs in certain communications receivers which use note tuning; they have audio-frequency circuits which resonate at the frequency of the signal note and help to separate it from any jamming signals which may be present.

Resistance coupling has obvious advantages when the object is uniform gain over a wide frequency range, and is much used in modern receivers. With suitable component values, there is little difficulty in obtaining practically uniform amplification of audio frequencies from, say, 25 to 10,000 c/s, an ample range for the highest fidelity of reproduction.

When valves were less efficient and R.F. and I.F. amplification more difficult, it was usual to see transformers used for audio-frequency intervalve coupling. A well-designed transformer will provide uniform gain over a range of audio frequencies sufficiently wide to ensure quite good reproduction, and it will increase the stage gain by approximately the step-up ratio of its primary and secondary windings. Thus, if a valve having an amplification factor of 20 is coupled to the succeeding one with a transformer of 1 : 3 ratio, the stage gain will approach 60; whereas with resistance coupling it can only approach 20 (see AMPLIFICATION FACTOR).

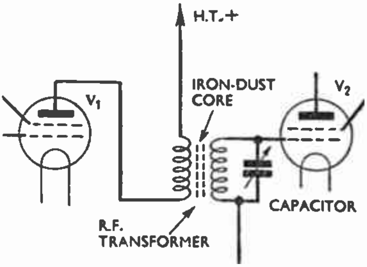


Fig. 26. Essentials of an R.F. amplifying stage with tuned-transformer intervalve coupling. The variable capacitor tunes the secondary of the transformer.

The transformer, therefore, seems attractive, but nevertheless it has become a rarity, partly because it is expensive and has certain practical drawbacks, but perhaps chiefly because designers tend to prefer that a greater part of the amplification shall be done at R.F. and I.F., and less at A.F.

Some of the most difficult amplification problems are met in the vision-frequency circuits of a television receiver. Here the range of frequencies to be amplified with reasonable uniformity runs from an extremely low bottom limit—theoretically zero, but say 20 c/s—to a very high top limit of the order of 2 Mc/s. Resistance coupling of carefully chosen values is the inevitable choice for such work. See AMPLIFIER, BALANCED VALVE-OPERATION, CLASS-A VALVE OPERATION, PHASE SPLITTING, POWER AMPLIFIER, VISION-FREQUENCY AMPLIFIER, VOLTAGE AMPLIFIER.

AMPLIFICATION FACTOR. Figure which indicates the magnifying power of a valve. The factor concerns the relation between a given change of grid voltage and the resultant change of anode current. More precisely, the amplification factor is the ratio between a given change of grid voltage and the change of anode voltage necessary to produce the same change of anode current.

Suppose, for instance, that it is found that a change of one volt on the grid alters the anode current by 2·5 mA, and that to produce the same change of current it would be necessary to vary the anode voltage by 25 volts; the valve would then be said to have an amplification factor of 25, since that is the ratio between the changes of grid and anode voltage which produce the same change of anode current (Fig. 27). Hence the full term is "voltage-amplification factor."

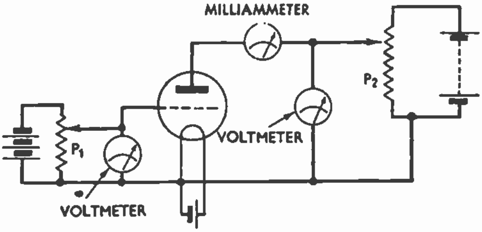


Fig. 27. Simple method of measuring the amplification factor of a battery-operated triode by finding the variations of grid and anode voltage which produce the same alteration of anode current; P_1 and P_2 are potential dividers.

The amplification factor of a valve may be measured as shown in Fig. 28; the grid is given a certain bias and the anode current is noted. A small positive or negative change in grid voltage is made, and the anode current increases or decreases. If the grid potential is reduced by ΔE_g volts, the anode current will increase by ΔI mA.

Now suppose the anode voltage is decreased so as to restore the anode current to its original value; if the necessary change in anode voltage is ΔE_a volts, the amplification factor is then $\frac{\Delta E_a}{\Delta E_g}$. The amplification factor is usually written as μ, mutual conductance as g_m and anode slope-resistance as r_a. It can be proved that $\mu = g_m r_a$.

As to the use of the factor, it may be regarded as a theoretical rating which indicates the maximum amplification obtainable from a particular valve, assuming that there is no voltage magnification inherent in the inter-valve coupling device—as there may be if the coupling is, say, a transformer of some kind. With simple, non-magnifying couplings, such as those of the resistance-capacitance type, the amplification factor of the valve represents the theoretical maximum gain to be had from the stage, a maximum which in practice may be approached but cannot be exceeded. In fact, the stage gain in such a case is given by the expression $G = \frac{\mu R_o}{R_o + r_a}$, where G is the voltage amplification of the stage; μ the amplification factor of the valve; R_o the value of the coupling resistor, and r_a the internal resistance of the valve.

In practice the stage gain of a valve

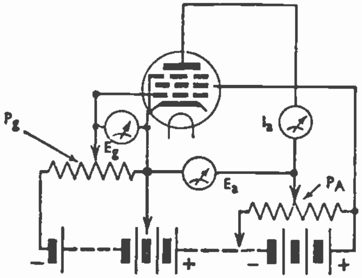


Fig. 28. Measuring the amplification factor of an indirectly heated pentode; the method is as in Fig. 27, using potential dividers P_A and P_g. If ΔE_a is the change in anode voltage and ΔE_g the change in grid voltage, $\mu = \Delta E_a / \Delta E_g$.

is always less than its amplification factor. The discrepancy is greater in pentode or tetrode valves than in triodes. See ANODE SLOPE-RESISTANCE, MUTUAL CONDUCTANCE, STAGE GAIN, TRANSCONDUCTANCE, VALVE CHARACTERISTIC.

AMPLIFIED A.G.C. Form of automatic gain-control wherein the original small control voltages are amplified before application to the valve or valves whose gain is to be controlled in accordance with the strength of the incoming signal. It may be desirable, for example, when the number of controllable valves is small; hence larger control voltages may be needed to produce adequate A.G.C. effects. See AUTOMATIC GAIN-CONTROL.

AMPLIFIED A.V.C. Synonym for AMPLIFIED A.G.C.

AMPLIFIER. Apparatus, circuit or valve performing the function of amplification. The term may, in fact, refer to a particular section of a receiver, as when one mentions the I.F. amplifier of a superheterodyne receiver; or to a self-contained and separate piece of apparatus such as the amplifier used with a public-address equipment; or to any valve which acts as an amplifier.

The amplifier which is a separate and distinct piece of apparatus is generally one for magnifying audio-frequency signals; circuits for amplifying at intermediate or radio frequencies are normally built-in as a fixed part of a complete receiver, for reasons to be discussed.

The self-contained audio amplifier serves many purposes; in amateur circles it is often made up as a separate unit because, being elaborate in design, it is too bulky to fit comfortably on the main receiver chassis; in some of the bigger and more ambitious commercially-made broadcast receivers, the audio amplifier is again built on a separate chassis, fitted on its own shelf in the cabinet, and generally provided with its own power-supply circuits.

An amplifier of this general type is usually made up on the conventional shallow-tray type of chassis: resistors and small capacitors underneath, transformers, smoothing inductors and valves on top, valve holders being set in holes in the tray. Where only a moderate amount of gain is required, the lay-out and the physical design generally is a comparatively simple matter, as the modern tendency to increase the R.F. and I.F. gain and so reduce the amount of work required from the A.F. circuits has made audio design somewhat easier.

Two stages are usually the maximum number employed; the first stage will, in most instances, give a substantial amount of gain—say, between 15 and 30 times—and will drive an output stage consisting of either a single valve or two or more working in a balanced circuit (see BALANCED VALVE-OPERATION). Whereas the first-stage valve is normally one of small power-handling capacity but high voltage-amplification factor, the output valve or valves will be of different type giving comparatively low amplification factor but large power-handling ability.

In any reasonably efficient radio receiving circuit, an audio amplifier of two stages will provide sufficient gain; but in many practical designs

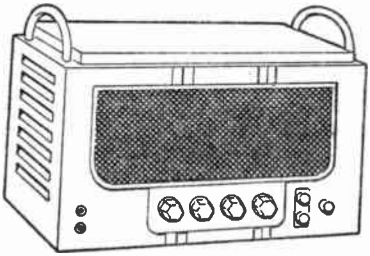


Fig. 29. For public-address work the audio amplifier is usually made up as a self-contained unit in a metal case having ample ventilation.

there are one or more additional valves. These seldom provide additional gain, but merely perform special functions such as contrast expansion, phase splitting, tone control, and the like. In receivers with high-gain R.F. and/or I.F. amplifiers, however, only a single A.F. stage is common.

A third stage of amplification is sometimes provided when only a small input voltage is available, as when the amplifier operates from a gramophone pick-up or microphone of low output. Design is then no longer quite so simple; greater care is necessary to ensure both stability and freedom from mains hum, by adequate smoothing and decoupling of supply circuits, proper lay-out, and attention to such details as arrangement of the wiring.

A well-designed audio-frequency amplifier, an example of which is shown at Fig. 29, is a reasonably stable piece of apparatus, and will tolerate external input and output leads of considerable length; it can be placed at some little distance from the receiver, microphone or gramophone pick-up which is the source of signals; and the loudspeaker can be some way from the amplifier, except that with a three-stage or other high-gain amplifier it may be advisable, even necessary, to use screened cables for these leads.

Amplifiers for radio and intermediate frequencies are quite different; naturally more sensitive to feedback through stray capacitances, they will almost always become unstable if any attempt is made to use them with long input and output leads unless those leads are run in correctly earthed metal sheathing; and unless this is done properly, by treating the connexions as transmission lines and giving due heed to impedance matching at either end, severe attenuation may result. Thus R.F. and I.F. amplifiers are most often found in the form of integral sections of a receiver, where it is easy to ensure stable operation by proper screening, lay-out and decoupling.

In both R.F. and I.F. amplifiers, the modern practice is to use valves with high amplification factors and some form of inter-electrode screening: examples are the screen-grid and the R.F. pentode. Such valves, with their freedom from internal feedback, allow the design of an amplifier which has high gain yet complete stability if proper attention is paid to decoupling and screening.

In some instances, where extremely high gain is the object, each stage of the amplifier may be enclosed in its own screening compartment and the inductors will be individually "canned" as well; for more usual amounts of gain, it is enough to enclose the valves and inductors in individual screening cans, and to separate anode and grid wires by running them on opposite sides of any convenient, earthed, metal object, such as the chassis, an inductor can or the body of a tuning capacitor.

This simplification of construction owes much to the reduction in size of components which has taken place in recent years. The use of iron-dust cores has enabled inductors to be made smaller, as well as more efficient, with a corresponding reduction in the size of their screening cans; similarly, tuning capacitors have shrunk as a result of the smaller plate spacings permitted by more precise methods of assembly. Fixed capacitors have also become smaller as the electrolytic principle has been applied more generally.

Smaller components make possible a less straggling lay-out and enable a skilful designer to produce an inherently stable amplifier with less use of screening; in many modern sets of quite high sensitivity, the only screening is that provided by individual component cans and by the metal chassis.

Compartment screening is perhaps more often seen in special amplifiers for the higher frequencies—above about 5 Mc/s. On such frequencies the individual screening of inductors is frowned upon by many designers and, indeed, on the highest frequencies it is scarcely practicable at all. The usual practice, therefore, is to enclose each stage in its own box, but to leave the inductors open inside that box. See AMPLIFICATION, AMPLIFICATION FACTOR, TETRODE.

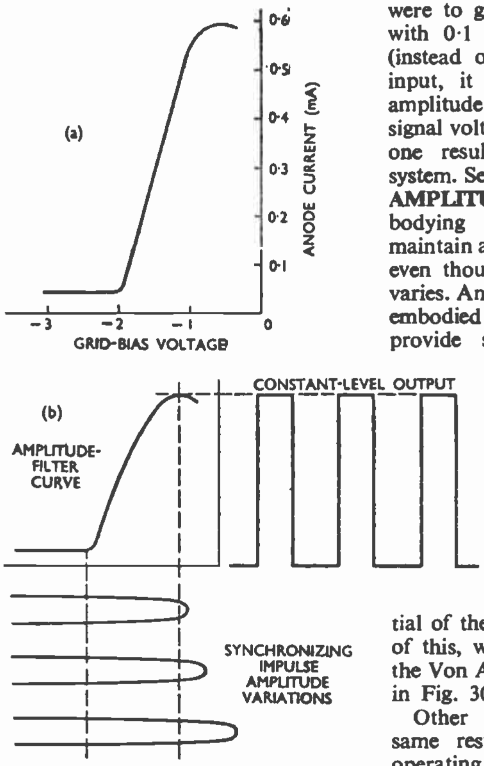


Fig. 30. Effect of amplitude filter on the output of a tetrode: (*a*) grid-volts/anode-current characteristic when screen voltage is higher than anode voltage; (*b*) levelling effect obtained.

AMPLIFIER NOISE. See SET NOISE.

AMPLITUDE. As a noun, synonym for PEAK VALUE.

AMPLITUDE DISTORTION. Variation in the ratio of output to input of a system as the input amplitude is varied. For example, if an amplifier were to give an output of 100 volts with 0·1 volt input, and 180 volts (instead of 200 volts) with 0·2 volt input, it would be said to exhibit amplitude distortion over this range of signal voltage. Amplitude distortion is one result of non-linearity in the system. See NON-LINEAR DISTORTION.

AMPLITUDE FILTER. Device embodying a tetrode or pentode to maintain an output of constant voltage even though the voltage of its input varies. Amplitude filters are frequently embodied in television circuits to provide synchronizing impulses of constant voltage.

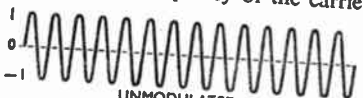
In the original form, the valve is operated so that its grid is always at a negative potential in relation to the cathode. This is achieved because the screen-grid voltage is automatically adjusted in accordance with reductions of the negative potential of the control grid. The principle of this, which is generally known as the Von Ardenne system, is illustrated in Fig. 30.

Other methods of achieving the same result are used, such as so operating the valve that, when its negative grid voltage is reduced beyond a certain point, a comparatively large reduction of anode current results. See LIMITER.

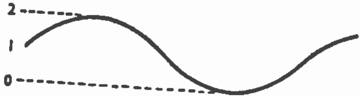
AMPLITUDE MODULATION. Modulation in which the amplitude of the carrier wave is varied by the modulating wave (see MODULATION). Amplitude modulation of a carrier wave is shown in Figs. 31 and 32. In Fig. 31 the modulating factor is unity; in Fig. 32 it is 0·6 (see MODULATION FACTOR). Received signals are stronger as the modulation factor is greater (see MODULATION DEPTH). The modulation envelope shows greater changes as the modulation factor is increased, and it is the variation of the modulation envelope which causes the amplitude of the received signals to vary (see DETECTION, MODULATION ENVELOPE).

The amplitude modulation of a carrier wave by a sinusoidal modulating wave can be considered to be due to adding other sinusoidal waves to the carrier wave. These added waves are called SIDEBAND WAVES (q.v.) and have frequencies which are different from the carrier wave.

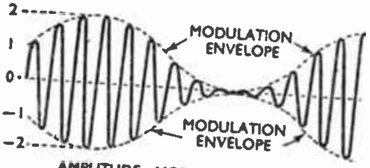
If f_c is the frequency of the carrier wave, then the frequencies of the sideband waves are $f_c + f_m$ and $f_c - f_m$, where f_m is the frequency at which the carrier wave rises and falls; that is, the frequency of the modulating wave.



UNMODULATED CARRIER WAVE
(a)



MODULATING WAVE
(b)



AMPLITUDE–MODULATED WAVE
(c)

Fig. 31. Diagram showing the wave form produced (c) when a steady carrier wave (a) is amplitude-modulated by (b). The modulation factor is 1.

The amplitude of the sideband waves is determined by the depth of modulation (see MODULATION DEPTH); for a modulation factor of unity each sideband wave has half the amplitude of the carrier wave. Since power depends upon the square of a voltage, and hence on the square of the amplitude of the resultant vector, the peak power in a fully modulated wave (modulation factor = 1) is divided so that ⅔ of it is contained in the constant-amplitude carrier wave and ⅓ in the sideband waves.

Thus an amplitude-modulated wave is composed of a carrier wave which is of constant amplitude and two sideband waves. The difference between the frequency of the carrier wave and one or other sideband wave is equal to the frequency of the modulating wave, and the carrier-wave frequency is hence the mean of the frequencies of the sideband waves. The difference between the frequencies of the sideband waves is twice the modulating-wave frequency.

The amplitude of the sideband waves determines the modulation depth of the carrier wave; and for sinusoidal modulation the modulation factor is $2S/C$, where C is the carrier wave and S the sideband-wave amplitude.

The power of a carrier wave that is amplitude-modulated to a depth of 100 per cent by a sinusoidal wave is 1·5 times that of the unmodulated carrier wave. See AMPLITUDE MODULATOR, ANODE MODULATOR, CARRIER WAVE, COMMUTATION MODULATION, FREQUENCY-CHANGING, LINEAR MODULATION, MODULATED WAVE, MODULATING WAVE, MODULATION, MODULATION FACTOR, NON-LINEAR MODULATION, SINGLE-SIDEBAND MODULATION, SUPPRESSED-CARRIER MODULATION.

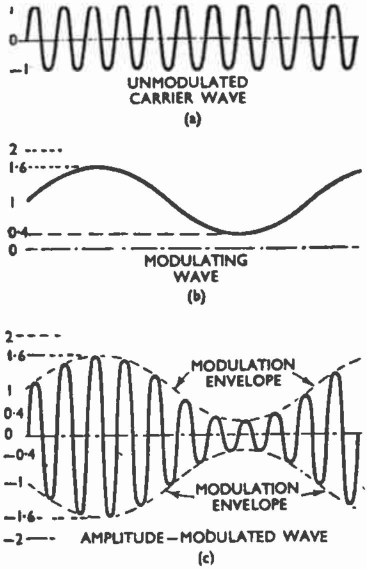


Fig. 32. Wave-form diagram in all respects similar to Fig. 31 except that here modulation depth is less. This diagram is drawn to a modulation factor of 0·6.

AMPLITUDE MODULATOR. Modulator designed to cause a carrier wave to be varied in amplitude in accordance with the amplitude of a modulating wave. See ANODE MODULATOR, LINEAR MODULATION, NON-LINEAR MODULATION.

AMPLITUDE RESONANCE. Term used to distinguish a voltage from a current resonance; but as, in both cases, the amplitude of a quantity is increased at resonance, the term is of little value. See RESONANCE.

ANGLE OF CURRENT FLOW. Fraction of a cycle of an alternating voltage, applied to the grid of a valve, during which there is a flow of anode current. This fraction is expressed in degrees according to the usual convention by which a complete cycle is regarded as consisting of 360 deg. In a class-A amplifier, the angle of current flow is 360 deg., because anode current flows throughout the entire cycle; in more heavily biased valves, anode current may be suppressed during a considerable part of the negative half-cycle of the input voltage. See CLASS-A, CLASS-B, CLASS-C VALVE OPERATION.

ANGLE OF ELEVATION. Angle formed by the ionospheric ray emanating from a sending aerial, and the earth's surface. If the angle of elevation were 90 deg., then the ionospheric ray would be radiated vertically upwards into the ionosphere. See IONOSPHERIC REFRACTION.

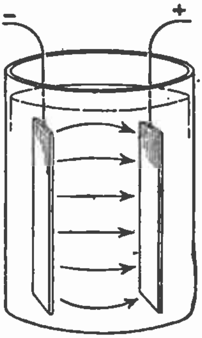
ANGLE OF INCIDENCE. Angle formed by the incident ionospheric ray and a perpendicular drawn from the earth's surface upwards through the ionosphere. See IONOSPHERIC REFRACTION.

ANGLE OF POLARIZATION. Angle between the plane of polarization and vertical plane containing the direction of propagation. See PLANE-POLARIZED WAVE, POLARIZATION.

ANGULAR FREQUENCY. Periodicity of an alternating current, or other repetitive phenomenon, in terms of radians per second. This is equal to 2π times the frequency in cycles per second.

ANGULAR SPACING. Angle which bears the same ratio to 360 deg. as the physical spacing does to one wavelength in a direction-finding system employing spaced aerials. Thus, if the spacing is equal to one-eighth of the

Fig. 33. In an electrolytic cell the negatively charged anions migrate to the positive electrode.



wavelength, the angular spacing is 45 deg.

ANION. Negatively charged particle which moves towards the positive electrode in an electrolytic cell (Fig. 33), or a similar particle in a discharge taking place in a gaseous medium. See IONIZATION.

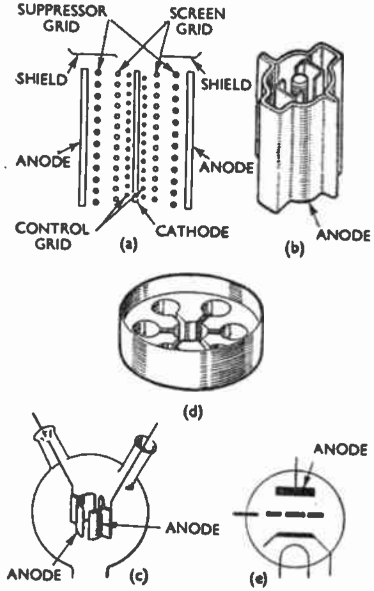


Fig. 34. The anode in various forms of valve: (*a*) diagrammatic section through a pentode; (*b*) the anode structure of a beam tetrode, (*c*) a split-anode magnetron, (*d*) a multi-cavity magnetron; and (*e*) representation distinguishing the anode in an indirectly-heated triode.

ANODE. Electrode of a tube or valve which is held at a positive potential with respect to the cathode, and is the principal collector of electrons. Unlike a grid electrode, the anode is usually of solid construction and electrons do not pass through it. The anode is usually the electrode which is farthest from the cathode, and it generally encloses the grid electrodes. In some screen-grid valves, however, the screen grid is located on both sides of the anode. Although there are exceptions to these generalizations, the anode is distinguished by one or another of the characteristics set out above.

In a glow-tube, either electrode can be made positive and so be properly called the anode, but usually the electrodes are of different shape, and the tube functions better when one of the electrodes is made positive with respect to the other. In a cathode-ray tube, the electrode which controls the axial velocity of the electrons is sometimes called an anode; its proper description is an accelerator.

Fig. 34 distinguishes the anode electrode from others in different types of valve. See AIR-COOLED ANODE, ANODE CURRENT, ANODE DISSIPATION, ANODE-FEED CURRENT, ANODE IMPEDANCE, ANODE SLOPE-RESISTANCE, WATER-COOLED VALVE.

ANODE A.C. CONDUCTANCE. See ANODE SLOPE-CONDUCTANCE.

ANODE A.C. RESISTANCE. See ANODE SLOPE-RESISTANCE.

ANODE BATTERY. Synonym for HIGH-TENSION BATTERY.

ANODE BEND. Curved portion at the bottom of the anode-current/grid-voltage characteristic of a valve (see CHARACTERISTIC CURVE). With a valve operated at a given anode voltage, a sufficient negative voltage on the grid prevents anode current from flowing, the negative field due to the grid being more than sufficient to counteract the positive field due to the anode. As the grid is made less negative, a condition is reached where the two effects balance exactly. Reducing the (negative) grid voltage still further permits anode current to flow.

The relationship between anode current and grid voltage is of the form shown in Fig. 35. It will be seen that the current increases slowly at first, and then more rapidly, finally settling down to a straight-line, or linear, condition in which current and voltage are linearly related. The first part of the characteristic is called the anode bend, or bottom bend, while the latter part is referred to as the linear portion.

ANODE-BEND DETECTION. Detection of a radio signal by means of a valve operating over the curved portion of the anode-current/grid-voltage characteristic (see DETECTION). If a valve is operated at a point such as *A* in Fig. 35, making the grid less negative will produce an appreciable increase in anode current; whereas making the grid more negative will produce only a small reduction in the already small anode current.

Hence, if we apply a symmetrical voltage variation to the grid, above and below the chosen mean value, the increase in the anode current on the positive half-cycles will be greater than the decrease on the negative half-cycles. Consequently, the mean anode current will increase. Thus, although the signal variations may be occurring too rapidly to be detected by certain methods, their presence will be indicated by the change in anode current which has resulted.

ANODE-BEND RECTIFICATION. Rectification produced by the curvature of the anode-current/grid-voltage characteristic. See ANODE-BEND DETECTION.

ANODE CIRCUIT. Circuit which offers an impedance to the valve anode when the valve is considered as a generator of alternating current. The anode circuit also conducts current from the high-tension source to the anode, and forms part of the anode load. Fig. 36 shows a valve amplifier and distinguishes, by bold lines, what is usually spoken of as the anode circuit. See ANODE LOAD, ANODE-FEED CURRENT.

ANODE CONDUCTANCE. See ANODE SLOPE-CONDUCTANCE.

ANODE CONVERTER. Any converter which gives a D.C. voltage for application to the anode of a valve.

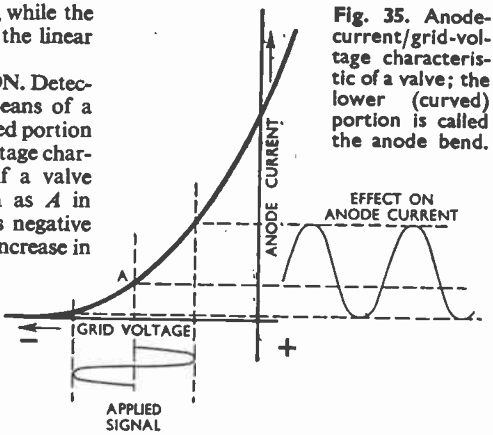


Fig. 35. Anode-current/grid-voltage characteristic of a valve; the lower (curved) portion is called the anode bend.

ANODE CURRENT. Current flowing to and from an anode electrode such as that in a valve or vacuum tube. See ANODE-FEED CURRENT.

ANODE D.C. CONDUCTANCE. Reciprocal of anode D.C. resistance.

ANODE D.C. RESISTANCE. Anode voltage divided by the anode current (Fig. 37). The anode D.C. resistance of a valve is not important in most circumstances; the important resistance as regards an electrode, be it anode, screen-grid or control-grid (when grid current flows), is the slope resistance. See SLOPE RESISTANCE.

ANODE DISSIPATION. Term denoting the dissipation of heat by the anode. Electrons travelling at high velocity strike the solid anode and

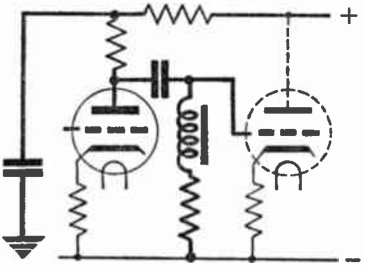


Fig. 36. In this triode-amplifier diagram the anode circuit is distinguished by the use of heavy lines.

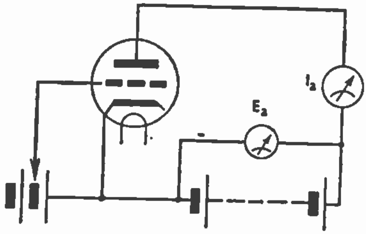


Fig. 37. To find the anode D.C. resistance of the valve, anode-voltage E_a is divided by anode-feed current I_a. The p.d. across the instrument measuring I_a is assumed to be negligible.

generate heat (see ELECTRON VELOCITY). The dissipation is proportional to the anode-feed current, as read by a moving-coil ammeter or milliammeter, multiplied by the anode volts as read by a voltmeter.

When the valve has to handle considerable power, special precautions have to be taken to dissipate the heat generated at the anode, otherwise it would melt. For valves handling powers up to 100 W, the anode is a cylinder of metal and no special cooling measures are necessary. For handling powers which are measurable in kilowatts, the bulb may be made of silica glass and a jet of air blown upon the surface of the bulb. For higher powers, the anode electrode is not enclosed in the bulb and external means are used to cool it. In one arrangement, air is blown upon fins attached to the anode; in another, water circulates over the anode surface. See AIR-COOLED ANODE, COOLED VALVE, RATED ELECTRODE DISSIPATION, WATER-COOLED VALVE.

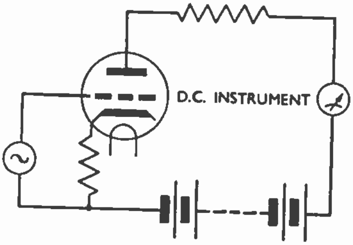


Fig. 38. An instrument which records only the D.C. component of current flowing to and from the valve anode reads the anode-feed current.

ANODE DROP. Synonym for VOLTAGE DROP in an anode circuit.

ANODE-FEED CURRENT. D.C. component of the current flowing to and from the anode electrode. When a valve is used as an amplifier, the current flowing to and from the anode electrode is made up partly of a direct, and partly of an alternating, current. The anode current is the total current, however made up; the anode-feed current is the D.C. component of the total current; and the anode-load current is the A.C. component of the total current (Fig. 38). See ANODE CURRENT.

ANODE-FEED RESISTANCE. Resistance of the anode-feed resistor.

ANODE-FEED RESISTOR. Resistor, shunted by a capacitor which forms the circuit to decouple the anode circuit from the high-tension source. Fig. 39 shows the anode-feed resistor in a resistance-capacitance-coupled amplifying valve.

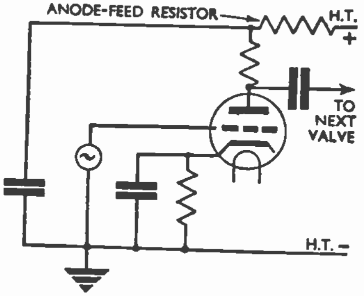


Fig. 39. Typical decoupling circuit showing use of an anode-feed resistor.

ANODE IMPEDANCE. Internal impedance between the anode and cathode of a valve, considered as a generator of A.C. See ELECTRODE IMPEDANCE.

ANODE LOAD. Circuit mainly responsible for the anode-cathode impedance of a valve and in which the major part of the power or volt-amperes is delivered by the valve anode when this is considered as a source of power. Fig. 40 shows a valve connected as an amplifier; it is clear that the alternating voltage developed at the anode will produce alternating current in all the circuits which branch from the anode, including the conductive circuit in which the anode-feed current flows.

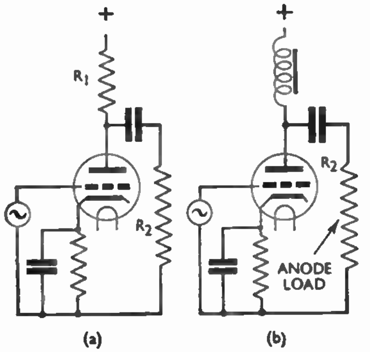


Fig. 40. Anode load of the voltage amplifier (*a*) is, strictly, R_1 and R_2 in parallel, but in the assumed power amplifier (*b*) it is properly R_2.

In diagram (a), if R_2 is equal to or greater than R_1 (as it might be in a resistance-capacitance amplifier) the anode load is strictly R_1 and R_2 in parallel; but the power dissipation in R_1 and R_2 would be small, as the valve is a voltage rather than a power amplifier. In Fig. 40b the load is R_2; its value is usually of the order of the anode slope-resistance of the triode, whereas the impedance of the choke is very much greater. Very little power is delivered to the inductor carrying the anode-feed current because its resistance is usually very small. See ANODE CIRCUIT, ANODE CURRENT, ANODE-FEED CURRENT.

ANODE MODULATOR. Amplitude modulator using valves. The anode voltage of a class-C amplifier, which amplifies the carrier wave, is varied in accordance with the amplitude of the modulating wave. The carrier-wave output from the class-C amplifier varies in accordance with its anode voltage, and hence in accordance with the variations of the modulating wave. The diagrams of Fig. 41 show forms of anode modulator. The so-called modulated amplifier is adjusted so that the carrier-wave output is substantially proportional to the anode voltage.

This anode voltage, as seen from the diagrams, is determined by the output from the modulating-wave amplifier. In order that the carrier-wave output from the modulated amplifier may be doubled or reduced to zero (100 per cent modulation, see MODULATION FACTOR) it is necessary for anode voltage to swing between twice a mean value and zero. If both the modulated

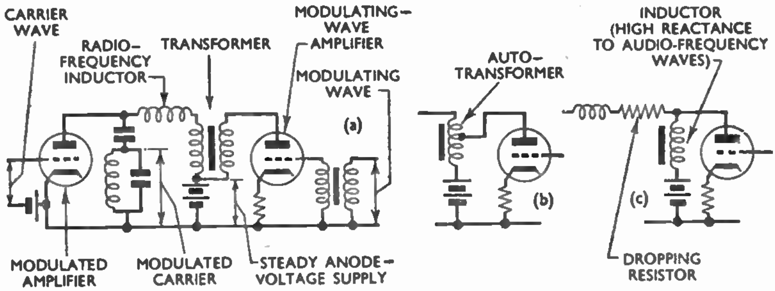


Fig. 41. Anode-modulator circuits (*a*), (*b*) and (*c*) differ only in the method by which the modulating-wave voltage is added to the steady anode voltage.

and modulating-wave amplifiers were energized by the same value of high-tension voltage, the voltage from the modulating-wave amplifier would also have to swing between zero and twice a mean value.

This condition is impossible to attain without introducing severe distortion (see AMPLIFIER). Thus arrangements must be made to ensure that the steady anode voltage of the class-C, or modulated, amplifier is considerably less than that supplied to the modulating-wave amplifier.

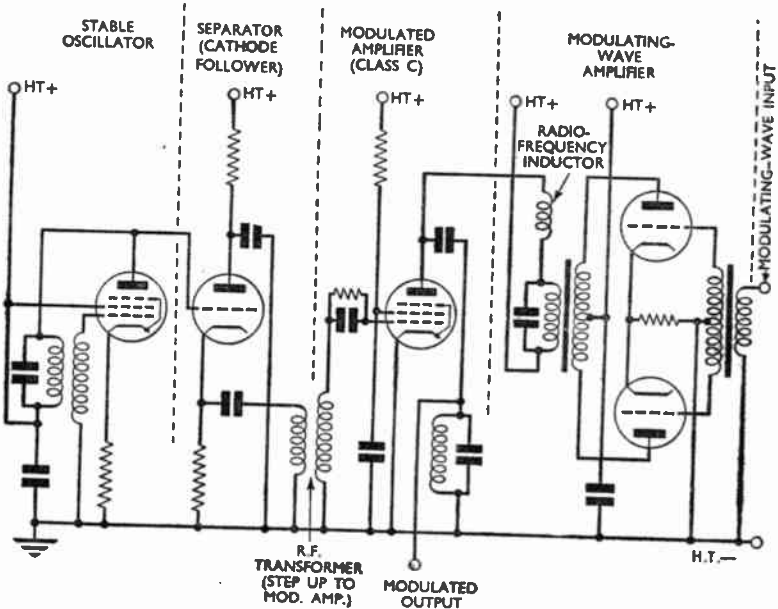


Fig. 42. Schematic diagram of a low-power anode modulator comprising four stages: stable oscillator, cathode follower, an R.F. amplifier and an A.F. amplifier.

The arrangements shown in Fig. 41—a transformer in (a), an auto-transformer in (b) and a dropping resistance in (c)—ensure this condition. Fig. 42 shows a more detailed diagram; the separator valve is necessary to ensure that the output from the modulated amplifier is of constant frequency, because an oscillator, when anode-modulated, slightly varies its frequency. See AMPLITUDE MODULATION, AMPLITUDE MODULATOR.

ANODE RECTIFICATION. Any rectifying action which arises from a non-linear relationship between anode current and applied voltage. The term is usually employed in the same sense as anode-bend rectification.

It should be noted, however, that there is another way in which anode rectification can arise. This is due to conditions where another curvature of the anode-current characteristic occurs as, for example, that shown in Fig. 43. Such a condition can arise in a valve in which the emission is limited by saturation or deliberate restriction as, for instance, in the case of a tetrode or pentode with low screen voltage.

Clearly, under such conditions, a similar process to anode-bend detection can take place, the difference being that the positive grid swings produce little change of anode current, while negative swings produce an appreciable reduction, the asymmetrical action resulting in rectification.

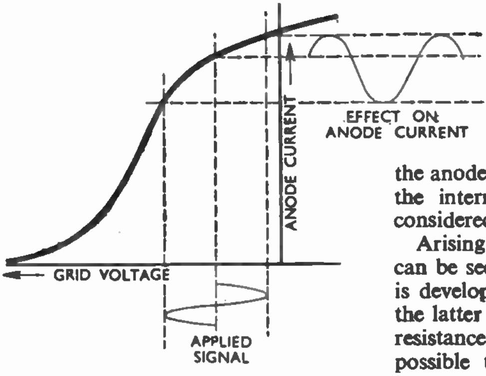


Fig. 43. Characteristic of a tetrode or pentode in which emission is limited, providing conditions in which anode rectification will take place.

ANODE RESISTANCE. Synonym for ANODE SLOPE-RESISTANCE.

ANODE SLOPE-CONDUCTANCE. Reciprocal of ANODE SLOPE-RESISTANCE.

ANODE SLOPE-RESISTANCE. Slope resistance is the ratio of a small path of a valve (see SLOPE RESISTANCE). Slope resistance is the ratio of a small voltage change to the resulting current change produced in any non-linear conductor. Thus anode slope-resistance is the reciprocal of the slope of the anode-volts/anode-current characteristic of a valve in terms of anode-voltage change/anode-current change.

Considered as a generator of power, the valve, like any other electrical generator, can be regarded as an e.m.f. in series with an impedance; the impedance is often, and may be here considered as, a resistance (Fig. 44). Thus the anode slope-resistance of a valve is the internal resistance of the valve considered as a generator of power.

Arising out of this conception, it can be seen that the maximum power is developed in the anode load when the latter is equal to the anode slope-resistance. It may not always be possible to match these resistances; in the case of a pentode, it is impossible, and the maximum power with minimum distortion may not be obtainable. By using negative feedback with pentode valves, or by using triodes, the resistance match can be made and the maximum power thus delivered to the load.

A pentode has a very high anode slope-resistance, sometimes of the order of megohms, but the load cannot be matched to so high a resistance and smaller loads must be used. Thus the pentode is equivalent to a constant-current generator.

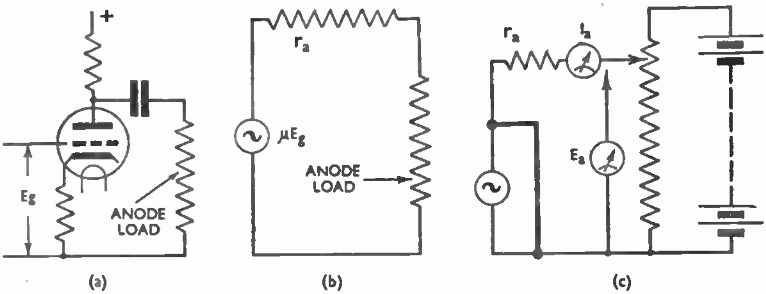


Fig. 44. Typical valve amplifier circuit (*a*); in the electrical equivalent (*b*) the valve is substituted by a generator of e.m.f. μE_g. In (*c*) is shown the method of measuring, with the e.m.f. short-circuited, the slope resistance r_a as $\Delta E_a/\Delta I_a$.

A typical power triode has a slope resistance which can easily be matched to the load; the anode slope-resistance is $r_a = \frac{\Delta E_a}{\Delta I_a}$, where ΔE_a is a small change of anode voltage, and ΔI_a the resulting small change of anode current; the mutual conductance is $g_m = \frac{\Delta I_a}{\Delta E_g}$, where ΔE_g is a small change of grid voltage and I_a the resulting change of current. Therefore, $r_a g_m = \frac{\Delta E_a}{\Delta I_a} \times \frac{\Delta I_a}{\Delta E_g} = \frac{\Delta E_a}{\Delta E_g}$; but the amplification factor $\mu = \frac{\Delta E_a}{\Delta E_g}$; thus we arrive at the important conclusion that $\mu = g_m r_a$. This expression relates the three fundamental characteristics of a valve. See AMPLIFICATION FACTOR, MATCHING, MUTUAL CONDUCTANCE, TRANSCONDUCTANCE, VALVE CHARACTERISTIC, VOLTAGE AMPLIFIER.

ANODE STOPPER. See PARASITIC STOPPER.

ANODE TAP. In a tuned-anode circuit, the point on the inductance coil to which the anode is connected so that the valve works into optimum impedance.

ANODE VOLTAGE. Steady component of the voltage between anode and cathode of a valve; or, the alternating component of the anode voltage; or, the steady component plus the alternating component of the anode voltage. The term is sometimes used as being synonymous with "anode potential."

ANODE-VOLTS/ANODE-CURRENT CHARACTERISTIC. Characteristic obtained by plotting anode current against anode volts on a graph. The anode-volts/anode-current characteristic of a valve is useful when designing amplifiers (see HARMONIC DISTORTION, LOAD LINE). Fig. 45 shows a typical set of curves for a triode. The slope of any graph, at any point on it, gives the anode slope-conductance at the given anode volts and anode current. The graphs of valves with a control grid are usually plotted for different fixed values of grid bias. In a pentode the anode-current/anode-volts curve is plotted as described with the screen-grid volts fixed. A different set of graphs for the pentode are obtained for different fixed values of screen-grid volts. See GRID-VOLTS/ANODE-CURRENT CHARACTERISTIC, VALVE CHARACTERISTIC.

ANOMALOUS DISPLACEMENT CURRENT. Current in a circuit containing a capacitor with imperfect dielectric. It is additional to the normal leakage current, and continues to flow after the charging or discharging current has ceased or attained a very low value.

ANOMALOUS PROPAGATION. Freak propagation of very high-frequency radio-waves which appears to coincide with a condition of temperature inversion in the lower atmosphere.

Very high-frequency waves generally obey optical laws in that their range is limited by the horizon; anomalous propagation (sometimes abbreviated to "anoprop") extends the propagation of very high-frequency waves beyond, and sometimes very considerably beyond, the optical range. See CENTIMETRIC WAVE, VERY HIGH-FREQUENCY WAVE.

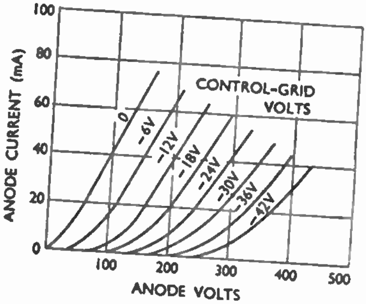


Fig. 45. Typical set of curves representing the anode-volts/anode-current characteristic of a triode.

ANTENNA. Synonym for AERIAL.

ANTENNA EFFECT. Error which results in a direction-finder when a closed aerial, such as a loop, tends to act as an open aerial, the complete assembly being connected to earth through, for instance, the stray capacitances of the associated receiving circuits (Fig. 46). If the paths to earth from either side of the loop circuit are not of equal impedance, a difference of potential is set up *across* the loop circuit, which in turn produces signals in the receiver and obscures or vitiates the direction-finding indications.

In practice, antenna effect is overcome in a number of ways. For example, a balancing capacitor may be used to equalize the impedance to earth from either side of the aerial circuit, or some scheme of centre-point earthing may be used with an inductive coupling from aerial to receiver.

ANTI-INDUCTION NETWORK. Network which may be inserted in two telegraph circuits with the object of reducing crosstalk.

ANTI-INTERFERENCE AERIAL-SYSTEM. Arrangement in which pick-up of energy is confined to the aerial itself, usually by the use of a screened or balanced feeder or down-lead (lead-in). The system is chiefly beneficial in reducing man-made interference originating at or near ground level.

ANTI-MICROPHONIC VALVE HOLDER. Valve holder designed to insulate the valve from mechanical vibration. Slight movement of valve electrodes relative to one another causes modulation of the anode current. This is particularly undesirable in the early stages of a multi-stage amplifier (because resultant noise is amplified by later stages) and in any stage of a high-quality amplifier.

ANTINODE. Any point in a system having a non-uniform distribution of current (or voltage) at which the current (or voltage) has maximum r.m.s. value. See NODES AND ANTINODES.

ANTISTATIC AERIAL. See ANTI-INTERFERENCE AERIAL-SYSTEM.

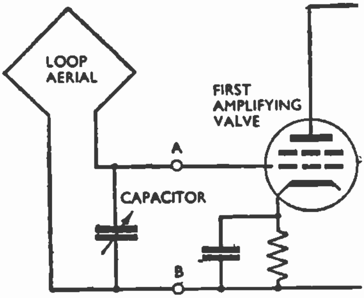


Fig. 46. Antenna effect is produced because capacitances to earth from the two sides (*A* and *B*) of the tuned circuit are unequal, creating voltages across the capacitor which do not respond normally to rotation of the loop.

APERIODIC. Without natural frequency; responding equally to all frequencies. See NATURAL FREQUENCY, RESONANCE.

APERIODIC AERIAL. Aerial working on frequencies other than its resonant frequencies, and sufficiently remote from them to ensure reasonably uniform functioning over its range of operating frequencies. This arrangement, though in many ways less effective than a fully tuned aerial-system, offers substantial advantages when the circuits of a receiver are to be gang-tuned (see GANGING).

It then eliminates a circuit—that of the aerial-earth system—which possesses constants so different from those of the closed circuits of the receiver as to defy ganging by normal methods. This, of course, applies to the open form of aerial. A loop can more readily be ganged with the closed circuits of a receiver.

APERIODIC CIRCUIT. Circuit without frequency discrimination, responding equally to all. The term is commonly applied to circuits which are not truly aperiodic, but whose resonant frequency is outside the range on which they work. They thus function with approximately equal efficiency over that range. See TUNING.

APERTURE DISTORTION. Distortion in television due to the impossibility of using a sufficiently small aperture in the sender of a television system. In the case of mechanical scanning, the aperture is the area illuminated by the moving spot of light which scans the scene. In the case of a storage camera, the effective size of the aperture is the size of the cathode-ray spot which scans the mosaic.

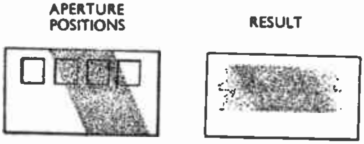


Fig. 47. Scanning of a simple pattern (*left*) results in irregular outlines (*right*) where the aperture "enters" and "leaves" the pattern—an effect known as aperture distortion. The smaller the aperture the sharper the outline produced on the screen.

It will be obvious that it is impossible to transmit details finer than the area represented by the aperture. Fig. 47 shows a simple type of image, consisting of a pattern scanned by a square aperture. As the aperture moves from left to right, the average light intensity of the portion covered by the aperture varies gradually, instead of suddenly, from light to dark and a more or less distorted pattern is the result.

APPARATUS. Assembly of components in which each component performs some definite function. Bridges, potential dividers and signal generators, for instance, are referred to as "measuring apparatus." But the term is variously used, and is often made to appear as synonymous with "equipment" and, notably in U.S.A., with "component." See MEASURING INSTRUMENTS.

APPARENT RESISTANCE. Synonym for IMPEDANCE.

APPLETON LAYER. See F-LAYER, IONOSPHERE.

ARC. Luminous electrical discharge that takes place through ionized gas.

ARC-BACK. Reversal of current flow in the arc of a MERCURY-ARC RECTIFIER (q.v.). In certain conditions electrons pass from the anode to the mercury pool, instead of in the opposite direction. This may be due to overheating of the anode or to condensation of mercury on it. The effect of arc-back is to cause a short-circuit on the H.T. transformer.

ARC CONVERTER. Complete arc assembly in a Poulsen arc generator (see POULSEN ARC). The converter comprises the arc electrodes, an electromagnet on either side of the electrodes for lengthening and stabilizing the arc, and an hydrogenous vapour container; the vapour lowers the temperature of the arc.

ARC GENERATOR. In an arc sender, the discharge across the arc which generates the high-frequency oscillations in the sender circuit.

ARC MODULATION. System of light control in which an ordinary arc light is controlled in intensity by variation of the voltage across it. The system is unsuitable for high-definition television, and is relatively insensitive as it requires considerable power in order to provide light variation.

ARC RECTIFIER. Any electric arc which has a greater conduction when a voltage is applied to it in one sense than in the other. The mercury arc is commonly used as a rectifier in practice. See MERCURY-ARC RECTIFIER.

ARC SENDER. Radio sender in which R.F. oscillations are generated by means of an electric arc. See POULSEN ARC.

ARC TRANSMITTER. Synonym for ARC SENDER.

ARMATURE. Normally, the rotating part of a D.C. motor or generator (see MOTOR). The term is also used sometimes to describe the *stator* of a synchronous generator. In addition, the term is employed to denote the moving part of any electrical device, such as an electric bell or a relay.

ARMSTRONG CIRCUIT. Name sometimes given to the superheterodyne circuit, in recognition of its inventor, Major Edwin Armstrong. See SUPERHETERODYNE RECEPTION.

ARTICULATION. Percentage of speech-sounds correctly received over a radio-communication or reproducing system, or, in reference to acoustics, the percentage that is heard in an auditorium.

ARTIFICIAL AERIAL. Circuit possessing the values of inductance, capacitance and resistance characteristic of a particular type of aerial, but which does not radiate any appreciable fraction of the energy put into it. It is chiefly used in the testing of senders when a radiating aerial might cause interference. It is sometimes known as a dummy aerial.

ARTIFICIAL EARTH. See COUNTERPOISE.

ARTIFICIAL LINE. Electrical network, usually consisting of inductors, capacitors and resistors, the values and arrangement of the components being such as to simulate some or all of the characteristics of a given transmission line.

ARYTHMIC SYSTEM. See START-STOP SYSTEM.

A-SERVICE AREA. Service area in which the field strength is greater than 10 mV/m. See SERVICE AREA.

ASPECT RATIO. Ratio of the breadth to the height of a television picture.

ASTIGMATISM. Inability to focus a beam in all axial planes simultaneously, due to imperfection in the lens. Most cathode-ray tubes suffer more or less from astigmatism, usually in two planes at right-angles. When the focusing control is adjusted to bring the spot to sharpest focus horizontally it is not quite in focus vertically and appears as a short vertical line; and vice versa, as shown in Fig. 48. In a television receiver, it is usually advisable to give preference to horizontal focus, allowing the vertical size of the spot to occupy a complete line width, thereby rendering the line structure least visible. See CATHODE-RAY TUBE, ELECTRON LENS, FOCUSING.

ASYMMETRICAL DEFLECTION. Unequal deflection of the electron beam about a centre line in a CATHODE-RAY TUBE (q.v.). The effect may be due to the application of unequal potentials to opposing deflector plates or coils, or to magnetic effects outside the C.R.T. assembly, especially if the tube is inadequately shielded. The term is perhaps most frequently applied in the case of a C.R.T. of which one deflector plate is maintained at zero or earth potential, while the opposing plate is made positive or negative.

ASYMMETRICAL SIDEBAND MODULATION. System of modulation in which one group of sideband waves is transmitted without attenuation, the other group being attenuated in the outer regions of the sideband. In normal amplitude modulation, the amplitudes of the sideband waves in the upper and lower sidebands are equal, but in asymmetrical sideband modulation, one group of sideband waves suffers increasing attenuation as the frequency of the sideband wave increases or decreases from the sideband carrier-wave frequency.

The object of the scheme is to decrease the effective frequency band

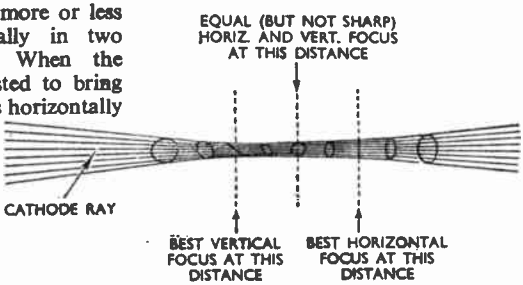


Fig. 48. Diagram showing the cross-sections at various distances along a cathode ray suffering from astigmatism.

occupied in broadcasting programmes from a radio sender. Distortion is inevitably created by attenuating sideband waves in this manner, but this distortion can be made negligible in sending speech and music, because the higher frequencies of the modulating wave have less amplitude than those in the lower. The system has not been put into practice in the broadcasting of sound, but it has application to television senders. See MODULATION DISTORTION.

ASYMMETRICAL SIDEBAND TRANSMISSION. System of radio sending in which one sideband is partly suppressed; this reduces the band width of the transmission and enables more channels to be accommodated within a given frequency band. One method is to employ a single-sideband system of sending, with a reduced carrier amplitude and a residual second sideband. With this system, the band width is reduced to about 60 per cent of that which is occupied by a double-sideband transmission. See ASYMMETRICAL SIDEBAND MODULATION.

ASYNCHRONISM. Reverse of synchronism.

ATMOSPHERIC ARC RECTIFIER. Arc rectifier in which the arc takes place in air at atmospheric pressure. Such a rectifier, however, finds no use in practice.

ATMOSPHERICS. Electromagnetic radiation due to natural causes. It is often called static, especially in America, though that term, if used at all in this connexion, should be reserved for the third of the four classes of natural interference described below. Atmospherics are among the main types of interference and noise, and in some circumstances limit or entirely prevent long-range radio communication, especially on certain frequency bands.

LIGHTNING, which is occurring in some part of the world at practically all times of day or night, is the most important source of atmospherics. The power radiated during a flash is enormously greater than that from any radio station, and its path—which is equivalent to a radiating aerial—is often miles long, and is generally high up, so the conditions for long-range propagation are favourable. Moreover, the transient nature of the discharge means that appreciable radiation occurs at all radio frequencies except, possibly, the very highest. Each flash is heard in the receiver as a crash, which is often prolonged by reflections. The intensity of interference likely to be experienced depends, in a complicated manner, upon time, place and frequency.

When a thunderstorm is taking place within a hundred miles of the receiver, interference is received directly, the greatest intensity being at about 10 kc/s, falling off fairly uniformly with increasing frequency, until it is negligible at ultra-high frequencies unless within a few miles.

Lightning is most prevalent during summer afternoons and evenings over large tropical land areas. In such areas, radio communication at the lower frequencies varies from difficult to impossible. In temperate and arctic latitudes, where local thunderstorms are exceptional, most atmospherics come from whichever tropical area is enjoying a summer afternoon at the time; and the mean intensity depends on the propagation conditions for the frequency of reception.

Low radio-frequency waves are directly propagated to great distances, and atmospherics are received more or less strongly and continuously all over the world. Around one and two megacycles per second they are very weak by day but fairly strong by night because of ionospheric reflection. At 10–20 Mc/s this situation is reversed, and above about 30 Mc/s reception is negligible at all times except during local storms.

Means for reducing interference by atmospherics include restricting the band-width of reception to the minimum necessary for the desired signal, using a directive aerial to exclude atmospherics coming from all directions other than that of the desired station, and making use of circuits to limit amplitude to that required for the desired signal. Frequency modulation is an effective type of transmission for this purpose.

PRECIPITATION. Electrically charged rain, snow, hail, dust or steam can sometimes charge an insulated receiving aerial or adjacent conductor to a sufficiently high potential for it to emit sparks, causing intense click interference. If the aerial is so well insulated that the potential reaches the corona point, a hissing noise results, which may be enough to blot out all except strong signals.

This type of interference, although occasionally troublesome on the ground, is of great concern to aviation. Aircraft are often charged, not only as just described, but by the friction of dry precipitation on the structure. The corona point may be reached in a few seconds, and the resulting discharge may render the radio ineffective under conditions when it is most needed. One remedy is to tow a fine wire or a metallized cotton wick to discharge the aeroplane more quietly at a point remote from the aerial.

STATIC. If an aircraft approaches an intense electromagnetic field, such as that near a thunder cloud, it may reach a sufficient potential for a noisy corona discharge, or static, to take place, as with precipitation. The same phenomenon sometimes occurs at ground stations, causing a hissing sound in contrast to the crashes and rumbles of lightning.

COSMIC NOISE. Sometimes called Jansky noise after the observer who first reported it in 1932, this consists of a weak hissing or rushing not easily distinguished from set noise. From the fact that it appears mainly to come from the Milky Way, the inference is that it must emanate from outer space, and that it is possibly brought about by a sort of cosmic thermal agitation.

Jansky detected the noise at 20 Mc/s but, more recently, Reber has investigated it on 160 Mc/s. At relatively low frequencies it is masked by other types of interference. Although it has little practical bearing on radio, cosmic noise is of great astrophysical interest. See CORONA, INTERFERENCE, NOISE, THERMAL-AGITATION VOLTAGE.

ATOM. Smallest particle of an element capable of entering into a chemical relationship. The atom is postulated as consisting of a heavy nucleus carrying a positive charge of electricity, surrounded by a system of electrons which represent negative charges and by their number decide the chemical properties of the element.

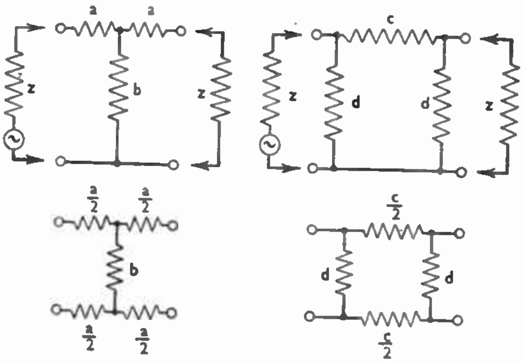
ATTENUATION. Effect due to loss of power in resistive parts of a circuit which reduces the amplitude of a wave or direct current between two points in the circuit. When a wave passes through any network there is likely to be a change of amplitude between two points in the network. If there is a reduction of amplitude due to losses in resistance, the network is said to cause attenuation of the wave.

In general, there are two effects present when a wave passes through a network, one brought about by the effects of resistance, the other by reactance. Attenuation is a term concerned with changes of amplitude due to losses in resistive parts of the circuit. Phase changes also produce alteration of amplitude, but such changes are due to the effects of reactance and there is no loss of power.

In line telephony, the signals at the input to the line are generally of greater amplitude than when they appear at the output terminals of the line; the line is then said to have produced attenuation of the waves representing the signal. In the propagation of radio-waves over the earth's surface, losses in the ground cause the strength of the waves to fall by a greater amount than determined by the inverse-distance law; such waves are attenuated. See ATTENUATION COEFFICIENT.

ATTENUATION COEFFICIENT. Ratio expressing by how much the amplitude of a wave is changed by losses in resistive parts of the circuit, when the wave passes through a transmission channel. Thus the term is descriptive of the real part of the propagation coefficient. The propagation coefficient is a ratio of vector quantities and contains two parts, called real and imaginary; the real part is associated with changes of amplitude due to loss of power in resistance, the imaginary part with effects of reactances causing phase change. Thus the attenuation coefficient is that which concerns loss of power. See PHASE-CHANGE COEFFICIENT, PROPAGATION COEFFICIENT.

ATTENUATION CONSTANT. Synonym for ATTENUATION COEFFICIENT.



ATTENUATION db	$\frac{a}{z}$	$\frac{b}{z}$	$\frac{c}{z}$	$\frac{d}{z}$
1	0·0575	8·667	0·1154	17·39
2	0·1146	4·305	0·2323	8·724
3	0·1710	2·839	0·3523	5·848
4	0·2263	2·097	0·4770	4·420
6	0·3323	1·339	0·7470	3·009
10	0·5195	0·7027	1·423	1·925
15	0·6980	0·3673	2·723	1·432
20	0·8182	0·2020	4·950	1·222
30	0·9387	0·0633	15·80	1·065

Fig. 49. Data for calculating values of elements of a resistive attenuator.

ATTENUATION DISTORTION. Distortion due to variation of loss or gain with frequency. The term is inappropriate and is rarely, if ever, used, the effect being generally known as *frequency* distortion. It is measured by applying to the input of the unit under test a sinusoidal signal, and noting the ratio of r.m.s. value of fundamental output to that of the input, over the band of frequencies concerned; care is taken to avoid or allow for non-linear distortion.

The result is generally expressed as a graph of gain or loss (in decibels) against frequency. Ideally, all amplifiers and other links in a chain of communication should be equally effective at all frequencies within the desired band; but if that is impracticable or uneconomical, the alternative is to impose an equal and opposite distortion by means of a tone control or equalizer. See DISTORTION, EQUALIZER, PRE-EMPHASIS, RESPONSE GRAPH, TONE CONTROL.

ATTENUATION EQUALIZER. Equalizer placed in the output circuit from a line to produce substantially equal amplitudes of waves of different frequency. When a group of waves is passed through a transmission line, it is possible that those of higher frequency are more attenuated than those of lower frequency. In speech transmission over lines, this effect distorts the speech, making the lower frequencies predominant. An attenuation equalizer is arranged to compensate for this effect and gives a greater attenuation of the low- than of the high-frequency waves. See ATTENUATION.

ATTENUATION FACTOR. Synonym for ATTENUATION COEFFICIENT.

ATTENUATOR. Network inserted in a line or between other networks to

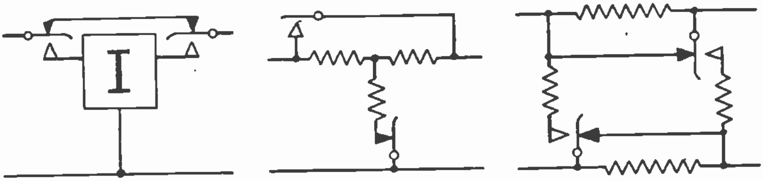


Fig. 50. Three methods of providing stepped adjustments to an attenuator network, in which attenuator pads are switched in by means of lever keys or switches. The use of a rotary switch for the purpose is illustrated in Fig. 51.

introduce a variable transmission loss without causing distortion at the same time. It is used for precise adjustment of the amplitude of a transmitted wave, usually for purposes of measurement, and is calibrated in decibels or decinepers. As well as having variable attenuation, an attenuator is so designed that its insertion does not change the impedance of the circuit, in contrast with an attenuator pad, which introduces a fixed loss and may be used to match together two circuits of different impedance.

Attenuators most commonly consist of a series of attenuator pads of the resistive type, using π- or T-networks for unbalanced circuits and H- or O-networks for balanced circuits. Figures for calculating the values of resistive network elements in terms of the magnitude *Z* of the characteristic impedance of the circuit are shown in the table at Fig. 49.

The attenuation is adjustable in discrete steps by means of lever keys or switches (Fig. 50). In another type (Fig. 51), the attenuator consists, in effect, of an infinite artificial line; the output is taken from one end, whilst the input is applied to one of a number of intermediate points of the line by means of a multi-point rotary switch. The input power divides at the point of entry to the artificial line and flows equally in each direction. Also, half the input power is dissipated in the impedance-matching series resistor. The maximum output power is therefore only one-quarter of the input power and the minimum attenuation is approximately 6 db.

The latter type may be adapted to provide continuously variable attenuation by making the series resistors a continuously wire-wound element in contact with a wiper or slider. When the moving contact is in between the junction points of the parallel resistors, there is some departure from linearity of scale and constancy of impedance; but this effect is not harmful in some applications, such as volume faders and mixers.

In order to be free from distortion, all the elements of an attenuator network must be of the same kind, either resistive, inductive or capacitive. Resistive types are satisfactory at audio frequency and, if carefully designed, up to medium radio frequencies. Above these frequencies, capacitive attenuators are sometimes used. Inductive attenuators are comparatively rare.

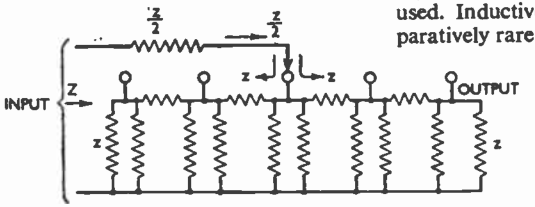


Fig. 51. Diagram showing attenuation adjustment by the use of a multipoint rotary switch.

The stray capacitance and inductance associated with switch-type attenuators, which control the upper working limit of frequency, are equally troublesome with capacitive and inductive types. For this reason, capacitive and inductive attenuators usually consist of a single network with one or two variable elements. This method of adjustment suffers from the defect that the network ceases to be of constant impedance; but by suitable precautions in design, either the input or the output impedance can be made substantially independent of attenuation setting.

AUDIBILITY. In terms of loudness, the range of sound which can be heard by the human ear. The range extends from the threshold of hearing, at which a sound is just audible, to the threshold of feeling, where the intensity of the sound causes physical pain. See SPEECH AND HEARING.

AUDIO FREQUENCY. Wave frequency which lies within the AUDIO RANGE (q.v.).

AUDIO-FREQUENCY AMPLIFIER. Apparatus, circuit or valve which amplifies signals at audio frequency, usually taken to range from 30 to 10,000 c/s. However, the limits are difficult to define; those just quoted are certainly desirable for high-fidelity reproduction, but for less exacting purposes a range of 50–5,000 c/s is adequate.

Unlike the great majority of radio-frequency amplifiers, the audio type is designed to cover a wide range of frequencies with equal efficiency. Apart from any special corrections to suit particular circumstances, the frequency-response graph of a good audio-frequency amplifier is something approaching a straight line over the range of audible frequencies. See AMPLIFICATION, AMPLIFIER.

AUDIO-FREQUENCY TRANSFORMER. Transformer used in circuits which handle waves lying within the audio-frequency band. See TRANSFORMER.

AUDION. Name, now seldom used, given by Lee de Forest, the inventor of the triode, to the first valve which contained anode, cathode and control grid.

AUDIO OSCILLATOR. Instrument designed to produce oscillations at audio frequency. It is used extensively in testing the performance of audio-frequency amplifiers. Such an instrument usually contains a variable component enabling any frequency within the audible range to be selected. See OSCILLATOR.

AUDIO RANGE. Term given to the complete range of frequencies which can be detected by the normal human ear. The lower limit of the range is usually taken as 16 c/s and the upper limit as 20,000 c/s. See SPEECH AND HEARING.

AUSTIN-COHEN FORMULA. Formula for calculating the signal strength of low-frequency waves at long distances from the sender. The electric field strength to be expected at distances of up to 300 miles from the sender is given approximately by the formula:

$$V \text{ (volts per metre)} = \frac{377hI}{\lambda d},$$

where h is the effective height of sending aerial (metres), I the current in sending aerial (r.m.s. amperes), λ the wavelength in metres, and d the distance from the sender (metres).

This formula makes no allowance for absorption losses suffered during long-distance propagation; to allow for such losses, Austin and Cohen added an exponential factor, $\varepsilon^{-ad/\sqrt{\lambda}}$, where ε is the base of the Napierian logarithms, a the constant (0·0015 for transmission over sea water), d the distance from sender in kilometres and λ is the wavelength in kilometres.

The full formula for the field strength at a distant point thus becomes:

$$V = \frac{0{\cdot}377 \times 10^6 \times Ih \times \varepsilon^{-ad/\sqrt{\lambda}}}{\lambda d}$$

micro-volts/metre, where h, λ and d are in kilometres.

The Austin-Cohen formula cannot

be applied to the ionospheric wave which is relatively less-attenuated than the ground wave. See ABSORPTION. FIELD STRENGTH, GROUND RAY.

AUTO-CAPACITIVE COUPLING. Coupling of two circuits by a capacitor common to both circuits. See COUPLING, FILTER.

AUTO-CAPACITY COUPLING. Synonym for AUTO-CAPACITIVE COUPLING.

AUTODYNE. Synonym for AUTOHETERODYNE.

AUTODYNE OSCILLATOR. See AUTOHETERODYNE OSCILLATOR.

AUTOHETERODYNE. Beat-frequency reception arrangement in which the local oscillations are generated by a valve which also serves as the detector. This system is commonly used for reception of type A1 waves, although it involves some detuning of the detector circuits in order to produce the desired beat-frequency.

On the higher frequencies, this detuning is not serious, since the beat-frequency represents but a small fraction of the signal-frequency. See BEAT FREQUENCY, BEAT RECEPTION.

AUTOHETERODYNE OSCILLATOR. Valve which performs the dual function of detection and generation of local oscillations for beat reception. See BEAT-FREQUENCY OSCILLATOR, BEAT RECEPTION.

AUTOMATIC ALARM. Alarm device, such as an electric bell, buzzer or lamp, operated by the automatic making or breaking of an electrical contact when an emergency occurs. The principle is applied in many different forms, each being designed to serve a particular purpose.

AUTOMATIC-CALL DEVICE. In radio telegraphy, a receiver which incorporates a series of relays designed to operate only when signals of a predetermined formation are received. The device is fitted to ships on which constant radio watch is not maintained, the apparatus operating on receipt of distress signals and ringing alarm bells to attract the operator's attention.

AUTOMATIC DIRECTION-FINDER. Direction-finder in which some or all of the operations normally performed manually are done automatically by the equipment. A simple example is the cathode-ray direction-finder. With this, the operator is not required to rotate a loop or other pivoted aerial-system, nor the search coil of a goniometer, to determine the bearing of the station whose signals he is picking up; instead, the bearing appears automatically on the tube screen and is read off a scale of degrees mounted round its rim (see CATHODE-RAY DIRECTION-FINDER).

In a more elaborate system, a rotating direction-finding beacon radiates a television signal which conveys a simple picture of the figures giving its bearing from moment to moment as it rotates. By noting the characteristic variation in the signal, the receiving operator can decide the instant at which the beacon is aimed directly towards him and, by noting the figures then being televised, can determine his bearing.

Still more elaborate devices to give automatic readings are in use in certain forms of radio compass. Continuously revolving, power-driven loop aerials or goniometers are used in some of these, with various electrical devices which cause the correct bearing to be displayed on a dial or other suitable indicator. See DIRECTION-FINDER, DIRECTION-FINDING.

AUTOMATIC FREQUENCY-CONTROL. Circuit arrangement for maintaining an oscillator at or close to a predetermined frequency; or for adjusting it to that frequency when brought near to it by some automatic tuning device, such as a press-button system.

Such arrangements may be found in sender circuits, where their purpose is to minimize drift of carrier frequency, or applied to the local oscillator of a superheterodyne receiver to correct small errors in tuning. See FREQUENCY DISCRIMINATOR.

AUTOMATIC GAIN-CONTROL. Arrangement for holding a radio receiver's output at a substantially constant level despite considerable fluctuations in the strength of the incoming signal.

Satisfactory listening demands that, once a signal has been set at a suitable level of loudness, it shall remain at that level without need of further adjustment. Convenient operation of a radio receiver requires that it can be tuned from station to station by means of a single control, without manipulation of gain. A manual form of gain control meets neither of these requirements, for it needs constant adjustment to maintain a uniform level of output if the transmission is subject to fading, and it commonly requires re-setting when changing stations.

Attempts to provide an automatic control of the output level were made in quite early days of radio, but little success was possible until variable-mu valves were introduced. These valves have the property that their gain is directly controllable by variation of grid-bias voltage. And they do this without giving the undesirable effects which would result if the same type of control were attempted with valves of the normal or non-variable-mu type.

With such valves in the radio- and/or intermediate-frequency amplifier of a receiver, it can be seen that there is at once a possibility of truly effective automatic gain-control. All that is needed is to derive from the signal a voltage proportional to its average amplitude, and apply this to the grids of the variable-mu valves in such a way that, as the signal grows stronger, the special bias voltage reduces the amplification of the valves to compensate as nearly as possible for the fluctuations.

It is well to admit at this point that perfect constancy of output is impossible with any simple device; there must be *some* alteration to enable the automatic gain-control to function at all. What the device can, in fact, do is to ensure that the variations in output level are too small for the human ear to detect.

A suitable voltage for this modern form of automatic gain-control can be obtained by rectifying a type A3 signal at some suitable point in the receiver. A unidirectional voltage proportional to the signal strength will thus be obtained. The modulation of the carrier will seem, at first glance, to introduce a complication, because it will naturally appear in the rectified voltage, just as it does in the case of a detector valve.

If the rectified voltage that we intend to use for gain control were allowed to follow the modulation, the result would be an undesirable form of negative feedback. This can be prevented by introducing a simple filter circuit into the system (Fig. 52). If the filter is suitably proportioned, it will smooth out the audio-frequency variations in the rectified carrier voltage, but will still permit this voltage to follow the slower changes in carrier amplitude due to fading.

The filter usually consists of two components only: a series resistor and a reservoir capacitor. The values are

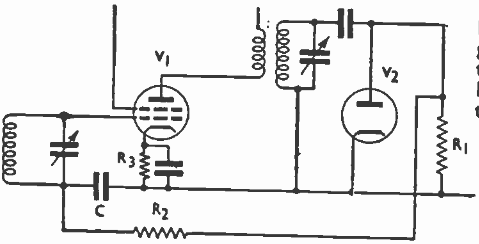


Fig. 52. Principle of automatic gain-control. Signal voltages in the output of V_1 are rectified by V_2 and appear across R_1; they are then passed to the grid circuit of V_1 via the filter R_2,C, so adding to the normal bias provided by R_3 a further negative voltage proportional to signal strength.

not critical, but should be such that the time-constant of the combination is several times longer than a half-cycle of the lowest modulation frequency likely to be encountered. Where automatic gain-control is applied to more than one stage in the receiver (as is usual), a separate filter will generally be provided for each valve. These are sometimes combined with voltage-dividing arrangements which cause each valve to receive a different amount of control voltage, according to the ideas of the particular designer.

The rectified voltage for gain-control purposes is usually derived from that point in the receiver at which the signal has undergone the maximum of amplification at radio or intermediate frequency before detection. For example, in a superheterodyne receiver (probably the only type of receiver in which automatic gain-control can be used to the fullest advantage), this means the final circuit of the intermediate-frequency amplifier; the same circuit, in fact, as that which feeds the detector.

A separate rectifier is normally used to supply the gain-control voltage, often in the form of a second diode in the same envelope as the detector (Fig. 53). A favoured arrangement, for instance, is that in which a double-diode-triode provides detection, automatic gain-control rectification, and a stage of audio-frequency amplification.

The behaviour of a receiver fitted with a fully effective system of automatic gain-control is somewhat modified basically. It tends to give a uniform level of output on the majority of transmissions, and fading is much reduced. (Except the high-speed variety, which causes a distorted signal; the automatic control cannot follow this for reasons which will be apparent from what has been said about the filtering of the control voltage.) Instead of causing a fall in the output level, deep fades merely produce a rise in background noise, the natural result of the increase in gain which countered the fade.

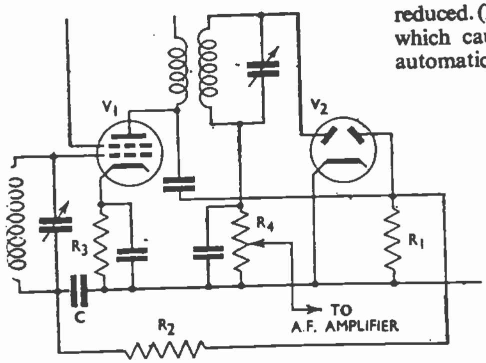


Fig. 53. In practice a double-diode may be used for detection and automatic-gain-control rectification. The arrangement, which may be compared with Fig. 52, is shown in outline only. R_4 provides both load resistance for the detector and gain control for the A.F. amplifier which follows.

Again, a receiver with full automatic gain-control does not exhibit that sharp peaking of the signal at a given reading on the tuning dial which is characteristic of a highly selective set without the automatic control. Instead, the signal is heard at almost uniform strength over a narrow range on the dial, although it will tend to be of unsatisfactory audio quality at settings not near the centre of the range.

To enable the unskilled user to locate the centre point with greater ease, many of the more elaborate broadcast receivers are fitted with some sort of tuning indicator. In this way, the designer hopes to induce the operator to set the tuning correctly, and so enable the receiver to give the highest fidelity of reproduction of which it is capable. See GAIN CONTROL.

AUTOMATIC GRID-BIAS. Grid bias obtained by connecting a resistor and capacitor in parallel in the grid circuit of a valve (Fig. 54a). When alternating potentials are applied between grid and cathode, the resulting grid current flowing in the resistor causes the grid to be negatively biased (see GRID-LEAK). The term is also applied to circuits in which a resistor is connected between the common cathode of a valve or valves and high-tension negative (Fig. 54b).

AUTOMATIC SIGNALLING. In telephony, a system with which calling and supervisory signals are automatically transmitted when the circuit is set up or released.

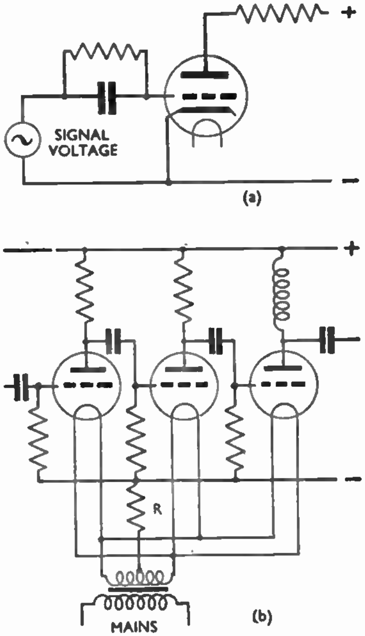


Fig. 54. Automatic grid-bias given (*a*) when the signal voltage causes the grid of the valve to become positive in respect of the cathode, and (*b*) by the resistor *R* in which the cathode currents of all the valves flow, thus putting the three cathodes at the same potential above earth.

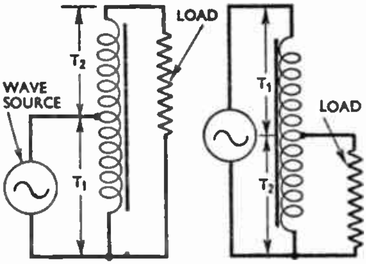


Fig. 55. Voltage transformation ratio of an auto-transformer is equal to the number of turns in the wave-source circuit (primary) to the number of turns in the load circuit (secondary); thus, in (*a*) it is $T_1 : (T_1 + T_2)$, and in (*b*) $(T_1 + T_2) : T_2$.

AUTOMATIC TUNING-CONTROL. Circuit arrangement for maintaining an oscillator at or close to a chosen frequency; *or* mechanical arrangement for tuning apparatus to a pre-selected frequency at a certain time, as in automatic watching systems. The latter is the more usual sense. See AUTOMATIC FREQUENCY-CONTROL.

AUTOMATIC VOLUME-CONTRACTOR. See COMPRESSOR.

AUTOMATIC VOLUME-CONTROL. Synonym for AUTOMATIC GAIN-CONTROL.

AUTOMATIC VOLUME-EXPANDER. See EXPANDER.

AUTO-TRANSFORMER. Transformer with one winding, the transformation of voltage and current being between one pair of tappings and another pair on the same winding (Fig. 55). Provided all the turns on the winding are so coupled that there is no leakage of flux, voltages in the whole of the winding will be induced by passing an alternating current through part of the winding. The turns ratio of the transformer is the ratio of the turns included in one circuit to those included in the other circuit.

The advantages of the normal transformer over the auto-transformer are: first, that it is easier to ensure close coupling with two distinctly separate windings; and, second, that it is often of great advantage to be able to isolate circuits in respect of D.C. connexion, but to couple them as regards A.C. On the other hand, the auto-transformer may be a cheaper form of construction. See TRANSFORMER.

AUXILIARY GRID. Grid electrode of a valve used as a control grid in conjunction with another control grid. A valve may be specially designed to contain an auxiliary control grid; alternatively, the screen grid of a normal pentode or tetrode may be employed as an auxiliary control grid. See CONTROL GRID, DUAL-GRID VALVE, PENTODE, SPACE-CHARGE-GRID VALVE, WUNDERLICH VALVE.

AVAILABLE GRID SWEEP. Total excursion of grid voltage about the grid-bias voltage which can be swept through without causing distortion. See GRID SWEEP.

A.V.C. Abbreviation for AUTOMATIC VOLUME-CONTROL.

AZIMUTH. Synonym for TRUE BEARING.

B

BACK-ELECTROMOTIVE FORCE. Phenomenon which opposes the normal flow of an electric current. A typical example is that of a current increasing in a circuit containing inductance; the increasing magnetic field induces a voltage in the circuit which opposes the applied voltage and thus delays the growth of current. A related phenomenon occurs when a current begins to fall in such a circuit; the collapsing magnetic field then generates a voltage which tends to maintain the current and so delays its fall.

BACKGROUND NOISE. See RANDOM NOISE.

BACKLASH. Synonym for REVERSE GRID CURRENT.

BAFFLE. Form of sounding-board used to improve radiation of sound energy from an electrical reproducer such as a loudspeaker. It consists of a single-plane structure, with the diaphragm or cone of the reproducer usually placed at the centre, as shown in Fig. 1. Its purpose is to minimize interaction between frontal and back radiations from the reproducer, which tend to cancel each other at low frequencies, producing attenuation.

Ideally, the dimensions of the baffle should be such that its perimeter is twice the wavelength of the lowest frequency to be reproduced. See BOX BAFFLE.

BAKELITE. Proprietary name for synthetic resin formed from formaldehyde and cresol or phenol. It is used for insulators and in varnishes and plastics products.

BALANCED ADCOCK DIRECTION-FINDER. Adcock direction-finder derived from the elevated type (see ELEVATED H-TYPE ADCOCK DIRECTION-FINDER), but differing in that

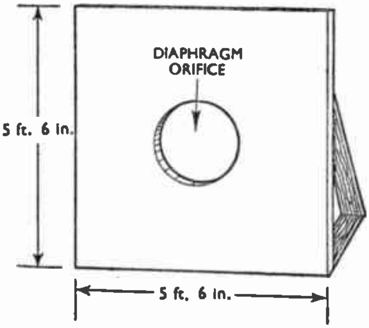


Fig. 1. Rectangular loudspeaker baffle for ideal reproduction when the lowest audio frequency required is 100 c/s. With a smaller baffle, some attenuation at very low frequencies is inevitable.

the lower section of each vertical dipole is replaced by a connexion to earth through a balancing-impedance network (Fig. 2). The aim of the modification is to obviate the need for raising the receiver building to the level of the dipole centres as is done in the elevated-H type.

BALANCED ARMATURE. In a moving-iron loudspeaker or gramophone pick-up, an armature pivoted at or near its centre of gravity, both ends of the armature moving in a magnetic field. See GRAMOPHONE PICK-UP.

BALANCED CIRCUIT. Circuit symmetrically disposed with respect to a point of zero or constant potential. In a balanced circuit, the sum of the potentials at similar points, symmetrically disposed about the steady potential point, is zero. Another definition postulates that, if the input and output terminals are changed over simultaneously, it will make no difference to circuits external to, and connected to, the balanced circuit. In a balanced circuit, one part of the circuit forms the mirror image of the other. Thus, if one half of the circuit is drawn, and a mirror placed along the earth potential line, the mirror shows the other part of the balanced circuit.

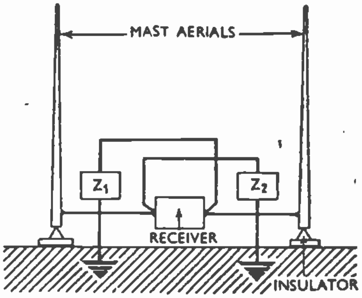


Fig. 2. One of the two pairs of mast aerials which comprise a balanced Adcock direction-finder system; Z_1 and Z_2 are the balancing impedances.

In Fig. 3, diagrams (a), (b) and (c) show the evolution from unbalanced to balanced circuit for equal load power of a quadripole with series impedances Z_1, Z_3 and shunt impedance Z_2; (b) and (c) differ only in that the shunt arm in (c) is $Z_2 = Z_2/2 + Z_2/2$ of (b), and the load resistance in (c) is $R = R/2 + R/2$ of (b). The full line of (b) is a connexion to zero potential. The dotted line of (c) shows the zero-potential region; the electrical centre point of R in (c) could be connected to earth, as could be the electrical centre of Z_2, without disturbing conditions.

Diagrams (d), (e) and (f) of Fig. 3 show the distinction between balanced and unbalanced valve connexion. The valves in (e) and (f) presumably each absorb less power than that in (d) because of the assumption that the load power is the same in the case of balanced and unbalanced circuits.

Balanced circuits are uneconomical in the use of components, but circumstances may compel their use. Thus, if balanced transmission lines are generally used, the currents in the two conductors are made to flow in opposite directions and the external field is, ideally, zero. Moreover, a balanced transmission line is automatically protected against the effects of external stray fields which induce equal and opposite voltages in the two conductors.

It is, therefore, sometimes necessary that terminal apparatus joined to a transmission line shall be balanced in order to feed into a balanced line. For this purpose, the transformer is of great value as it can easily change an unbalanced to a balanced circuit. Transformers, however, cannot be used when the ratio of maximum to minimum frequency of the waves is very high, or when the maximum frequency is extremely high. Some valve circuits can be used to change from balanced to unbalanced conditions, and will function equally well over a wide frequency band. See BALANCED QUADRIPOLE, CATHODE FOLLOWER, UNBALANCED CIRCUIT.

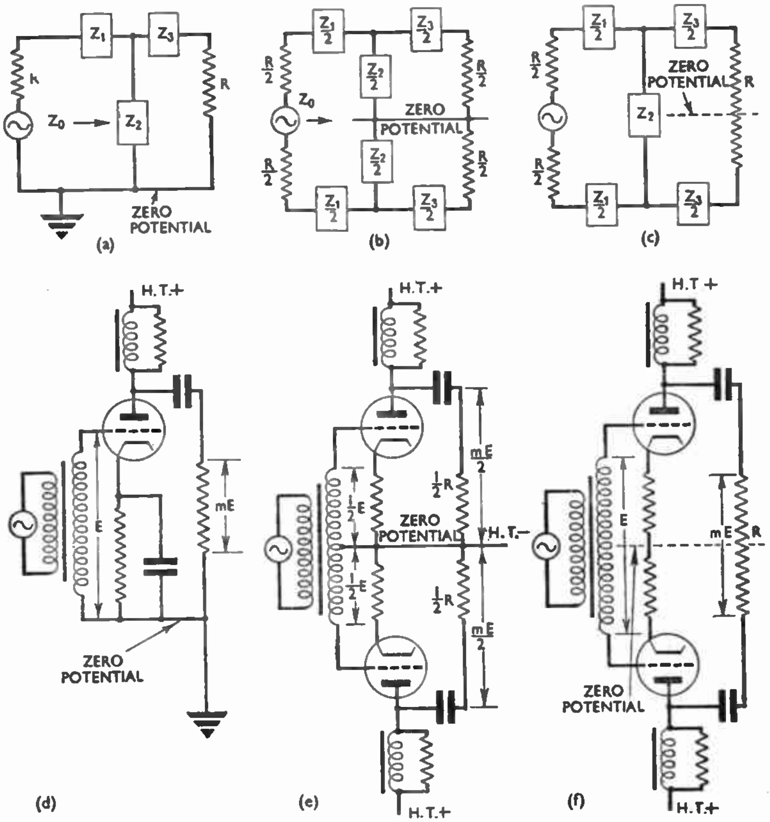


Fig. 3. Distinction between unbalanced and balanced circuits and between unbalanced and balanced valve connexions. All the diagrams assume that the power in the load resistance *R* is the same for unbalanced and balanced circuits.

BALANCED FEEDER. Connexion between aerial and sender or receiver comprising two conductors having equal capacitance to earth. See FEEDER.

BALANCED MICROPHONE. Microphone with three electrodes of which the centre one—that attached to the diaphragm—is earthed, the outer electrodes being connected to the two ends of the primary winding of a centre-tapped microphone transformer (Fig. 4). This arrangement provides a push-pull input to the microphone amplifier. See CARBON MICROPHONE.

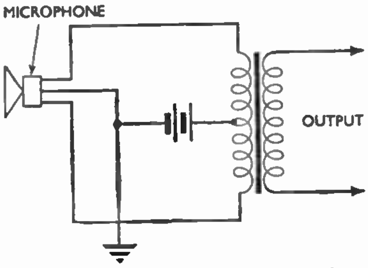
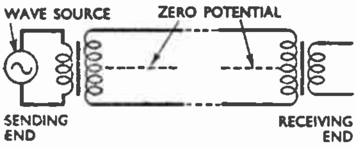
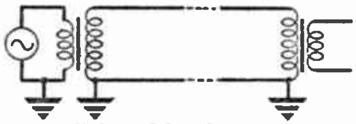


Fig. 4. Connexion details of the three electrodes in a balanced microphone.



BALANCED LINE



UNBALANCED LINE (PHYSICAL CONNEXION FOR RETURN PATH)

UNBALANCED LINE (EARTH RETURN)

Fig. 5. Diagrams showing the difference between balanced and two forms of unbalanced transmission lines. All lines used in telephony and telegraphy are balanced to prevent both the radiation of waves from them and the induction in them of voltages from stray fields.

BALANCED QUADRIPOLE. Quadripole connected as a balanced circuit. In other words, a quadripole such that the input terminals can be interchanged, and the output terminals similarly interchanged, without affecting the circuit external to the network.

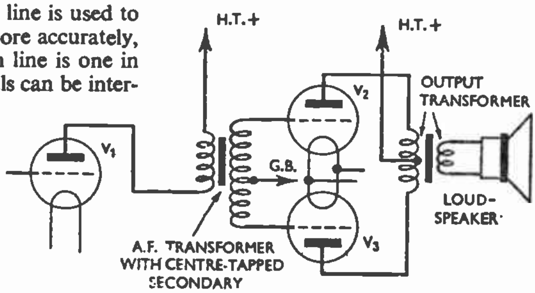
BALANCED TRANSMISSION LINE. Transmission line in which the two conductors are at equal and opposite potentials above and below zero potential when the line is used to transmit intelligence. More accurately, a balanced transmission line is one in which the input terminals can be interchanged, and the output terminals simultaneously interchanged, without affecting the circuit external to the line. Fig. 5 may help to show more clearly the difference between a balanced and unbalanced transmission line. See BALANCED CIRCUIT.

BALANCED VALVE-AMPLIFIER. Amplifier containing a pair of similar valves, or a double valve, so connected that the control grids receive voltages which are of equal amplitude but of opposite phase, the outputs being combined in a balanced output circuit. See BALANCED VALVE-OPERATION.

BALANCED VALVE-OPERATION. System of operation in which an amplifying stage consists of a pair of valves so arranged that each carries only half the signal; their outputs are combined in proper phase to reconstitute the signal. The essential feature of the balanced valve system is that the signal is split and the halves which are applied to the grids of the two valves are in opposite phase. Thus, if at a given instant the signal is making the grid of one valve negative, it will be sending the grid of the other positive.

The balanced system is easiest to understand in its earliest form, originally known as a push-pull circuit, in which the signal is split by means of an intervalve coupling transformer with a centre-tapped secondary winding; the centre point is earthed through the grid-bias circuit and the two ends of the winding are connected to the

Fig. 6. Elements of a balanced valve A.F. amplifying stage, in which V_2 and V_3 are the balanced, or push-pull, output valves.



respective valve grids (Fig. 6). In a similar manner the complementary anode currents of the two balanced valves are recombined with an output transformer with a centre-tapped primary. This system is still used.

As in all balanced-operation output circuits, since each valve carries only half the signal, its power-handling capacity can be considerably smaller than that which would be required in a valve to handle the same signal single-handed. Moreover, in the balanced circuit certain forms of distortion due to overloading tend to cancel out in the two halves of the stage, and so it can be "driven" a little harder than would be permissible if the valves were used separately.

The balanced system is at first sight difficult to apply where the intervalve-coupling device is a resistance, but various ingenious solutions have been devised. See PHASE SPLITTING.

BALANCING AERIAL. Aerial employed to pick up any undesired signal, which is then fed into the main receiving circuits in phase opposition to balance out the effects of the interference. The balancing aerial might be, for instance, a loop whose directive properties enable it to pick up strongly the unwanted signals while deriving but little voltage from the wanted signal.

BALANCING CAPACITOR. Capacitor connected so as to perfect the balance of a line. Sometimes, notably in open-wire lines used for telegraphy, the line is unbalanced due to asymmetries of construction or of insulation. In such cases, a balancing capacitor is connected to the line to improve the balance.

BALANCING CONDENSER. Synonym for BALANCING CAPACITOR.

BALANCING NETWORK. Network designed to simulate the impedance presented by a line or another network (see ARTIFICIAL LINE). In telegraphy, a balancing network is known as a duplex balance.

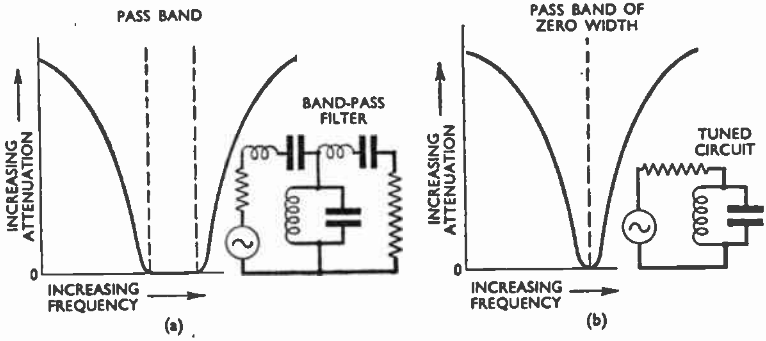


Fig. 7. Graphs distinguishing between the effect of using a band-pass filter (*a*) and a selective tuned circuit (*b*). Assuming that reactive elements in both cases have zero loss, the former provides theoretically zero attenuation over a band of frequencies, while the latter gives it at only one frequency.

BALLAST RESISTOR. Resistor having a high temperature coefficient of resistance and used to maintain a substantially constant current in, for example, the heater circuit of an A.C./D.C. receiver. See BARRETTER.

B-AMPLIFIER. In a broadcast chain, the amplifier which follows the A- or microphone amplifier.

BAND ARTICULATION. In telephony, the percentage of speech-bands correctly received over the system, as compared with those transmitted. See ARTICULATION, SPEECH-BAND.

BAND-ELIMINATION FILTER. Synonym for BAND-STOP FILTER.

BAND FILTER. Synonym for BAND-PASS FILTER.

BAND-PASS FILTER. Filter which gives a relatively small attenuation to waves lying within a frequency band and larger attenuation to waves lying outside this "pass band." A band-pass filter composed of elements which gave no loss (zero power factor) ideally terminated, would give zero attenuation to waves lying in its pass band (see EQUALIZER, FILTER, FREQUENCY BAND, PASS BAND, TUNED CIRCUIT).

Theoretically, and sometimes in practice, a band-pass filter gives equal attenuation to waves of different frequency lying within the pass band. It is thus essentially different from the frequency-selective tuned circuit, which has a maximum response at only one frequency. This distinction is brought out in Fig. 7.

A distinction is sometimes made between band-pass filters in which the coupling is inductive, and those in which it consists of a reactance common to two circuits. The electrical similarity between so-called "directly coupled" and "indirectly coupled" band-pass filters is obvious; in an inductively coupled band-pass filter, the shunt impedance is the mutual inductance; in a directly coupled band-pass filter, it may be an inductive reactance, a capacitive reactance, or a combination of both (Fig. 8). The inductively coupled band-pass filter is used in the intermediate-frequency circuit of superheterodyne receivers and the directly coupled type is nearly always used in commercial transmission systems, broadcasting senders and so forth.

The response of the inductively coupled band-pass filter is determined by the resonant frequency, the value of the Q-factor and the coefficient of coupling of the two tuned circuits. If the two tuned circuits are tuned to the same frequency and have the same Q-factor value, increasing the coupling effects an increase in the frequency difference between two response peaks (Fig. 9).

The directly coupled band-pass filter can be made to give almost any shape of response curve, provided that the value of the reactive elements and of the Q-factor, the number of sections and the termination are correctly related. In some cases, quartz crystals are used instead of reactive elements.

The crystal element, while expensive, has an effective Q-factor value far greater than any combination of reactors; Q-factor values up to even 10,000 are possible and the ideal of a

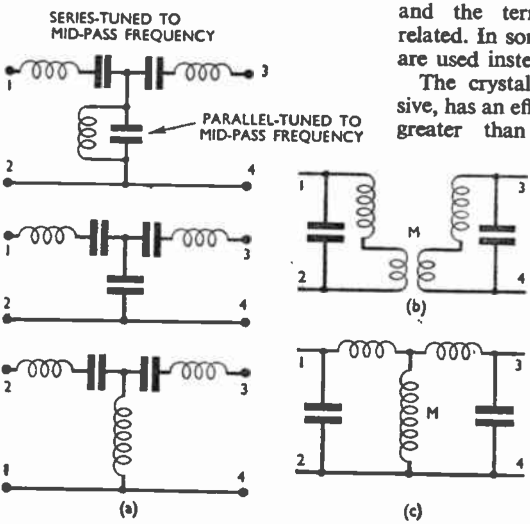


Fig. 8. Band-pass filters (*a*) are sometimes termed "directly coupled" to distinguish them from one that is inductively coupled (*b*) by mutual inductance *M*. Broadly, however, the mutual inductance may be considered as forming a direct coupling (*c*).

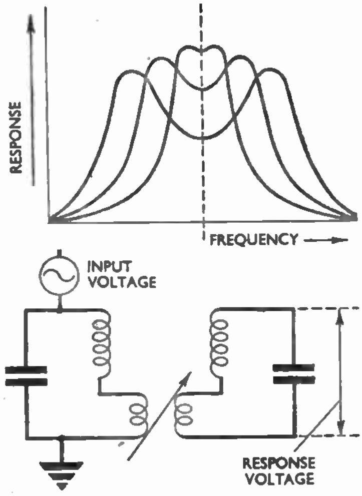


Fig. 9. Response graphs and band-pass filter. If two similar parallel-tuned circuits are separately tuned to the same frequency and then coupled together, the curves have double peaks.

low-loss filter element is the more nearly achieved. See COUPLING COEFFICIENT, QUARTZ CRYSTAL, REACTOR, SUPERHETERODYNE RECEIVER.

BAND-PASS TUNING. Tuning which produces a somewhat flat-topped resonance curve and, hence, gives more even response to a band of frequencies than do circuits having a sharply peaked graph (Fig. 10).

Sharp-peaked curves tend to attenuate high modulation frequencies in a carrier wave, with ill effects on quality of speech and music, or on definition in television pictures. Band-pass tuning can be arranged to give a substantially even response over the required band of frequencies; moreover, the sides of such a flat-topped curve tend to fall away more steeply, with beneficial effect on general selectivity.

Band-pass effects are usually obtained by means of a suitable degree of magnetic and/or capacitive coupling between a pair of tuned circuits, the width and flatness of the curve's top depending on a suitable adjustment of the coupling. The effect, indeed, is one of an approach to the double-humped curve which is characteristic of tightly coupled circuits.

The separation of the pair of incipient peaks which form the flattened top is given by $f = \frac{\sqrt{\omega^2 M^2 - r^2}}{2 \pi L}$, where f, the separation frequency, is in cycles, M is the mutual inductance in henrys, r is the radio-frequency resistance, L is the inductance in

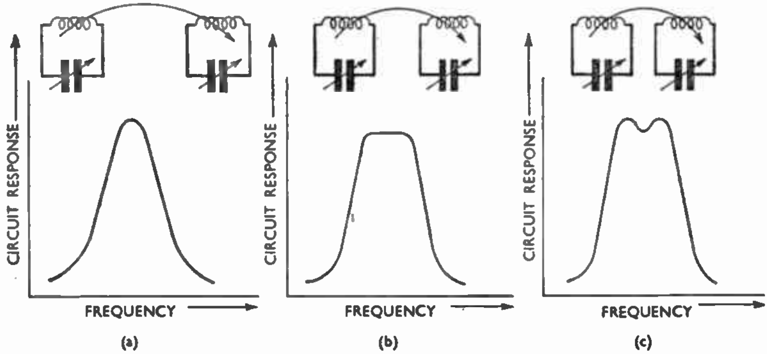


Fig. 10. Two loosely coupled circuits (*a*) give a narrow-peaked resonance curve like that of a single low-decrement type of circuit. With closer coupling, however, they give the flat-topped "band-pass" type of curve (*b*). If the coupling is still further increased (c), a double-humped curve is developed.

henrys, and ω is 2π times the natural frequency of the tuned circuits.

This expression, which applies to magnetic coupling, demonstrates that the width of the curve varies with frequency, becoming wider at the higher frequencies. A generally similar formula for capacitive coupling shows a similar effect when the coupling capacitor is connected as in (a) of Fig. 11, but an opposite one when it is placed as in (b). By skilful combination of these various coupling methods the designer can produce a response graph which remains of substantially equal width over a considerable tuning range. See COUPLING, RESONANCE CURVE.

BAND-REJECTION FILTER. Synonym for BAND-STOP FILTER.

BAND RELAY. Synonym for PUBLIC-ADDRESS SYSTEM.

BAND REPEATER. Synonym for PUBLIC-ADDRESS SYSTEM.

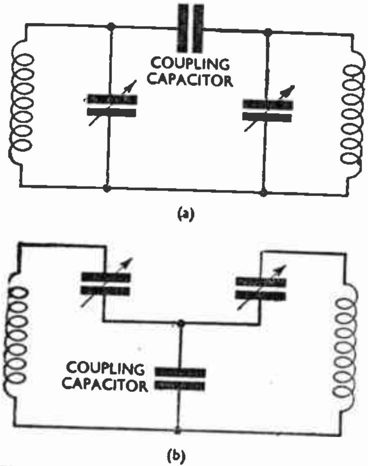


Fig. 11. Method of overcoming, in band-pass tuning, the tendency of coupling devices to vary in efficiency with frequency. In (*a*) the coupling capacitor tightens the coupling at higher frequencies, while in (*b*) it produces the opposite effect; by combining the two a substantially constant band width can be obtained.

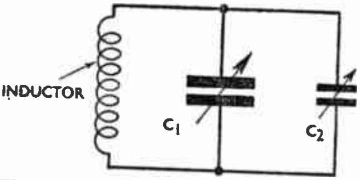


Fig. 12. In the band-spreading system of tuning, a large capacitor C_1 is employed to make approximate adjustments, and a smaller one C_2 to cover each particular band of frequencies.

BAND SPREADING. Common device in short-wave receivers that facilitates tuning adjustments by provision of a small variable capacitor in parallel with the principal tuning capacitor.

Without some such expedient, short-wave tuning tends to be excessively critical, since a variable capacitance large enough to cover an adequate wave band on each coil unit is also large enough to demand extremely accurate adjustment. A much smaller variable capacitor is, therefore, placed in parallel with the main one, as shown in Fig. 12, so that, as the latter is set to certain major reference points on its scale, each small band of frequencies can be spread over the dial of the former.

BAND-STOP FILTER. Filter which gives a relatively large attenuation to waves lying within a certain frequency band, and a smaller or theoretically zero attenuation to waves lying outside this stop band. If the filter elements give no loss (power factor zero) and the filter is ideally terminated, the attenuation in the stop band would be infinite. This infinite attenuation may be given for a wave of a certain frequency or for waves lying within a frequency band. Fig. 13 shows two types of band-stop filter and the resulting response curves. It is assumed that both have ideal elements and are ideally terminated. Note that the less complex type gives infinite attenuation at only one frequency, whereas the other gives infinite attenuation over a frequency band.

If the term filter is used to describe only those networks containing purely reactive elements, whatever the nature of the termination, then the band-stop filter is restricted to the forms illustrated. Certain resistance-capacitance networks, and tuned circuits associated with resistors, are sometimes loosely classified as band-stop filters; other such networks, performing the same function in a different way, are described under different headings. See ACCEPTOR CIRCUIT, FILTER, NULL NETWORK.

BAND SWITCHING. System of switching, usually of coil units, to enable a receiver or other apparatus to function on more than one band of frequencies. In modern radio receivers, the wave-band switching is somewhat complex since, to pass from one wave band to another, the constants of several circuits must be altered simultaneously. The required multiple switches are usually linked on a single spindle and often give a complete change-over between separate coil units, as indicated in Fig. 14.

BARKHAUSEN-KURZ OSCILLATIONS. See ELECTRONIC OSCILLATIONS.

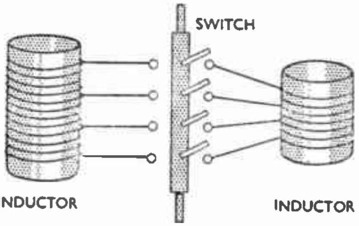


Fig. 14. Purely diagrammatic representation of band switching with a multiple switch, usually of the rotary type.

BARKHAUSEN OSCILLATOR. Generator of oscillations having a frequency above 100 Mc/s.

BARREL DISTORTION. Intermodulation between X and Y deflector systems in a cathode-ray tube, causing, for example, a picture to be distorted as shown overleaf in Fig. 15. It is due to non-uniformity of the deflecting fields.

BARRETTER. Form of ballast resistor for maintaining in a circuit a substantially constant current, in spite of a varying applied voltage or a varying potential drop inside the circuit. A common application is in A.C./D.C. receivers where the valve heaters are connected in series with each other, a voltage-dropping resistor and a barretter, all across the supply mains.

The barretter consists, usually, of an iron-wire filament in a hydrogen-filled glass envelope, and has the appearance of a small incandescent lamp. The iron filament has a high value of temperature coefficient of resistance, such that, over an appre-

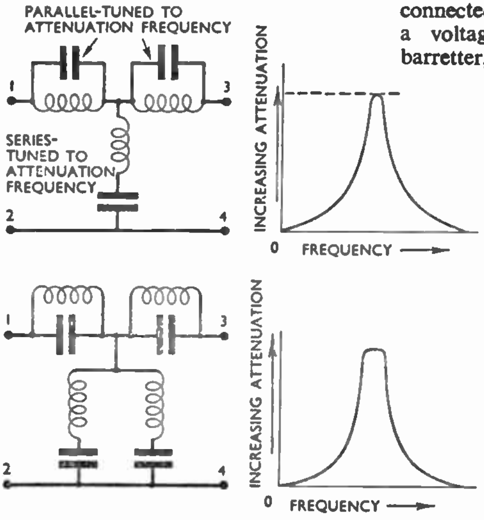


Fig. 13. Two types of band-stop filter and the resulting attenuation graphs. It is assumed that the reactive elements have no loss, and that the filter is ideally terminated.

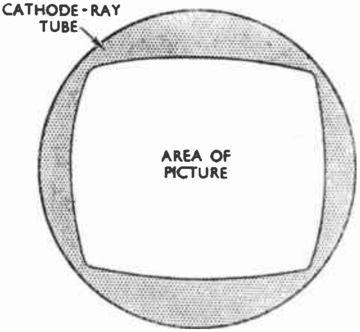


Fig. 15. Distorted shape of picture area on a cathode-ray-tube screen when barrel distortion is present.

ciable range of voltage, the current is substantially constant. A typical current-voltage characteristic is illustrated in Fig. 16.

The term barretter was also used to describe an early form of detector of high-frequency currents which operated by virtue of its change of resistance.

BARRIER-LAYER RECTIFIER. Rectifying type of photocell. It comprises two electrodes in contact; one is a conductor and the other is normally a relatively poor conductor of electricity. When the cell is exposed to light, a flow of electrons occurs across the contact between the electrodes, and rectification can, therefore, take place.

BASKET COIL. Coil for use as an inductor at radio frequencies wound on a special former consisting of a hub with an odd number of radial spokes. The wire is wound spirally and passes from one side of one spoke to the opposite side of the next. The method is similar to that used for making the bottom of a circular basket, to which the finished coil bears some resemblance.

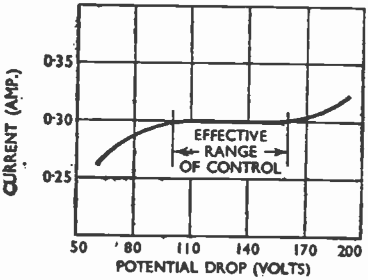
This type of coil, which can be made readily by hand, was popular in the early days of broadcasting. It has now fallen into disuse, however, and is superseded by machine-wound coils of the wave-wound or lattice-wound types. The object of the design is to minimize the capacitance between adjacent turns by limiting their close proximity to the points where they cross over.

BATTERY. Two or more cells, capacitors, resistors or other pieces of apparatus electrically connected in one circuit. The term is commonly used in connexion with a battery of cells rather than for resistors, capacitors, etc. To speak of "a battery" instead of "a cell" is a common error in terminology; a battery describes essentially a plurality of like things. See ACCUMULATOR CELL, HIGH-TENSION BATTERY.

BATTERY CHARGING. See ACCUMULATOR CHARGING. (Inasmuch as the term "battery charging" may well mean the charging of a battery of accumulators, it may be correctly used; but, since accumulators have the unique property of being able to be charged, the term "*accumulator* charging" to describe the process seems preferable.)

BATTERY COUPLING. Method of valve coupling in direct-current amplifiers. See D.C. AMPLIFIER.

Fig. 16. Barretter and (*below*) a graph showing characteristics. It will be seen that the current is substantially constant over a voltage range of approximately 100-160.



BATTERY ELIMINATOR. Mains unit for domestic receivers used for the reception of broadcast programmes. The term is more properly used when the mains unit is not a part of the receiver proper, but rather a separate assembly.

Early broadcast receivers were energized from separate high- and low-tension batteries. In some cases it was convenient to get rid of the batteries and replace them by a unit energized from the mains; this gave a direct-current supply of 150–200 volts, which replaced the high-tension battery, and a low-voltage alternating supply to feed the heaters and do away with the low-tension battery. The term "battery eliminator" for this unit was obviously appropriate.

B-BATTERY. Synonym for HIGH-TENSION BATTERY.

BEACON DIRECTION-FINDER. Form of sender radiating signals of such a type or in such a way that a distant receiving station can determine its bearing by listening to them. See AUTOMATIC DIRECTION-FINDER, NAVIGATIONAL AID.

BEAM. In light, a group of parallel light rays; in thermionics the stream of electrons emitted from the cathode of a valve or cathode-ray tube; in radio transmission, radiation from a directional aerial and confined within a certain angle.

BEAM AERIAL. See AERIAL-ARRAY.

BEAM APPROACH. See LORENZ BLIND-LANDING SYSTEM.

BEAM ARRAY. See AERIAL-ARRAY.

BEAM CURRENT. In a cathode-ray tube, the current which flows from the anode to the cathode and is carried by the electron beam which strikes the screen.

BEAM EFFECT. Differential focusing of high audio-frequency radiation from a loudspeaker, the diaphragm of which has a diameter similar to, or greater than, the wavelength of some of the sounds radiated.

BEAM POWER-VALVE. Tetrode, designed to overcome the effects of secondary emission, in which the electrons are concentrated into a beam. The essential feature of a beam power-valve is that a virtual cathode is formed between screen grid and anode (see VIRTUAL CATHODE). In a beam tetrode, this virtual cathode shields the screen grid from secondary electrons emitted by the anode (see SECONDARY EMISSION, TETRODE). The beam valve may be either a tetrode or pentode, but is more frequently a tetrode.

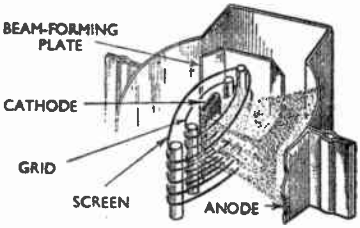


Fig. 17. Partly cut-away internal structure of a beam power-valve. In addition to the usual electrodes there are two beam-forming plates which help to concentrate the electrons in a uniform high-density beam.

Fig. 17 shows the electrodes of a beam-tetrode. Plates concentrate the electrons into a beam, and the screen and control grids are aligned (see ALIGNED GRID) so that the electrons are concentrated in sheets. The spacing between screen grid and anode is larger than in ordinary tetrodes and contains a concentration of electrons which constitute a virtual cathode.

The potential gradient in the space between anode and screen grid is such that secondary electrons cannot pass to the screen grid. The transition of the slope conductance from a high to a low value is more gradual in a beam power-tetrode than in a pentode. This is an advantage of the beam principle. See ANODE SLOPE-RESISTANCE, ANODE-VOLTS/ANODE-CURRENT CHARACTERISTIC.

BEAM SUPPRESSION. In television, the suppression of the electron beam during fly-back by the application of a large negative potential to the modulator electrode of the cathode-ray tube. See FLY-BACK.

BEAM SYSTEM. In radio communication, a system of transmission in which the carrier wave is directed along a narrow beam towards a specific reception point. The system serves two purposes; it secures a measure of secrecy, since messages can be picked up only at points along the beam, and by avoiding radiation in all unwanted directions a longer range is obtained for a given sender power-output.

BEAM TETRODE. See BEAM POWER-VALVE.

BEAM TRAP. Electrode in a cathode-ray tube employed to trap the electron beam when it is not required to excite the fluorescent screen.

BEAM VALVE. Valve, usually a tetrode, in which the electron stream is directed to the anode by deflector plates internally connected to the cathode. See BEAM POWER-VALVE.

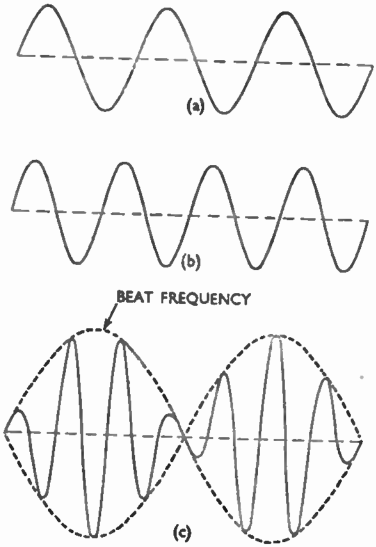


Fig. 18. The waves in (*a*) and (*b*) are of different frequencies (3:4); the result of adding together their amplitudes is shown at (*c*), where the envelope is the wave produced by beating.

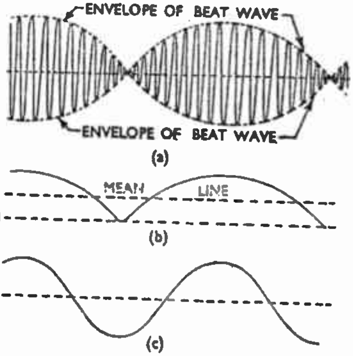


Fig. 19. When the typical wave produced by beating (*a*) is rectified, the result is as (*b*), which contains the fundamental and second harmonic; (*c*) is the fundamental component.

BEARING. Angle between the direction of some distant object and either true or magnetic north. The bearing is always reckoned from north through east; that is, clockwise round the compass scale, east being 90, south 180, west 270 and north 0 or 360 deg.

BEARING ERROR. Difference between the true bearing of a distant object and its bearing as determined by some apparatus subject to error, such as a direction-finder.

BEAT. One complete cycle of the variation of amplitude of a wave produced by BEATING (q.v.).

BEAT FREQUENCY. Frequency of the wave produced by BEATING (q.v.).

BEAT-FREQUENCY OSCILLATOR. Oscillation generator in which two R.F. oscillators are coupled together, producing a third oscillation the frequency of which is equal to the difference between the frequencies of the R.F. oscillators.

If the frequency of one R.F. oscillator is made variable, then beat-frequency oscillations of different frequencies may be obtained. For example, if one R.F. oscillator has a frequency of 50 kc/s and the other is variable between 50 kc/s and 60 kc/s, then oscillations having a beat frequency from 0 to 10,000 c/s can be produced. This is the principle of an audio oscillator working on the beat-frequency system.

BEATING. Production of a low-frequency wave by the interaction of two higher-frequency waves. The phenomenon of beating is not confined to radio; it occurs, for instance, with sound waves.

Almost everyone is familiar with the throbbing sound of multi-engined aircraft; this slow rising and falling of sound intensity is caused by beating between the sounds of engines which are not synchronized. Fig. 18 shows two waves of equal amplitude which are not of exactly the same frequency.

Adding the amplitudes of the two waves of (a) and (b) produces a wave of the form shown in Fig. 18c. The envelope of (c) is seen to rise and fall to form a wave in which the amplitude rises and falls. The wave formed by the resultant of adding together two waves is the wave produced by beating.

As seen from Fig. 19, the wave must be rectified before its amplitude variation can be appreciated. In the rectified-beat wave there is a strong second harmonic which gets smaller as the ratio of the amplitudes of the waves producing beating is increased. It may also be noted from Fig. 20 that any device, not necessarily a rectifier, which responds to power rather than to voltage or current also extracts the beat wave. Thus polarized telephones would not reproduce beats from the wave of Fig. 20a; unpolarized ones would. We hear beats because human ears do not respond linearly.

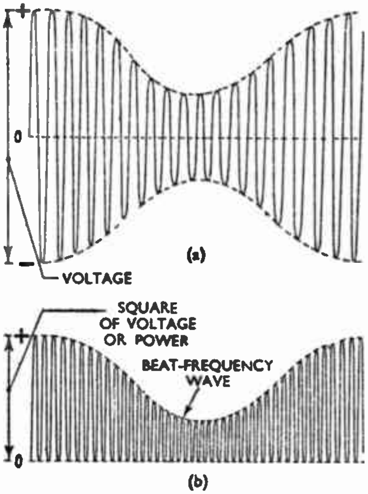


Fig. 20. Wave produced by beating (*a*) when two waves of slightly different frequency from which it is formed are also of different amplitudes; if (*a*) is passed through a power-integrating device, the wave (*b*) is produced.

The phenomenon of beating is used in beat reception. The beat-frequency oscillator was so called because, in its

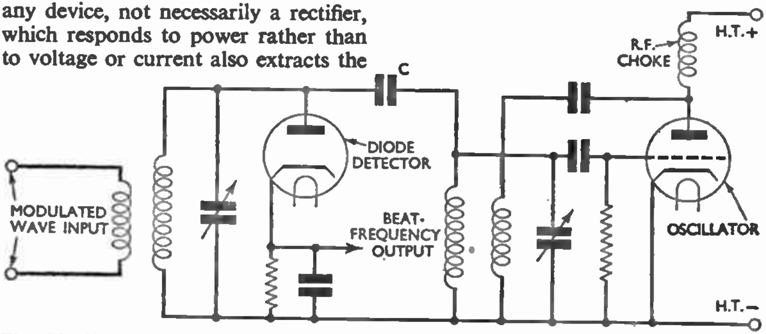


Fig. 21. One circuit arrangement of a beat oscillator used in a receiver to make C.W. (type-A1-wave) transmissions audible. C is a capacitor of about 2 $\mu\mu$F.

first form, a lower-frequency audio wave was produced by beating between higher-frequency waves. In modern practice, amplitude modulation is used to create lower- from higher-frequency waves. This is the distinction between beating and amplitude modulation, and between a beat oscillator and a beat-frequency oscillator. See BEAT FREQUENCY, BEAT OSCILLATOR, BEAT RECEPTION, FREQUENCY-CHANGING, MODULATION.

BEATING OSCILLATOR. Synonym for BEAT-FREQUENCY OSCILLATOR.

BEAT OSCILLATOR. Any oscillator the output of which is mixed with another wave to produce a difference or BEAT FREQUENCY (q.v.). Communications receivers contain a beat oscillator which is coupled to the detector circuit to produce an audible beat note with any signal wave present. In this way Morse transmissions of type A1 waves (C.W.) can be made audible (Fig. 21).

Certain A.F. generators make use of the beat principle. Basically, the generator consists of a fixed-frequency oscillator and a variable-frequency oscillator, both feeding into a frequency-changer stage where the beat frequency—the wanted A.F. output—is produced. The variable-frequency oscillator is adjusted to give the required beat frequency.

BEAT RECEPTION. System in which locally-generated oscillations interact with incoming signals to produce a new frequency. This important principle has many applications. In its typical form, it is used for reception of type-A1 Morse signals, which would produce merely a succession of clicks if submitted only to normal processes of amplification and detection, since they are not modulated, but are simply "chopped" into long and short bursts.

To generate an audible frequency from such signals, they are combined with a local oscillation of slightly different frequency, beats then occurring at the arithmetical difference of the two frequencies. This, after detection, gives an audible note equal to the beat frequency. See AUTO-HETERODYNE, BEAT FREQUENCY, BEAT OSCILLATOR.

BEATS. Characteristic sounds heard in one ear when two sounds having slightly different frequencies are produced. The effect is a rhythmic increase and decrease in the intensity of the combined sound. See BEATING.

BEL. Ten decibels. See DECIBEL.

BELLINI-TOSI AERIAL. Two aerials, usually of the loop type, arranged with their planes at right-angles and connected to the stationary windings of a goniometer in a BELLINI-TOSI DIRECTION-FINDER (q.v.).

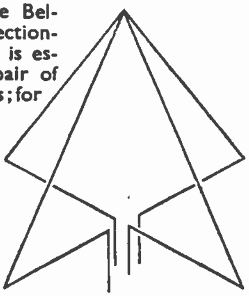


Fig. 22. The Bellini-Tosi direction-finder aerial is essentially a pair of crossed loops; for practical convenience, however, the loops are often triangular.

BELLINI-TOSI DIRECTION-FINDER. Direction-finder using crossed loop-aerials connected to the receiver through a goniometer. The two loops, of a size suited to the intended working frequencies, are normally set at right angles (Fig. 22); and each is connected to one field winding in the goniometer (Fig. 23). Each field winding sets up a magnetic field proportional to the signal strength picked up by the aerial connected to it, and this in turn is proportional to the direction of travel of the passing waves.

If, therefore, the goniometer search coil is rotated to find some measure of the *resultant* maximum or (usually) minimum field, it will provide an indication of the direction in which the waves are crossing the aerials, and

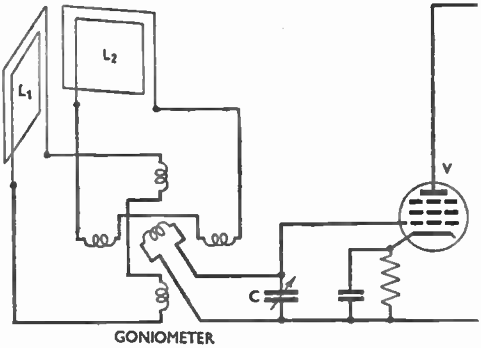


Fig. 23. Elements of a Bellini-Tosi direction-finder. *L*₁ and *L*₂ are loop aerials fixed at right angles; the goniometer, of four fixed coils and a search coil tuned by *C*, forms the input circuit of the R.F. amplifying valve *V*.

so of the apparent direction of the sender. See RADIOGONIOMETER, SPACED-AERIAL DIRECTION-FINDER.

BETHENOD-LATOUR ALTERNATOR. High-frequency synchronous generator developed in France for use in radio telegraphy. See SYNCHRONOUS GENERATOR.

BEVERAGE AERIAL. Horizontal wire of considerable length but low height (Fig. 24), connected to earth at one end through the receiver and at the other through a resistance or resistance network equal to the line impedance. This aerial has marked directional properties, receiving most strongly from the direction of the end remote from the receiver. Its length is at least comparable with the wavelength being received and preferably equal to several wavelengths. See WAVE AERIAL.

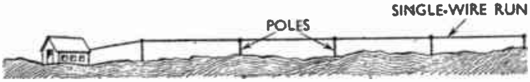


Fig. 24. Essential feature of the Beverage aerial is its great length in proportion to its height. It is commonly run on short poles in the manner of a telegraph line.

BIAS. Direct or steady component of an electrode voltage; the term is not applied to the anode, but is fairly commonly used in connexion with the screen grid and with the control grid and cathode (Fig. 25). In class-A amplification, the grid-cathode potential varies about a steady or direct negative potential, described as "grid bias" and expressed in volts.

The screen-grid potential is usually steady, and does not change with alternating potentials of other electrodes. This steady potential is the screen-grid bias, always positive with respect to cathode.

In some negative-feedback arrangements, however, the screen grid and cathode are connected together by an impedance low to signal frequencies, and their common potential varies at signal frequency.

The screen bias is the steady direct potential difference existing between the screen grid and the cathode. Cathode bias is the steady voltage of the cathode, as distinct from its varying potential when current feedback is used. See ANODE VOLTAGE, AUTOMATIC GRID-BIAS, CATHODE BIAS,

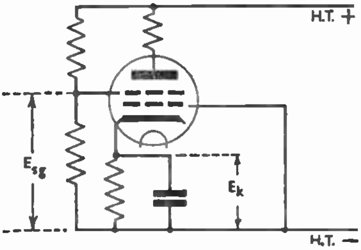


Fig. 25. How positive bias (E_{sg}) may be applied to the screen grid, and negative bias (E_k) to the control grid of a tetrode.

GRID BIAS, GRID POTENTIAL, SCREEN-GRID POTENTIAL.

BIAS DISTORTION. Distortion caused by the spacing or marking elements of signals being lengthened as a result of asymmetry in either the sending or receiving equipment.

BIASED AUTOMATIC GAIN-CONTROL. See DELAYED A.G.C.

BIGRID VALVE. Synonym for DUAL-GRID VALVE.

BILLI-CAPACITOR. Obsolete term describing a form of variable capacitor used in early types of radio equipment. It consisted essentially of two co-axial cylindrical electrodes separated by a tube of solid dielectric, usually ebonite. Adjustment was effected by axial movement of one cylinder with respect to the other so that the area of overlap was changed. It was used with a form of inductor known as a jigger.

BILLI-CONDENSER. Synonym for BILLI-CAPACITOR.

BIOTRON. Special form of two-stage amplifier in which regeneration is used over a wide range of frequencies. The biotron is not generally used in modern practice.

BLACK AMPLIFIER. Special form of negative-feedback amplifier named after its inventor, and used in line communication.

BLACK LEVEL. Percentage of carrier amplitude corresponding with black in a transmitted television picture. In the case of the Marconi-E.M.I. system of television, it is equal to about 30 per cent of the maximum modulation depth, the high lights increasing the modulation to 100 per cent.

Modulation below 30 per cent (below black level) is often referred to as "blacker" than black, and is that portion of the modulation range which is used for synchronizing impulses. Thus, a decrease of modulation below 30 per cent cannot affect the television screen, which is already dark. Yet, by suitable circuits, any decrease in modulation below this 30 per cent can be used by the receiver to provide synchronizing impulses.

The diagram (Fig. 26) shows the transmitted wave form of the system used. All control of brilliance of the cathode-ray receiver tube is carried out by the portion of the modulation above the black-level line. All the modulation variations below that line are employed for synchronizing purposes, and cannot affect the screen because they merely "increase" the blackness.

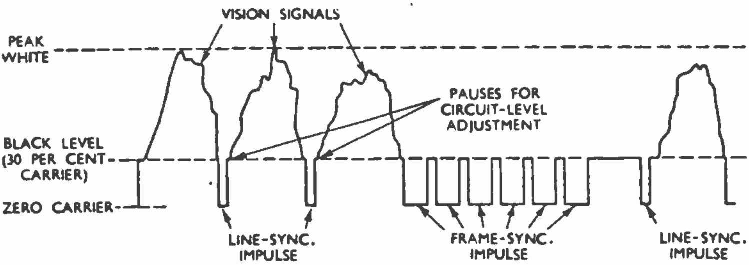


Fig. 26. Wave form of a television signal; the synchronizing impulses occupy, for line, about one-tenth and, for frame, four-tenths of the line duration. After each line-synchronizing impulse there is a slight pause before the signal is transmitted while the carrier black level is adjusted to 30 per cent.

BLACK-OUT POINT. Synonym for BLACK LEVEL.

BLACK-OUT VOLTAGE. Bias voltage on the modulator electrode of a valve or cathode-ray tube necessary to reduce the beam current for specified potentials of other electrodes to a negligibly low value. See BLACK LEVEL. CUT-OFF BIAS.

BLANKING. Term given to the process of cutting off the electron beam of a cathode-ray tube during the period when it is returning from the end of one scan to the beginning of the next. Thus, in television, the beam is cut off (by making the grid negative) during the fly-back from the end of each line to the beginning of the next, and from the end of the last line at the completion of a frame to the beginning of the first line to start the next frame.

This blanking is carried out so that the fly-back shall not trace a visible line of light across the screen. Normally, by turning the brilliance control well up, the fly-back can be seen, the blanking potential being overcome by the positive potential applied to the grid of the tube.

BLASTING. Non-linear distortion of a broadcast transmission due to the overloading of microphone, amplifiers, or sender. See NON-LINEAR DISTORTION.

BLATTNERPHONE. Obsolete type of magnetic recorder. See ELECTRICAL RECORDING.

B-LAYER. Ionospheric layer which is thought to exist below the C-layer. Pulse measurements have been obtained which suggest the presence of thin ionospheric layers below the D-layer. The names, C- and B-layer, have been given to two of them. Direct observation of the electrical state of the atmosphere by means of balloons has failed to reveal these ionized layers and their existence is still in doubt. See IONOSPHERE.

BLEEDER RESISTOR. Term used to describe a resistive form of potential divider, when the latter is used to derive a reduced voltage from a high-tension D.C. supply.

BLIND-LANDING SYSTEM. System by which a pilot may land an aircraft in conditions of poor visibility. See LORENZ BLIND-LANDING SYSTEM.

BLIND SPOT. Region where it is not possible to receive an audible signal from a particular sender operating on a specified frequency. Blind spots—often referred to as "dead spaces"—are spaces on the earth's surface between the points where the ionospheric ray is reflected from the earth. As the ray is successively reflected, the blind spots decrease in area and the zones of reception increase correspondingly.

Theoretically, there must always be some signal in the blind spot due to scattering from the ionosphere, but after one or two reflections and the consequent attenuation of the main ionospheric ray, the scattered signal becomes so small as to be below the noise level of the receiver.

Blind spots of a different and localized type also occur at medium, high, and very high frequencies, within the range of the ground ray. They are almost invariably found where the site of the receiver is in a valley, or where forests and high contours lie between the sender and receiver. The intervening contours act as screens and tend to absorb the ground rays. See ABSORPTION, IONOSPHERIC REFLECTION, SKIP DISTANCE.

BLIP. Small "bump" or deflection of the trace on the screen of a cathode-ray tube. This is caused by a pulse, which is sent out from a radar station and is received back at the station after reflection from an obstacle. From the position of the blip in the trace, the distance of the obstacle can be determined.

BLOCKING CAPACITOR. Capacitor used in a circuit to prevent the flow of direct current whilst allowing the passage of alternating current. The value of the capacitance of the blocking capacitor is usually chosen so that the flow of alternating current shall be substantially unaffected by its inclusion in the circuit.

Probably the most familiar form of blocking capacitor is that used to couple the stages of a resistance-capacitance amplifier or prevent the flow of direct current in the load circuit of a cathode follower. The blocking capacitor is also used to prevent direct current from flowing in transformer windings (Fig. 27). See CATHODE FOLLOWER, RESISTANCE-CAPACITANCE AMPLIFIER.

BLOCKING CONDENSER. Synonym for BLOCKING CAPACITOR.

BLOCKING OSCILLATOR. Relaxation oscillator in which the anode current of a valve is periodically blocked by a large negative bias on to the grid. The anode and grid circuits of the valve are tightly coupled magnetically, the grid circuit having a high ratio of inductance to capacitance, and a very high-value grid leak. When oscillation begins, grid current flows in the grid leak and develops across it a bias many times the cut-off value. In this way the anode current of the valve is blocked in less than one cycle, and oscillation ceases. The negative charge on the grid capacitor now leaks away slowly through the grid leak, and after a period the anode circuit becomes conductive again, oscillation starts and the cycle recommences.

If the resonant frequency of the circuit L_1C_1 (Fig. 28) is much greater than that of the relaxation oscillations, a saw-tooth wave form is produced across the grid capacitor; these oscillations can be triggered by synchronizing pulses injected in series with the grid coil. For this reason, blocking oscillators are extensively employed as time bases in television receivers.

BLUE GLOW. Condition when the gas in the bulb of a valve glows with a blue colour. The effect is due to the ionization of the residual gas and may occur in hard-vacuum power-valves. Valves may show a blue glow when about to go "soft." In a soft valve, the effects of ionization produce excessive electrode currents and the valve is useless; but a blue glow may also be seen in a valve which is working satisfactorily, and which may continue to work satisfactorily for a long period. See IONIZATION, GAS-FILLED VALVE, SOFT-VACUUM VALVE.

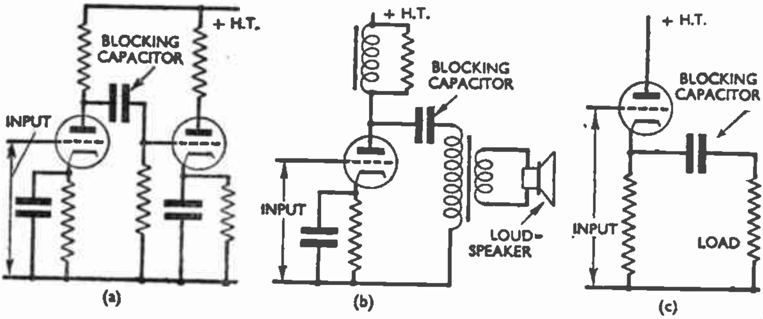


Fig. 27. Three uses of a blocking capacitor: (*a*) in a resistance-capacitance amplifier (in this case it may also be called a coupling capacitor); (*b*) to prevent D.C. from flowing in the transformer windings, while passing A.C., and (*c*) to prevent D.C. from flowing in the load of a cathode follower.

BOBBIN. Synonym for SPOOL.

BOLOMETER. Form of detector used in measuring output of centimetre-wave apparatus. Basically, it consists of a fine platinum wire enclosed in a vacuum; radio-frequency currents passing through the wire cause its resistance to vary and, by so doing, introduce "unbalance" in one arm of a WHEATSTONE BRIDGE (q.v.).

BOTTOM BEND. Curved portion at the bottom or lower end of a valve characteristic. The term is often used to refer specifically to the bottom portion of the anode-current/grid-voltage characteristic (see ANODE BEND). It can, however, refer to the curved portion at the foot of any valve characteristic.

BOTTOM-BEND DETECTION. Synonym for ANODE-BEND DETECTION.

BOTTOM-BEND RECTIFICATION. Synonym for ANODE-BEND RECTIFICATION.

BOX BAFFLE. Form of baffle construction for use where space is restricted; for example, the cabinet of a modern radio receiver or loudspeaker. See BAFFLE.

BREAKDOWN VOLTAGE OF GAS. See IONIZATION POTENTIAL.

BREAK IMPULSE. Any transient voltage or current produced by the sudden interruption of a circuit; but more specifically some impulse thus produced and used for signalling purposes, as in some form of automatic telephone system.

BREAK JACK. Jack which has extra contacts arranged to break a circuit when the plug is inserted. See PLUG AND JACK.

BRIDGED T-NETWORK. T-network in which the series impedances are bridged by a fourth impedance (Fig. 29). A lattice network may have an equivalent of a bridged T-network.

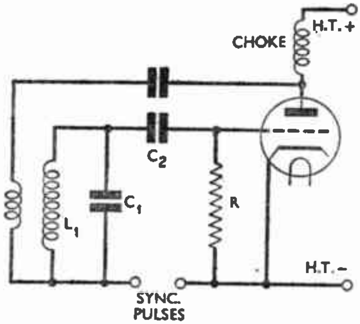


Fig. 28. Blocking oscillator in which C_1 may be the self-capacitance of L_1 or a separate component; C_2 is the grid capacitor across which saw-tooth waves are developed, and R is a grid-leak of very high value.

Null networks are in the form of bridged T-networks; certain forms of bridged T-networks have the property of giving virtually zero attenuation, but change the phase of the waves passing through them. See LATTICE NETWORK, NULL NETWORK, PHASE-CHANGE NETWORK, T-NETWORK.

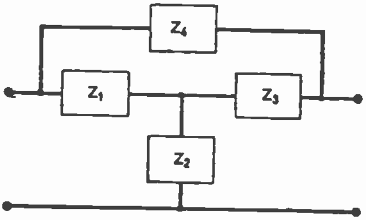


Fig. 29. Bridged T-network; the T-network is formed from impedances Z_1, Z_2 and Z_3, and the bridge by Z_4.

BRIDGE MEGGER TESTER. Resistance-measuring instrument operating on the principle of the Wheatstone bridge. It incorporates a meter and a hand generator. See INSULATION, WHEATSTONE BRIDGE.

BRIDGE NETWORK. Synonym for LATTICE NETWORK.

BRIDGE NEUTRALIZING. Process of employing an R.F. amplifying circuit in which two valves are connected for balanced operation, the neutralizing voltages being fed from the anode of one to the grid of the other through a suitably small capacitance (Fig. 30). (This is, in effect, negative feedback, and counteracts the positive feedback through the internal capacitance of a triode.)

This method of stabilizing a triode-valve R.F. amplifier is complicated and has been little used in receiver design. Like other neutralizing systems, the bridge method disappeared when the screen-grid valve came into use. The circuit is, however, often employed in high-power senders. See BALANCED VALVE-OPERATION, NEUTRALIZATION.

BRIDGE RECEIVER. Type of radio receiver employing the WHEATSTONE BRIDGE (q.v.) principle, sometimes

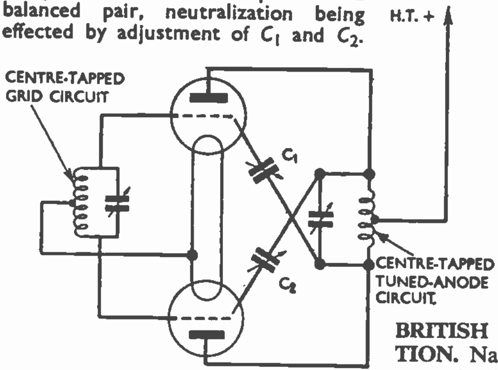


Fig. 30. Simple form of bridge neutralizing circuit. The valves operate as a balanced pair, neutralization being effected by adjustment of C_1 and C_2.

used when two-way working is carried on at the same frequency.

BRIDGE-SET. Arrangement of transformers which may be used instead of the hybrid coil when a four-terminal, radio-transmission system is joined to a two-wire telephone system. See HYBRID COIL.

BRIDGE TRANSFORMER. See HYBRID COIL.

BRIDGING AMPLIFIER. Monitoring amplifier of any type which can be bridged across a circuit without drawing any appreciable amount of power therefrom, thereby enabling a broadcast programme, for instance, to be checked without interfering with its passage to the sender.

BRIGHT-EMITTER VALVE. Valve with a filament which glows brightly, in contrast with those having filaments which glow a dull red or those having indirectly heated cathodes which also glow a dull red. The term is obsolescent; in earlier development of the valve, emission was obtained from filaments which worked at much greater temperatures than do modern types. Valves using newer types of filament and indirectly heated cathodes were later introduced and were designated dull-emitter valves. See CATHODE, EMISSION.

BRILLIANCE CONTROL. Operating adjustment of a cathode-ray tube which permits the intensity of the electron beam to be varied. It may be necessary for a brilliance control on a television receiver to be set in conjunction with the contrast control so that good contrast is retained between the black and the white portions of a picture. If the television signals are weak, increasing the brilliance of the picture may appear to cause some reduction of the contrast.

BRITISH STANDARDS INSTITUTION. National organization for the promulgation of British Standard terms, definitions, codes of practice and specifications for materials, articles, etc., and methods of test. The offices of the Institution are in London, and complete sets of British Standards are maintained in Public Libraries and Colleges in several of the principal towns of Great Britain, the British Commonwealth and America.

The definitions of terms given in this encyclopaedia have, in many cases, been based on the British Standard definitions.

BRITISH THERMAL UNIT. Measure of quantity of heat, defined as the amount needed to raise the temperature of 1 lb. of water by 1 deg. F. A more precise definition stipulates that the temperature rise shall be from 60 to 61 deg. F. See CALORIE.

BROADCAST CHANNEL. Channel reserved for, or appertaining to, a broadcasting sender. See CHANNEL.

BROADCAST COVERAGE. See COVERAGE, SERVICE AREA.

BROADCAST EXCHANGE. Synonym for RADIO RELAY SYSTEM.

BROADCASTING. Process of diffusing programmes of information or entertainment by means of electricity, so that such programmes can be heard or seen by use of a receiver. A schematic diagram of a sound-broadcasting system appears at Fig. 31. The programme to be broadcast takes place at what is labelled the programme location. Here the microphone is located; this converts variations of air pressure representing the sounds to be broadcast into variations of electrical potential. Associated with the microphone is the microphone amplifier, which raises the power generated by the microphone to a sufficient level for its transmission over the link between programme location and control room (see MICROPHONE, MICROPHONE AMPLIFIER, RADIO LINK).

The microphone output appears at the control room, and is applied to an amplifier with an adjustable gain control. This raises the output to a level suitable for routing to the sender or senders.

The control room is the place in which a team of engineers not only controls the level of the currents which are sent to the various sending stations, but also routes the programmes coming from different programme locations to different senders, so that a minute-to-minute plan for the service as a whole may be obeyed (see CONTROL ROOM, SIMULTANEOUS BROADCASTING).

The control room is linked to the sender so that the controlled level coming from the microphone may be suitably fed into the modulation circuits of the sender equipment.

The sender may be linked to any number of receivers, only one of which is shown at Fig. 31, and these are adjusted by their users to receive the broadcast signals. The receiver energizes a headphone or, more commonly, a loudspeaker, which converts the signals received from the sender into air pressure-waves which reproduce the instantaneous frequency and relative amplitude of the sound waves impinging on the microphone at the programme location (see BROADCAST RECEIVER, HEADPHONE, LOUDSPEAKER).

Obviously, the system shown in Fig. 31 suffices to diffuse only one programme over a limited area; in a normal broadcasting system there are many senders linked together by a telephone network. In principle, the links between the various stages of a broadcasting system may be formed by any sending system such as a radio or transmission line, the latter carrying audio-frequency or modulated carrier-frequency currents. In practice, however, the link between programme location and control room is usually a transmission line—an ordinary telephone line—carrying the audio-frequency currents which comprise the output from the microphone. The output of the microphone is so small, however, that it is considerably

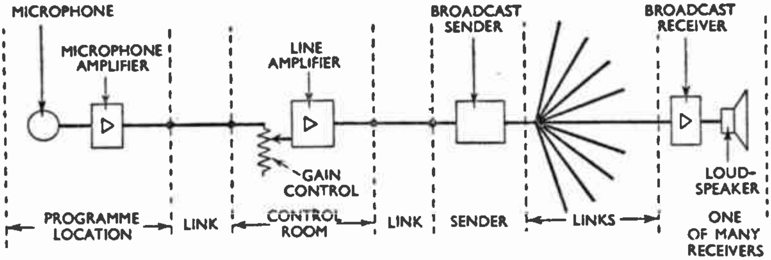


Fig. 31. Schematic diagram showing the essential features that are linked up in a single-programme sound-broadcasting system: programme location, control room, sender, and receiver. The scheme applies also to television broadcasting, except that the microphone is then augmented by a vision pick-up and the loudspeaker by a fluorescent screen on which the moving pictures appear.

amplified first. When it is impossible to use a transmission line to link programme location and control room, a radio link is employed (see TRANSMISSION LINE).

In virtually all circumstances, the link, between sender and the receiver used by the listener, is a radio link. The senders are thus radio-telephone senders. The replacement of this radio link by a wire network has been suggested, but not implemented.

The receivers used by the listening public are primarily designed for use by unskilled persons. The superheterodyne principle is almost always used.

There is an adjustment which makes the receiver sensitive to emissions from the chosen station, and this is called the tuning control; another adjustment, to set the sound intensity at a certain level, is the volume control; and a further adjustment enables senders on long, medium or short waves to be received and tuned-in.

There is no basic technical difference between sound and vision receivers, except that the former has a continuously variable tuning arrangement whereas the latter is frequently designed to work on a fixed frequency. At the sender, the microphone is replaced by a vision pick-up; at the receiver, the loudspeaker is replaced by a screen on which the moving pictures appear.

The enormously wide frequency band containing the waves coming from a vision pick-up makes extreme care necessary when deciding the transmission characteristics of the links joining the various locations. Thus, in the link from studio to the control room, if these are far apart, the transmission line must be equalized, and at every few miles it is necessary to insert repeaters. This is why television studios are usually located close to the television sender. For outside broadcasting, special lines must be used to link the programme location with the studio. The same reasons necessitate the use of a high-frequency carrier wave, and wide band widths. See BROADCAST SENDER, OUTSIDE BROADCASTING, RADIO RELAY SYSTEM.

BROADCASTING STUDIO. Room or auditorium designed for the purpose of rehearsing and performing productions forming the items of broadcast programmes. Broadcasting programmes are composed of a great number of different items. The organization responsible for the programmes equips itself with a building or buildings within which rooms or halls are set aside as studios.

As the programme material may originate from a symphony orchestra or an individual speaker, a great number of different sizes of studio is necessary. But more important is the question of suitable acoustics; the reverberation of an auditorium which is suitable for a large orchestra would be wholly unsuitable, apart from waste of space, for a single speaker. A brass band demands a different acoustical environment from a theatre orchestra; plays and variety shows demand their own special type of studio. Thus there are talks studios, drama studios, and orchestra studios. Apart from broadcasting studios there are the recording and television studios.

In the early days of broadcasting, the microphone and earphones used tended to resonate at frequencies approximating to 1,000 c/s. This gave a reverberation quality to the reproduction, apart from any added acoustic effect of the places where the performances took place. Thus it was necessary to damp studios, that is to say, to make them as little reverberant as possible. Studios in those days held literally thousands of pounds weight of wall-draping, soft carpets, padded ceilings and so on. As the characteristics of transducers improved, so the studios were partly undressed and, as a result of a great deal of acutely conceived and patient work, the modern studio is well adapted to its purpose and gives a pleasant synthesis of the various sounds that are being produced in it.

In dramatic work, movable screens and other devices are used to set up particular acoustical effects which give the listener a sense of varying distances, for instance. The echo room and effects discs also add to the illusion. See ECHO ROOM, STUDIO-CONTROL CUBICLE.

BROADCAST RECEIVER. Receiver designed for domestic use by the public which listens to broadcast programmes. The essential requirements of a broadcast receiver are reliability and simplicity of adjustment, while pleasant appearance is an important commercial attribute. The miniature receiver has found a wide market and, on the whole, the more compact a receiver, consistent with a reasonable performance, the better it pleases a majority taste.

A broadcast receiver is generally classified as a portable, a radio-gramophone, or as a "table" receiver, and may need an external aerial. There is also the sub-division of "mains" and "battery" receivers; the latter, generally portable, is designed for use where there is no mains electricity supply. The "radiogram" is seldom, if ever, battery-operated.

With the exception of miniature receivers and some battery-operated types, the superheterodyne principle of reception is used (see SUPERHETERODYNE RECEIVER). Thus, in typical practice, a frequency-changer precedes a stage of intermediate-frequency amplification; this, in turn, is followed by a detector or demodulator. The detector, usually a diode, feeds its output to the single audio-frequency amplifying valve, commonly a pentode, which energizes the loudspeaker. This is generally a moving-coil type with a permanent magnet, although energized types are still used.

Automatic gain-control is almost universally employed; this is obtained from the output of the intermediate-frequency amplifier by means of a diode detector, and the control voltage delivered by the diode is fed, as grid bias, to the signal-frequency amplifier (if used), the frequency-changer and the intermediate-frequency amplifier, all of which must be variable-mu valves (see AUTOMATIC GAIN-CONTROL, DELAYED AUTOMATIC GAIN-CONTROL). A typical four-valve superheterodyne circuit as used in broadcast receivers is shown in Fig. 32.

A tone-control adjustment may be used to vary the characteristic of a simple equalizer in the audio-frequency circuits. The manual gain-control may be, and usually is, a potential divider in the audio-frequency circuits. Where automatic gain-control is not used, the manual gain-control varies the bias of a variable-mu valve. Push-button tuning is sometimes used and automatic tuning-control by some form of discriminator circuit is employed in the more expensive types of receivers. The receiver is able to pick up signals on the long-, medium- or short-wave bands by the adjustment of an external knob, which puts different inductors into the tuning circuits, the same ganged variable capacitor being used on all wavelength ranges. One of the elements of this capacitor controls the frequency of the local oscillator (see SECOND-CHANNEL INTERFERENCE, TRACKING). To make it easier to tune-in short-wave stations, a so-called "band-spread" circuit is used.

The mains-operated receiver derives power for the anode circuits of the valves from a MAINS UNIT (q.v.) which is mounted on the chassis common to the whole receiver. The smoothing circuit uses electrolytic capacitors of 8–32 μF and an inductor of the order of 20 H. A mains-operated receiver consumes about 50 VA, and has a power factor of about 0·8. The radio-frequency inductors are often of the type having cores of finely divided iron dust and the tuning of the intermediate-frequency circuits may be effected by a mechanical adjustment of the position of such cores (see DUST-CORED INDUCTOR).

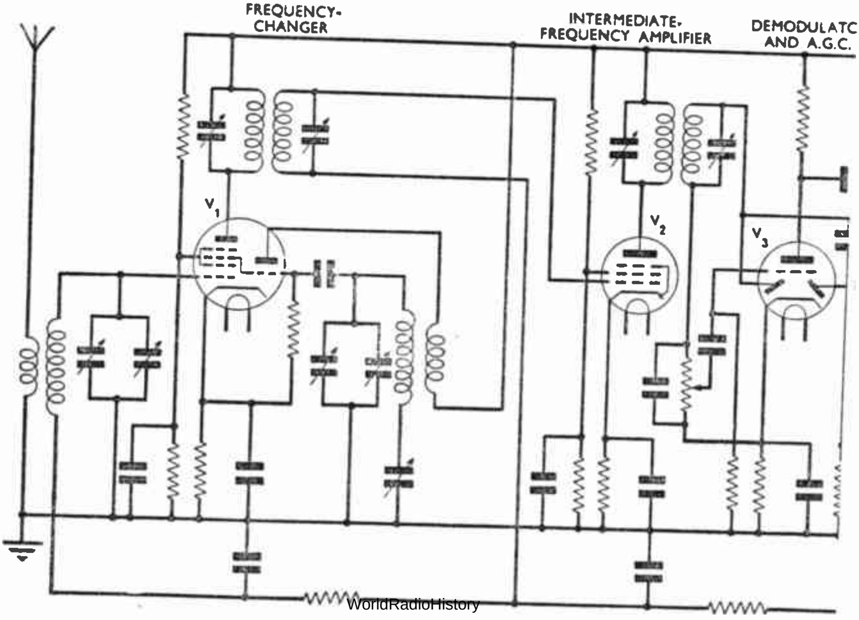
The miniature receiver is commonly formed from one tuned-anode high-frequency amplifier, an R.F. pentode used as an anode-bend detector, and an audio-frequency amplifier. In cheaper receivers only medium- or long- and medium-wave ranges are supplied.

This general description gives a picture of the basic characteristics of many types of receiver, but any one make may embody some or all of the features described. The more expensive types give all the refinements; but the lower the price, the fewer are the refinements offered.

The average receiver gives a flat response up to about 3,000 c/s; a gradual increase of attenuation with increasing frequency is then shown, and few sets give any worthwhile response at frequencies much above 6,000 c/s. The high-fidelity receiver does better and provides variable selectivity, so that better results may be obtained from local senders; while distant reception, at the expense of fidelity, is still possible. See AUTOMATIC TUNING-CONTROL, BAND-PASS FILTER, MAINS UNIT, PORTABLE RECEIVER, PUSH-BUTTON RECEIVER, SELECTIVITY, SMOOTHING CIRCUIT.

BROADCAST RELAY SYSTEM. Synonym for RADIO RELAY SYSTEM.

BROADCAST SENDER. Sender, forming part of a broadcasting system, which sends out modulated waves representing the intelligence being broadcast. All broadcasting systems, as at present constituted, use radio senders to form the link between the place where a programme takes place and the widely scattered listeners who receive the programmes. A broadcast sender is basically a radio-telephone sender. Every precaution is taken to ensure that distortion is reduced to a minimum; thus, if the modulation be sinusoidal, a perfect detector detecting the modulated wave would show the audio-frequency output from it to be virtually constant over a frequency range of from 30 to 10,000 c/s; the harmonic content of the detected wave should, in all conditions,



be negligible; and, therefore, the level of the output from the detector should be strictly proportional to the level of the input to the modulation circuits of the sender up to a modulation factor of 1, which is a modulation percentage of 100 (see MODULATION FACTOR).

Such ideals are not, in fact, realized in practice, while the frequency/modulation-depth characteristic is usually within 1 db. over a frequency range of 30 to 10,000 c/s. The harmonic content of the modulation envelope rises sharply for modulation factors greater than, say, 0·8 to 0·85; thus a modulation factor of 1 would, in many cases, show anything from 5 to 10 per cent harmonic distortion; below 80 per cent modulation, however, it could be less than 1 per cent. These figures apply to typical senders now in use, but more modern types may show improvement. It should be realized that an increase of the modulation depth from 0·8 to 1 produces an increase in detector output of only 2 db., barely detectable to the human ear.

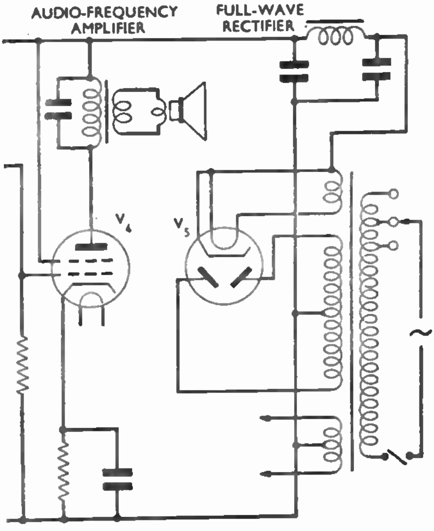


Fig. 32. Superheterodyne receiver for operation from A.C. mains; for clarity only a single wave-band circuit is shown. The circuit is typical of those used in modern broadcast receivers, V_1 being a frequency-changer, V_2 an intermediate-frequency amplifier, V_3 a diode demodulator, V_4 an audio-frequency amplifier, and V_5 a full-wave rectifier.

All British and European senders make use of high- or low-power amplitude modulation. In Britain, the older medium-wave senders use low-power modulation. Droitwich uses high-power modulation of the series-valve type (see ANODE MODULATOR, HIGH-POWER MODULATION, LOW-POWER MODULATION). The pre-Second World War Luxembourg sender used out-phasing modulation and claimed a power economy in so doing (see OUT-PHASING MODULATION).

Great care is taken to maintain the carrier-wave frequency of a broadcasting sender at a constant value so that there shall be a minimum sideband interference when senders are employing neighbouring frequency channels.

The necessity to stabilize carrier-wave frequency to avoid interference has resulted in a greater accuracy than is necessary for this purpose alone. Thus the Droitwich carrier is stabilized to one part in 10^7 for long-term stability and can be used as a frequency standard. Short-term stability is of the order of one part in 10^8. See AMPLITUDE MODULATOR, BROADCASTING, DETECTION, SIDEBAND WAVE.

BROADCAST TRANSMISSION ON SHARED CHANNELS. Two or more broadcast senders operating at the same nominal carrier frequency. Such senders are said to share a channel. If the carrier frequencies are not quite equal, receivers in positions where the two carrier waves are received at more or less equal strength produce a "flutter" or whistle depending on whether the difference in frequency is low or high. This spoils reception of both signals.

If one signal is very much stronger than the other the interference caused by the other is much reduced. Thus, if the stations are radiating different programmes there is an area surrounding each sender in which reception of the local programme is clear, but, in between the stations, there will be "mush" areas in which neither programme is heard clearly because of the flutter or whistle. This effect is minimized in practice by international agreement which ensures that senders using shared channels and radiating different programmes are so far apart geographically that the mush area is outside the service area of both the stations.

To give increased coverage, two or more stations of a national broadcasting system are sometimes placed fairly close to each other and radiate the same programme on the same carrier frequency. Such an arrangement produces extensive mush areas unless precautions are taken to keep the carrier frequencies and phases identical.

One way of achieving this result is by the use of a pilot tone which is obtained by frequency division from the carrier wave of one of the stations which is chosen as master. The tone is made low enough in frequency to be sent over telephone line to the other stations, known as slaves, where it is frequency-multiplied to the original value and is used to control the carrier frequencies of the slave stations.

An alternative method of eliminating mush areas caused by two stations radiating the same programme is to set up, in the mush area, a receiver containing a discriminator. The output voltage of the discriminator indicates by its sign whether one received signal is higher or lower than the other. The magnitude of this voltage gives a measure of the frequency difference. This voltage is passed to one of the senders, where it alters the carrier frequency to eliminate the difference in the two carrier frequencies.

BROADCAST TRANSMITTER. Synonym for BROADCAST SENDER.

BROADSIDE ARRAY. Aerial-array so arranged that maximum radiation or most effective reception is in a direction perpendicular to the plane of the array. See AERIAL-ARRAY, CURTAIN ARRAY.

BRUSH DISCHARGE. Phenomenon which occurs when the voltage on some charged body rises to a figure sufficient to cause an incipient breakdown in the insulation of the air which surrounds it, but not sufficient to cause an actual spark or arc. A brush or corona discharge occurs and this usually produces a slight fizzling or hissing sound.

B-SERVICE AREA. Service area in which the field strength is greater than 5 mV/m. See A-SERVICE AREA, SERVICE AREA.

B.Th.U. Abbreviation for BRITISH THERMAL UNIT.

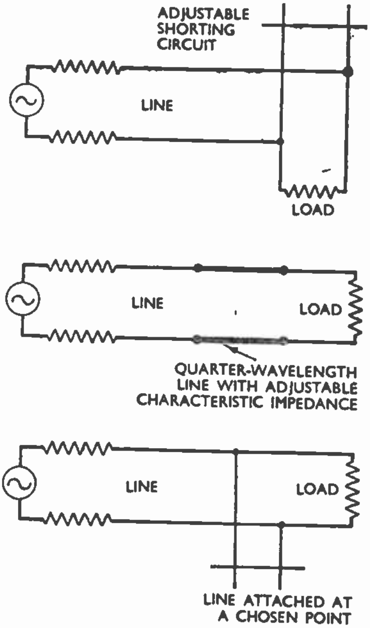


Fig. 33. Three examples of the manner in which a building-out network may be added to a line with the object of matching the load to the line.

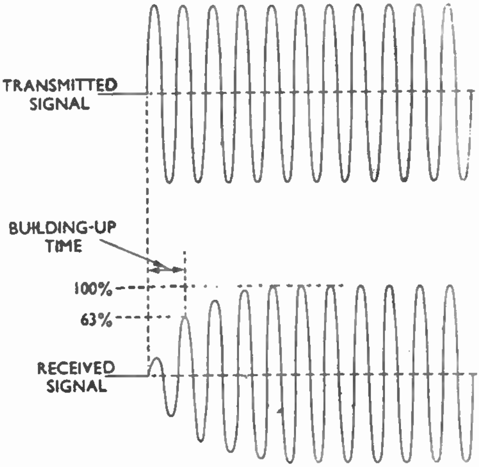


Fig. 34. When a sine wave of constant amplitude is applied to a resonant circuit, the building-up time is taken as that required for the current in the circuit to reach 63 per cent of its steady-state value.

BUFFER CIRCUIT. In radio, the circuit employed in a buffer stage; in electronic organs, the resistance-capacitance unit which controls the rapidity of the rise and fall in the sound waveform envelope.

BUFFER STAGE. Valve stage introduced into an amplifier or oscillator to prevent the characteristics of the earlier stages from being affected by load fluctuations in later stages. It is frequently referred to as separator stage.

BUFFER VALVE. Valve used in a buffer stage.

BUILDING-OUT NETWORK. Network connected to a line so that the impedance of the line is modified. Lines may be used to form the connexion between a generator and a load which is at some distance from the generator; for example, a line is generally used to couple the output of a sender to an aerial.

Maximum power is transferred from a line to its load when the load has an impedance equal to the characteristic impedance of the line. If the load impedance is of such a nature that it does not equal the characteristic impedance of the line, networks may be "built-out" from the line, that is to say, connected to a chosen point on it, so that the load receives the maximum possible power from the line (Fig. 33).

BUILDING-UP TIME. Interval between the time at which the envelope of a transmitted wave is first received and the time when it first reaches a specified fraction of its steady-state magnitude. For example, if a sine wave of constant amplitude is suddenly applied to a resonant circuit, the current in the circuit (or the voltage across it) grows exponentially, as shown in Fig. 34, and, theoretically, never reaches its steady-state value—though, for all practical purposes, it may reach it in a very small fraction of a second. It is usual, therefore, to specify the building-up time as the time that is required for the amplitude to reach approximately 63 per cent of steady-state value. See TIME CONSTANT.

BULB. Airtight container of a valve which encloses the electrode structure and preserves the vacuum or low-pressure gas within. The bulb is usually of glass, but may be of metal. See METAL VALVE, VALVE.

BUNCHER. Electrode and resonant chamber of a valve used for the generation or amplification of centimetric waves. The buncher is arranged so as to cause the electrons flowing between cathode and anode to form into concentrations or "bunches" along the electron stream; these "bunches" arrive at the catcher, which is equivalent to the anode of a valve. See BUNCHING, CATCHER, KLYSTRON, RHUMBATRON.

BUNCHING. Effect when electrons in the electron stream passing between cathode and anode form concentrations, or "bunches." See BUNCHER, KLYSTRON, RHUMBATRON.

BURIED AERIAL. Aerial consisting of a length of insulated cable buried in the ground to a depth of a few feet. Originally claimed to reduce atmospheric interference to a greater extent than the wanted signal, and therefore to give an improved signal-to-noise ratio, the buried aerial is now little used.

BUSBAR. Conductor used to connect a source of electricity supply to several feeders of consuming apparatus. The connexions are invariably made through switches. Low-tension busbars are often of bare copper supported on insulators, but in high-tension systems they are enclosed in an earthed metal casing.

BUSH. Lining for a hole; sometimes called a "bushing." In electrical apparatus, a non-conducting bush is used to insulate a live conductor passing through a metal plate, panel or screen. Insulating bushes are made of ceramics and plastics and of hard or soft rubber.

BUZZER WAVEMETER. Wavemeter in which a resonant circuit is connected across the vibrating contacts of a buzzer to produce oscillations of a given frequency. See WAVEMETER.

BY-PASS. Circuit element, or combination of circuit elements, connected in one part of a circuit to offer a low impedance to certain currents, with the object of preventing these from flowing in another part of the circuit. See BY-PASS CAPACITOR.

BY-PASS CAPACITOR. Capacitor having a reactance which is small compared with a resistance connected in parallel with it. If alternating voltages are applied to the parallel combination, most of the current flows through the capacitor, not through the resistor. A typical use of the by-pass capacitor is in a cathode-bias circuit (Fig. 35). When a wave is applied between control grid and earth, an alternating current is superimposed on the direct current flowing through the valve.

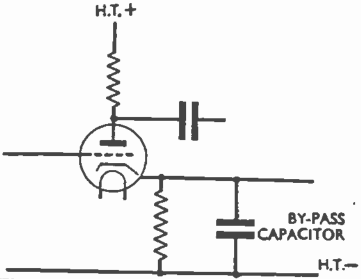


Fig. 35. Example of a by-pass capacitor used to pass the alternating-current component of the cathode current so that it does not flow in the parallel resistor; this current maintains the cathode at a fixed potential.

The by-pass capacitor ensures that the potential of the cathode does not change; to obtain this condition the reactance of the capacitor must be virtually zero at the frequency of alternation of the current flowing from the cathode of the valve. In other words, the alternating component of the cathode current flows through the by-pass capacitor and not through the resistor. If the capacitor has a large capacitance and the frequency of the current alternation is not too low, the voltage drop across the capacitor is nearly zero. See CATHODE BIAS, CURRENT FEEDBACK.

BY-PASS CONDENSER. Synonym for BY-PASS CAPACITOR.

C

C. Abbreviation for COULOMB(S).

CABLE. Special form of conductor containing one or more strands, insulated by a dielectric material from a protective sheathing adapted to the particular purposes for which the cable is intended.

CABOT QUILT. Quilt stuffed with dried eel grass and used in sound studios for producing specific acoustic effects by means of its sound-absorbing qualities.

CADMIUM CELL. Voltaic cell with a remarkably constant e.m.f. and, therefore, commonly used as a voltage standard. The cadmium cell delivers a voltage of 1·0183 volts at a temperature of 20 deg. C., and this figure can be relied upon to an accuracy of one part in a thousand. The cell contains a cadmium anode and a mercury cathode in a cadmium-sulphate solution. Mercury sulphate acts as the de-polarizer.

When intended as a standard of voltage, the cell has a series resistance of several thousands of ohms connected permanently to one of its terminals so that it shall not be damaged by accidental short-circuit. The cell is also known as the Weston cell. See PRIMARY CELL, VOLTAIC CELL.

CAESIUM CELL. Photocell in which the cathode is a very thin layer of caesium deposited on silver. Caesium is more sensitive to light than is any of the other metals (barium, strontium, etc.) that exhibit photo-electric properties, and is, therefore, the most widely used substance in modern photocells. As the caesium cell has increased sensitivity at the red end of the spectrum, it is best suited for use with artificial lighting. See PHOTOCELL.

CAGE AERIAL. Aerial consisting of a number of parallel conductors spaced in cylindrical fashion, and supported by means of hoops (Fig. 1). This type of aerial is characterized by high capacitance and low R.F. resistance. In some instances, the cage construction is applied only to the horizontal span, but in others the down-lead or lead-in is also in cage form.

CALIBRATION. Process of tabulating a set of figures obtained by measuring the performance of an instrument or electrical system, and entering such figures in the appropriate positions on the scale of the instrument, or on a separate graph or chart.

CALORIE. Measure of quantity of heat, defined in metric units. The gramme-calorie is the amount of heat needed to raise the temperature of a gramme of water by 1 deg. C.; a kilogramme-calorie, sometimes called a "large calorie," is 1,000 gramme-calories.

More strictly, the relevant temperatures should be defined; they are always assumed to be 15 and 16 deg. C. except in the case of the "mean calorie," which is determined by finding the amount of heat needed to raise the temperature of a gramme of water from 0 to 100 deg. C., and dividing this by 100 to find the amount per degree over that range. See BRITISH THERMAL UNIT.

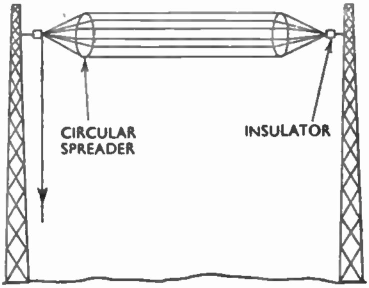


Fig. 1. Cage aerial with single-wire down-lead. The cage construction produces characteristics of high capacitance and low R.F. resistance.

C-AMPLIFIER. Synonym that is sometimes used for LINE AMPLIFIER.

CAPACITANCE. Property of a body which enables it to accept an electric charge, and to hold it subject only to leakage through such insulating arrangements as may be involved. A given amount of charge placed upon a capacitor raises its voltage by an amount which is inversely proportional to the capacitance.

Consider a metal sphere standing on a perfectly insulated pedestal. If the sphere is at the same electrical potential as its surroundings, it is said to be holding zero charge.

Now suppose that, by some means, a large number of extra electrons is placed on the sphere; it will then acquire a negative charge and its potential will differ from that of its surroundings. The extent to which its potential changes when a given quantity of charge is placed upon it is a measure of the capacitance of the sphere. If a large charge is required to produce a certain change of potential, the capacitance is large; if a small charge is sufficient, the capacitance is small. This may be compared with pumping air into a motor tyre; it takes more air to produce a given rise of pressure in a big tyre than in a small one.

The capacitance of an isolated sphere is a simple thing to evaluate; it is just a geometrical function of the surface area of the sphere. However, practical electrical work is not generally concerned with isolated objects in space; capacitances are generally used in circumstances wherein the object is in close proximity to something which profoundly modifies the situation.

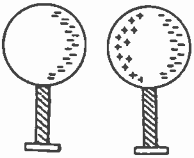


Fig. 2. If a negative charge is placed on one of two metal spheres on insulating stands, it will repel the electrons in the other sphere and so produce a positive-charge condition on the nearer surface.

By way of example, consider what happens when a second metal sphere is placed beside the first (charged) one (Fig. 2). By electrostatic induction, a charge of opposite polarity will be produced on the second, previously neutral, sphere; and this charge will attract the charge on the first sphere. The latter will therefore crowd into that part of the first sphere's surface which is nearest to the second one and the rest of the sphere's surface will thereby be depleted of charge, and will be able to accept some more at the same pressure as before.

In other words, the capacitance of the first sphere will have been increased by the presence of the second; this is a fundamental process in the practical application of the principle of capacitance. When a large capacitance is required for some purpose, it is always obtained by the close juxtaposition of metallic or other conducting surfaces, with some suitable insulating material between them. The capacitance then depends on the area of the metal surfaces facing each other, on the distance between them, and on the nature of the insulating material between. The larger the area and the closer the spacing, the greater is the capacitance. The insulating material affects the capacitance in accordance with its permittivity; the higher its specific permittivity, the greater the capacitance for a given conducting-surface area and spacing (see PERMITTIVITY.)

The evaluation of capacitance calls for a suitable unit, and the obvious basis for a unit is a definition of a standard capacitance in terms of the quantity of charge necessary to raise the potential by one volt; the farad, the basic practical unit of capacitance, is so defined. The farad represents the capacitance of a body whose potential would be raised one volt by one coulomb of electricity. As the farad is too big to be a convenient unit—the earth itself has a capacitance of only about one-seventh of a farad—fractions of a farad, the microfarad (a millionth) and the picofarad (a billionth), are used in practice.

In the experiment with the two metal spheres, a more precise understanding of what happens will result if the electron movements are considered in detail. When the negative charge (which, in fact, is just a quantity of extra electrons) is put on the first sphere, it causes a redistribution of the "loose" electrons in the second sphere; they are repelled by those on the neighbouring sphere, and move away to the opposite side of their own sphere. As they represent a negative charge, the region which they have vacated, being now deficient of electrons, is positively charged and attracts the negative charge of electrons on the first sphere.

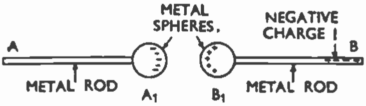


Fig. 3. Negative charge applied at *A* gathers on one side of sphere A_1, and induces a positive charge on the nearer side of sphere B_1 by repelling a corresponding negative charge to *B*.

The negative charge which has been induced in the second sphere, consisting of electrons trying to get as far away as they can from those on the first sphere, will escape altogether if given the chance. If a wire from earth is touched upon the second sphere in the middle of the negative charge, the negative charge will travel down the escape path thus provided, leaving an overall deficiency of electrons on the metal sphere. This phenomenon is more fully discussed elsewhere (see ELECTROSTATICS).

Of more present concern is a less extreme case, in which the escape path is not a complete one, but merely an extension rod attached to the side of the second sphere; with this arrangement, the repelled electrons concentrate at the far end of the rod (Fig. 3).

It is illuminating to follow the sequence of events a little more closely; suppose that there are no charges on the two spheres; a negative charge is inserted at point *A*—the tip of an extension rod fixed to the first sphere. Incoming electrons will then undergo a momentary distribution all over the rod and the sphere; but, as they take up their positions, they begin to repel electrons from the nearer side of the second sphere. These ejected electrons will be sent away down the other extension rod, and will appear as a negative charge at point *B*.

The interesting point is, that a negative charge has been inserted at *A*, and a negative charge has appeared at *B*, just as though there were a through-connexion from one point to the other. Thus the capacitance between the two spheres provides a path for such effects as the sudden application of charges to the system, or even changes in the amount of the charges.

It can now be understood that if an alternating voltage is applied to *A*, something very much like it will appear at point *B*; because the application of an alternating voltage is the same as putting a succession of alternately positive and negative charges into the circuit. In this sense, it is true to say that an alternating current can pass through a capacitance; in effect, it certainly does so; and does so more easily as the capacitance becomes larger and the frequency of alternation higher (see REACTANCE).

The capacitance between two equal parallel surfaces of known area and spacing may be calculated by:

$C = \frac{885A\kappa}{10^{10}d}$, where C is the capacitance in microfarads, A is the area of one surface in square centimetres, κ the permittivity of the material between the plates and d the distance between them in centimetres.

CAPACITIVE. Having the property of capacitance; functioning in a particular manner because of the presence of capacitance. Thus, in A.C. practice, a leading load is sometimes called a capacitive load. See LEADING LOAD.

CAPACITIVE ATTENUATOR. Attenuator, for use at medium and higher radio frequencies, consisting of capacitive elements. See ATTENUATOR.

CAPACITIVE COUPLING. Coupling in which a capacitor is the element common to the two circuits which are coupled. The term is not often used to describe the classic types of filter, in which the shunt arm is a capacitor. Thus a filter composed of series inductors and shunt capacitors is called a low-pass filter, and not a capacitively coupled filter.

CAPACITIVE FEEDBACK. Feedback of energy from one stage of a valve amplifier to another when they are coupled by a capacitance. The coupling may be provided by a capacitor purposely introduced to give feedback, or it may be due to the close proximity of certain components, giving unwanted positive feedback and, possibly, instability.

CAPACITIVE-FEEDBACK OSCILLATOR. Any valve oscillator in which the feedback of energy from the anode to the grid circuit takes place only via a capacitive link, for example, Colpitt's circuit.

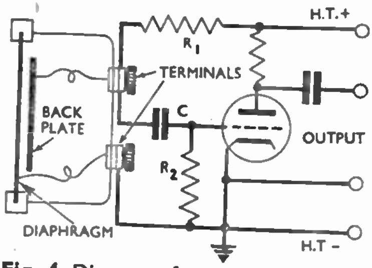


Fig. 4. Diagram of a capacitive microphone showing how the diaphragm and back plate form a capacitor. The alternating e.m.f.s produced at the terminals are amplified by a valve.

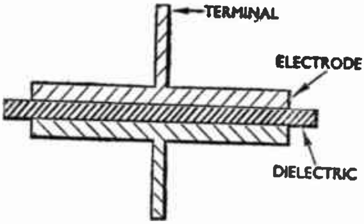


Fig. 5. Essential parts of a capacitor are two conducting electrodes, or plates, separated by a dielectric.

CAPACITIVE LOAD. Synonym for LEADING LOAD.

CAPACITIVE LOUDSPEAKER. Loudspeaker, the diaphragm of which forms one electrode of a large capacitor. The capacitor is charged by a D.C. potential, the charges being increased and decreased by the application of alternating potentials from an amplifier. This causes the diaphragm to vibrate at the frequency of the alternating potentials, thus producing sound waves. The type is almost obsolete. See LOUDSPEAKER.

CAPACITIVE MICROPHONE. Microphone, the diaphragm of which is one electrode of a capacitor. In Fig. 4 the capacitor is formed by the diaphragm and the back plate. The diaphragm is at earth potential and the back plate at about 200 volts above earth. Sound waves impinging on the diaphragm cause it to vibrate, thus varying the capacitance between diaphragm and back plate at the frequency of the sound waves.

The resultant alternating potentials are applied to the grid circuit of the valve via the capacitor C and resistor R_2. The resistor R_1, which may be of several megohms, is included to prevent the charge between diaphragm and back plate from leaking away through the source of supply. The advantages of a capacitive microphone are freedom from hiss (characteristic of the carbon microphone) and less susceptibility to blasting. See BLASTING, CAPACITANCE, MICROPHONE.

CAPACITIVE PICK-UP. Gramophone pick-up, using the principles of the capacitive microphone, the diaphragm being moved by the needle. This type is not, however, in general use.

CAPACITIVE REACTION. Synonym for CAPACITIVE FEEDBACK.

CAPACITIVE RETROACTION. Synonym for CAPACITIVE FEEDBACK.

CAPACITIVE TUNING. Variation of the resonant frequency of a circuit containing inductance and capacitance by varying the capacitance.

CAPACITOR. Device capable of storing electrostatic energy and having capacitive reactance as its principal property when used in alternating-current circuits. Its essential parts (Fig. 5) are two conducting electrodes closely spaced by a dielectric, or insulating medium. The electrodes usually consist of thin metal plates or foils, or a thin metal coating applied to opposite surfaces of the dielectric. The dielectric may be a vacuum; a gas, such as air; a liquid, such as oil; or a solid, such as mica, plastics film, wax-impregnated paper, or a film formed on the surface of the electrode, or plate, by electro-chemical means.

To make the unit compact, a number of electrodes interleaved with layers of dielectric may be stacked together, with alternate electrodes connected to one terminal and the remainder to the other. This multi-plate, or stacked, technique (Fig. 6) is commonly used when the dielectric is a gas, a liquid, or a rigid solid such as mica.

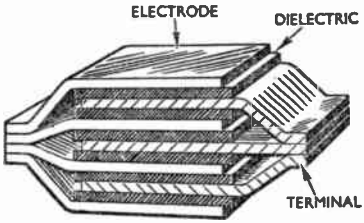


Fig. 6. Multi-plate capacitor showing the method of stacking the electrodes to provide a compact construction.

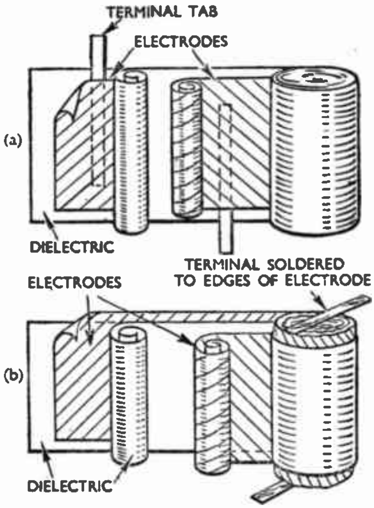


Fig. 7. Two forms of rolled capacitor showing assembly details when (*a*) the electrodes are buried, and (*b*) electrodes are extended or staggered.

With suitable materials, such as paper or plastics film, long strips together with similar strips of metal foil for the electrodes may be wound into a roll. The wound, or rolled, technique (Fig. 7) is much cheaper to produce than the stacked type.

The earliest form of capacitor was a glass jar (see LEYDEN JAR) coated on the inside and outside with metal foil, leaving a clear surface near the rim. It was invented to store electrostatic charges. Volta, the early experimenter, thought that the device had the property of condensing electricity and called it a "condenser," a name which came into general use. Over fifty years ago Kelvin suggested that the name was inappropriate, but it is only recently that it has been superseded by the word "capacitor."

Its property of capacitance C is proportional to the total effective area A of the electrodes, and inversely proportional to the thickness t of the dielectric. It is also proportional to the relative permittivity (dielectric constant) κ and may be expressed, $C \propto \frac{A\kappa}{t}$. If the non-uniformity of the electrostatic field near the edges of the electrodes be disregarded, then we may write $C = \frac{A\kappa}{3{\cdot}6\pi t}$, where A is expressed in square centimetres, t in centimetres and C in micro-micro-farads.

In the stacked construction, $A = na$, where n is the total number of layers of dielectric (one less than the number of conducting plates), and a is the overlapping area of one pair of plates.

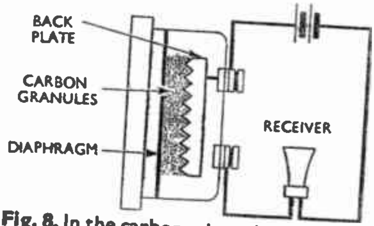


Fig. 8. In the carbon microphone, sound waves impinging on the diaphragm cause variation in the contact resistance of the carbon granules, producing variations in current in the external circuit which includes a receiver.

In the rolled construction, $A = (2m-1)\pi dw$, where m is the number of turns of each electrode (assumed equal), d is the mean diameter of the winding and w is the overlapping width of the electrodes (both in centimetres).

The volume υ of dielectric material per unit capacitance is $\frac{At}{C}$, so that if $C \propto \frac{A\kappa}{t}$, then $\upsilon \propto \frac{t^2}{\kappa}$. Also, if V is the safe working voltage of the capacitor and ε is the safe electric stress in the dielectric in volts per centimetre, then $t \propto \frac{V}{\varepsilon}$ and $\upsilon \propto \frac{V^2}{\kappa\varepsilon^2}$.

The size of a capacitor is not only of interest to the user from considerations of space, but also because size usually bears a close relationship to cost. The last equation given above is, therefore, of great interest to the designer and user. It shows firstly that, per unit capacitance, the size of a capacitor is proportional to the square of the working voltage, and secondly that it is inversely proportional to two properties of the dielectric: the relative permittivity and the electric strength. The latter property is the more important because it appears as a squared term.

For many materials the value of ε increases as the thickness decreases. Thus for impregnated paper about 0·03 mm. thick it may reach a value of 200 kV per mm., and for polystyrene films of the same thickness figures as high as 500 kV per mm. have been observed.

In D.C. circuits, another important property of the dielectric is its volume resistivity which determines the insulation resistance. If ρ is the volume resistivity in ohms per cm. per cm.^{2}, then the insulation resistance R is equal to $\frac{\rho t}{A}$ which, by substitution from $C \propto \frac{A\kappa}{t}$, may be written $R \propto \frac{\rho\kappa}{C}$. The insulation resistance per unit capacitance is therefore $\rho\kappa$.

For small values of capacitance, leakage over the surface of the dielectric at the edges becomes more important than that through the dielectric, but it does not lend itself to a simple formula.

In A.C. circuits, an important property of the dielectric is its power factor, to which is related the dielectric losses. At very high frequencies, this and the residual inductance of the electrodes and terminals are most important properties. If the power factor is cos φ, the equivalent shunt resistance across the capacitor is $\frac{1}{2\pi fC \cos\varphi}$, and the power loss at a working voltage V is $2\pi fC V^2 \cos\varphi$. Since C is proportional to $\frac{A\kappa}{t}$ and $V = t\varepsilon$, the power loss may be written: $P \propto 2\pi fA\kappa\, t\varepsilon^2 \cos\varphi$, and

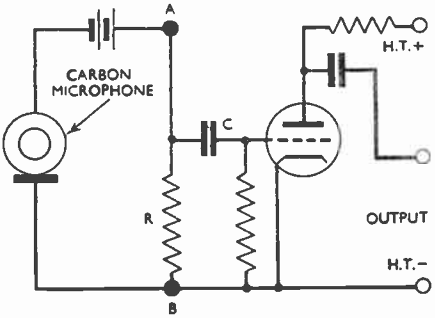


Fig. 9. Varying currents produced by sound waves on the diaphragm of the microphone are applied through a resistor *R*; corresponding alternating e.m.f.s are produced across *R* and are amplified by the triode.

the power loss per unit volume: $p \propto 2\pi f \varkappa \varepsilon^2 \cos \varphi$.

In general, therefore, it is necessary, at high frequencies, to reduce the working voltage in inverse proportion to the square root of the frequency. Thus a capacitor rated at 1,000 volts at 1 Mc/s should be run at no more than 100 volts at 100 Mc/s if the dissipation is to remain approximately the same. For a given working voltage, the product $\varkappa$ cos φ (sometimes called the loss factor) is a good indication of the quality of a dielectric for use at high frequencies. See CAPACITANCE, DIELECTRIC LOSS, FIXED CAPACITOR, VARIABLE CAPACITOR.

CAPACITY. See CAPACITANCE, CAPACITIVE.

CARBON MICROPHONE. Microphone working on the principle that the resistance of closely packed carbon granules varies under varying pressure. In Fig. 8 sound waves impinging on the diaphragm cause pressure variations to be exerted upon the carbon granules inserted between electrodes formed by the diaphragm and the back plate. A D.C. potential applied to the electrodes produces a current in the external circuit incorporating a receiver.

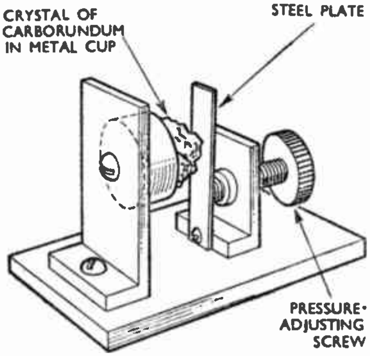


Fig. 10. In the carborundum detector a steel plate is held with fairly heavy pressure against a carborundum crystal secured in its cup by Wood's metal.

As the diaphragm vibrates at speech frequency, the contact resistance of the granules between the electrodes varies at the frequency of the diaphragm vibration. Therefore, the current through the receiver will rise and fall about a mean value, causing the receiver diaphragm to vibrate at the frequency of the microphone diaphragm. These principles are applied to the telephone.

When applied to radio broadcasting, the varying currents through the resistor *R* (Fig. 9) produce alternating e.m.f.s at the terminals *A* and *B* to which an amplifier is connected, the capacitor *C* preventing the D.C. potentials from reaching the amplifier. See MICROPHONE.

CARBON PICK-UP. Gramophone pick-up working on the principles of a carbon microphone. It is not in general use.

CARBORUNDUM CRYSTAL. Crystal of silicon-carbide used for detection of radio signals. See CARBORUNDUM DETECTOR.

CARBORUNDUM DETECTOR. Device for detecting radio-frequency signals; it consists of a carborundum crystal in contact with a steel plate,

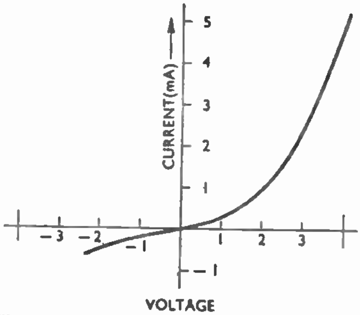


Fig. 11. Operating characteristic of a carborundum detector; best results are obtained when a small positive potential is applied, as in Fig. 12.

as shown in Fig. 10. Such a combination passes current more readily in one direction than in the other direction, and is therefore suitable for producing rectification. The carborundum detector has the advantage that a fairly heavy pressure is required between the steel plate and the crystal; hence it is not liable to be affected by mechanical vibration and it is thus stable in operation.

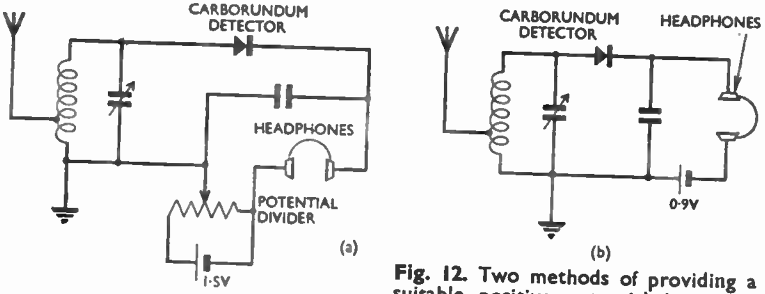


Fig. 12. Two methods of providing a suitable positive potential in a carborundum-detector circuit.

For optimum results a small positive potential is necessary, as will be seen from Fig. 11. To meet this requirement, the circuits of Figs. 12a and 12b are used. In the first, a potential divider is incorporated across a normal dry cell of 1½ volts e.m.f., and the slider adjusted until the most sensitive condition is obtained. The second arrangement uses a special cell of 0·9 volt, this being approximately the voltage that is required to bring the crystal to its most sensitive condition.

CARBORUNDUM RECTIFIER. See CARBORUNDUM DETECTOR.

CARDIOID DIAGRAM. Heart-shaped polar diagram obtained by combining the output of a loop- or frame-aerial with that of a simple vertical aerial. The diagram so obtained is of use in determining the "sense" of a bearing taken with direction-finding equipment (Fig. 14). See CARDIOID RECEPTION, DIRECTION-FINDING, POLAR DIAGRAM.

CARDIOID RECEPTION. Method of reception used in direction-finding whereby a loop-aerial is used in conjunction with a vertical aerial to produce a heart-shaped polar diagram capable of determining a bearing with "sense." The word "cardioid" is of Greek derivation and means heart-shaped.

The simplest form of direction-finder is a vertical loop-aerial capable of rotation about a vertical axis. On rotation of the coil, maximum signal strength is obtained when the plane of the loop points towards the sender, and minimum signal is heard when the plane of the loop is at right angles to the sender.

The polar diagram of the loop has the shape of the figure eight. The change of signal strength is much more

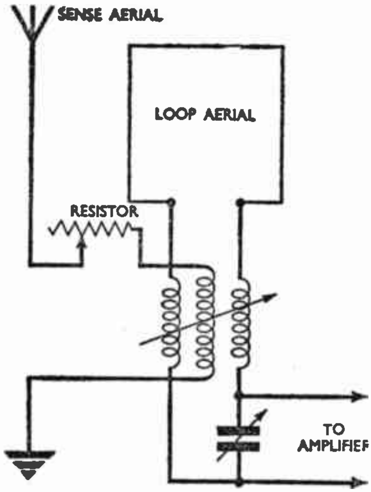


Fig. 13. Circuit by means of which a cardioid diagram is obtained. The resistor is adjusted so that the e.m.f. due to the sense aerial is made equal to that of the loop-aerial.

pronounced when minimum signals are being received than when maximum signal strength is obtained. Thus it is possible to determine a bearing more accurately from the zero-signal position, and in practice the zero-signal position is always used.

Unfortunately, there are two positions of the loop which will give zero signal, and the bearing taken may be not a true, but a reciprocal bearing. It is therefore necessary to find some means of determining which of the two bearings is the correct one; in other words, the correct sense must be determined.

To do this, both a loop-aerial and a simple vertical aerial are used; the polar diagram of the loop-aerial is in the shape of the figure eight, whilst that of the vertical aerial is circular, as it receives equally well in all directions.

In a sense-finding system, use is made of the maximum-signal-strength position of the loop diagram; for although the loop has two "maximum" positions, the current flow round the loop must be in opposite directions in the two positions as the side which formerly received the wave first now receives it last.

By coupling the loop-aerial and the vertical aerial to a second circuit, the loop voltages will add to the aerial voltages in one maximum position and will oppose them in the other. To obtain correct phase relationships in the second circuit, that is, to have the loop e.m.f. in phase or 180 deg. out of phase with the e.m.f. from the vertical aerial, an alteration in phase by 90 deg. of one e.m.f. relative to the other must be brought about.

This is achieved by inductively coupling the loop to the vertical aerial. Fig. 13 illustrates a typical circuit. The resultant polar diagram now becomes a combination of the loop- and vertical-aerial diagrams and may be obtained by adding the two vectorially. The diagram so obtained is a heart-shaped figure (Fig. 14), whose zero-signal point occurs when the loop is pointed towards the sender.

The zero of the cardioid is at 90 deg. from either of the zeros obtained with the loop alone, and, providing the

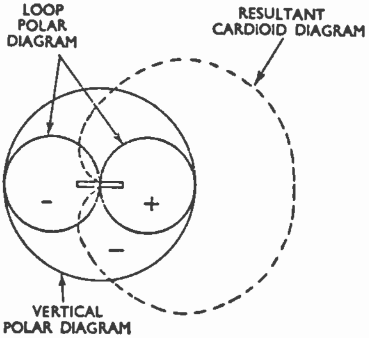


Fig. 14. Cardioid diagram representing the effect of coupling a short vertical aerial of correct size to a loop-aerial. There is now only one maximum and one minimum condition, both in line with the direction of the loop. The vertical aerial is normally switched in only to determine sense.

cardioid is perfect in shape, it may be used directly to take sensed bearings. But in practice the cardioid is rarely efficient for this purpose, and the loop alone is generally used to obtain a bearing, the cardioid being switched in only to determine the sense.

It is important to ensure that the e.m.f. at the amplifier due to the vertical aerial is exactly equal to that due to the loop, otherwise distortion of the cardioid results. If the loop e.m.f. is too small, zero-signal point is very flat; if it is too large, several zeros may appear.

To obtain this necessary equality of e.m.f.s a small, variable resistor is usually included in series with the vertical aerial and adjusted as required. The resistor also serves to maintain the correct phase relationships between aerial and loop. See DIRECTION-FINDING, LOOP DIRECTION-FINDER.

CARRIER. Carrier-wave transmission system for signalling over physical circuits; for example, carrier-wave transmission through telephone lines. The term is also used as an abbreviation for CARRIER WAVE (q.v.).

CARRIER AND DOUBLE-SIDE-BAND SYSTEM. Amplitude-modulated transmission in which the carrier and all the sideband waves are radiated.

CARRIER AND SINGLE-SIDE-BAND SYSTEM. Amplitude-modulated transmission in which the modulated wave contains the carrier wave and either the upper or lower sideband waves. The other sideband waves are eliminated by a filter. See SINGLE-SIDEBAND MODULATION.

CARRIER FREQUENCY. Frequency of the carrier wave. See CARRIER WAVE, CARRIER-WAVE TRANSMISSION.

CARRIER TELEGRAPHY. Telegraphic code transmission utilizing the modulation (generally at audio-frequencies) of a radio-frequency carrier current.

CARRIER TELEPHONY. Transmission of speech frequencies utilizing the modulation of a radio-frequency carrier current.

CARRIER TERMINALS. Terminals of a modulator to which the carrier wave is applied to be modulated. See MODULATOR.

CARRIER WAVE. Wave, in any modulation system, some characteristic of which is varied by the modulating wave. There are three waves in a modulation system; the wave of which some characteristic, such as amplitude, frequency, phase or duration, is changed; second, the wave which alters a characteristic of the carrier wave; and third, the wave resulting from modulation. In a carrier-wave transmission system, one of the characteristics of the carrier wave is changed by the modulating wave.

The modulated wave usually contains a component with the same frequency as that which, in the process of modulation, had its characteristic altered by the modulating wave, and this also is called the carrier wave. In amplitude modulation, the carrier wave in the modulated wave has a constant amplitude, and is accompanied by sideband waves (see AMPLITUDE MODULATION). In suppressed-carrier modulation, the carrier wave in the modulated wave is suppressed. In frequency and phase modulation, the carrier wave appears in the modulated wave, but its amplitude may differ according to the nature of the modulating wave and may even be zero (see FREQUENCY MODULATION, PHASE MODULATION, SIDEBAND).

In frequency-changing, the wave applied to the carrier terminals of a modulator is sometimes called the carrier wave. See CARRIER, CARRIER-WAVE TRANSMISSION, COMMUTATION MODULATION, MODULATION, PULSE MODULATION.

CARRIER-WAVE TRANSMISSION. Electrical transmission utilizing modulation of a single-frequency carrier current.

CASCADE CONNEXION. Circuit connexion in which the output from one circuit element or circuit elements forms the input to another similar circuit element or group of circuit elements. An amplifier is formed by the cascade connexion of valve stages, the output from one valve forming the input to the next.

In filters with several sections, there may be said to be a cascade connexion of sections, since the output from one section forms the input to the next.

In a ladder network there is a cascade connexion of similarly related groups of circuit elements, each comprising a section. See AMPLIFIER, FILTER, LADDER NETWORK.

CATCHER. Electrode and resonant chamber of a valve used for the generation and amplification of centimetric waves. It is equivalent to the anode in a class-C amplifier. The electrons arrive in bunches, cause pulses of current to reach the catcher, and set up resonating currents in it. See BUNCHER, BUNCHING, KLYSTRON, RHUMBATRON.

CATHETRON. American name for a valve in which the control grid is external to the bulb and so arranged that changes of potential on the grid tend to influence the flow of current between other electrodes within the bulb.

Claims have been made, from time to time, that it is possible to control the flow of current by means of a grid which, while it produces a field within a valve, is nevertheless situated outside the valve. A soft valve would be essential; in a hard valve with a glass bulb the electrons would collect on the glass and form a space charge which would not be altered by the grid potential. Apparently, not a great deal of success has been achieved, and so the cathetron has not been used in practice.

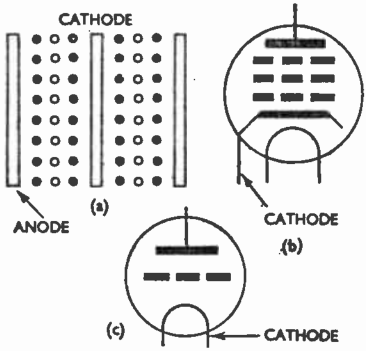


Fig. 15. Cross-section of electrodes in a pentode (*a*), showing the cathode at the centre. Diagrammatic representations are: (*b*) indirectly heated cathode and (*c*) filament cathode in a triode.

CATHODE. Electrode, of a glow-tube, tube, or valve, which is held at a negative potential with respect to the anode. The cathode of a valve, cathode-ray tube or X-ray tube is the electrode which emits electrons. This definition brings out the point that in a glow-tube, in which the conduction of electricity between anode and cathode is due to the ionization of a gas, the cathode does not emit primary electrons as it does in valves and tubes (see GLOW-TUBE, IONIZATION).

The cathode of a valve or tube may be in the form of a wire which is heated or it may be a metal tube, coated with certain metallic oxides, which is heated by a separate heater (Fig. 15b). In the former case, the cathode is known as a "filament"; in the latter, it is called an "indirectly heated cathode." In both these cases, the heating of a substance causes it to emit electrons which form in a cloud around the cathode and conduct electricity between cathode and anode, or between cathode and other electrodes.

The life of a valve depends upon how long the cathode continues to emit electrons. The cathode in a gas-filled valve may be destroyed by ion-bombardment if the voltage drop exceeds a certain value. In valves handling large power, the anode voltage is tens of thousands of volts and the residual gas may contain ions which fall on to the cathode at enormous velocity. This makes it necessary to use filament-type cathodes made of pure tungsten in such valves, as any coating on the filament would be destroyed. See EMISSION, FILAMENT, GAS-FILLED VALVE, INDIRECTLY HEATED CATHODE, VALVE.

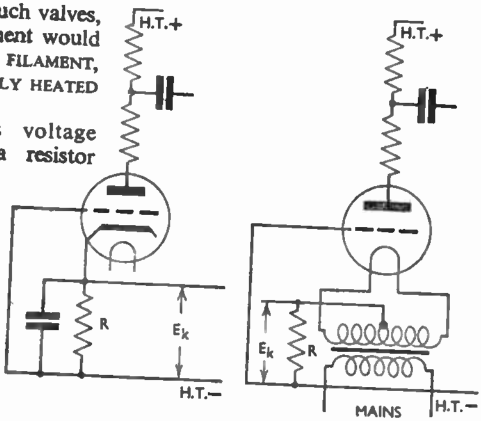


Fig. 16. Provision of cathode bias when the cathode is (*left*) indirectly heated and (*right*) a filament. The correct value of cathode resistor *R* is obtained by dividing the required grid-bias voltage E_k by the cathode current that flows with that value of bias.

CATHODE BIAS. Bias voltage obtained by connecting a resistor between cathode and the negative terminal of the high-tension supply. The grid-cathode potential in many forms of amplifier must be such that the grid is negative with respect to the cathode. Before the introduction of the indirectly heated cathode, it was common to connect one side of the filament to earth and to apply a negative potential to the grid.

With the indirectly heated cathode it is possible to earth the grid so far as bias potential is concerned, and make the cathode positive. This is conveniently done, as shown in Fig. 16, by causing the cathode current to pass through a resistor, thus making the non-earthy end positive with respect to earth. The great advantage of the indirectly heated cathode is that the valves in an amplifier may be given different values of cathode bias and yet be supplied by heater power from a common source.

When filament-type valves are to be given cathode bias, the second arrangement shown in Fig. 16 is used; if several valves require different values of cathode bias, each must have a separate transformer.

So far as steady bias potential is concerned, it makes no difference whether the cathode-bias resistor is shunted by a capacitor or not. But where the alternating potential of the cathode is concerned, the capacitor may have a profound effect; when it is connected, there is no negative-current feedback; when it is not connected, negative-current feedback occurs. See AMPLIFIER, AUTOMATIC GRID-BIAS, CURRENT FEEDBACK, FILAMENT, GRID BIAS, INDIRECTLY HEATED CATHODE.

CATHODE-BIAS RESISTOR. Resistor in cathode-bias circuits which maintains the cathode at a positive bias with respect to the grid. See CATHODE BIAS.

CATHODE COUPLING. Form of interstage connexion in a valve amplifier, in which the output from the stage is taken from the cathode. Thus a cathode-coupled amplifier comprises a number of cathode-follower ampli-

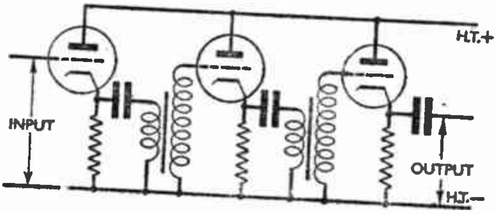


Fig. 17. Amplifier using cathode coupling. Although the transformers step up the voltage the circuit is that of a power amplifier.

fiers in cascade (Fig. 17). It should be noted that a cathode follower is not a voltage amplifier, although power is amplified; but it is possible to include transformers in such an amplifier to obtain a voltage gain. See CATHODE FOLLOWER.

CATHODE CURRENT. Total current flowing to and from the cathode electrode. No distinction is made between the steady and alternating components of the cathode current, such as that made concerning anode current (see ANODE CURRENT, ANODE-FEED CURRENT). The steady component of the cathode current is greater than the anode-feed current by the amount of other electrode currents, such as screen current and suppressor-grid current.

The control-grid current, when the control grid is positive with respect to cathode, must also be added to the cathode current. Thus the cathode current is essentially the total space current. See GRID CURRENT, SCREEN-GRID CURRENT, SPACE CURRENT.

CATHODE EFFICIENCY. Number expressing the milliamperes of emission per watt of power used in heating the cathode. The table below gives the cathode efficiency in terms of various materials used in cathodes of valves.

Tungsten and thoriated tungsten are used for filaments, oxide-coated materials for indirectly heated cathodes.

Tungsten filaments, in spite of their lower efficiency, are used because they alone are robust enough to withstand positive ion bombardment when the anode volts are of the order of 6–10 kV. That such voltages must be used when the anode dissipation is in the tens-of-kilowatts range is obvious, for lower voltages would require larger anode-feed currents, and hence greater emission, which would in turn imply more filament power. See EMISSION, FILAMENT, INDIRECTLY HEATED CATHODE, WORK FUNCTION.

Type of Emitter	*Normal Operating Temperature (deg. K.)*	*Cathode Efficiency (milliamperes per watt of heating power)*
Tungsten	2,450–2,600	3–15
Thoriated Tungsten ..	1,900	62·5
Oxide-coated Materials..	1,100–1,700	50–125

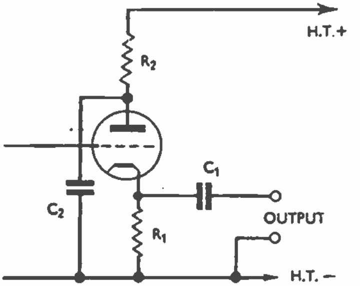


Fig. 18. Simple cathode-follower circuit in which the coupling components are resistor R_1 and capacitor C_1.

CATHODE FOLLOWER. Valve whose output is delivered from the cathode instead of from the anode circuit. Fig. 18 illustrates a typical cathode-follower circuit with a coupling resistance in series between cathode and earth; the coupling components are R_1 and C_1, the latter being the equivalent of the grid capacitor in a normal resistance-capacitance coupling; R_2 and C_2 are merely the decoupling components.

The special characteristics of the cathode follower are these: (1) its output voltage is in phase with that of the input, unlike the normal amplifying valve with output taken from the anode, where the voltages are in opposite phase; (2) the cathode follower gives no voltage gain but considerable negative feedback, and (3) its output impedance is low. These features make the cathode follower valuable for various special tasks, as in television circuits, passing signals into a low-impedance load such as a transmission line without a matching transformer, and the like.

CATHODE MODULATION. Amplitude modulation in which the modulating wave is applied to the cathode circuit of the modulated amplifier. The circuit (Fig. 19) may be regarded as a combination of a GRID MODULATOR (q.v.) and an ANODE MODULATOR (q.v.). When the modulating-wave voltage increases, the grid/cathode potential becomes more negative and the anode current is reduced; moreover the anode/cathode potential also is decreased, and this tends to decrease the anode current. Conversely, when the modulating-wave voltage decreases, the anode current rises. Thus the gain of the modulated amplifier varies in accordance with the form of the modulating wave, and the output of the modulating amplifier is an amplitude-modulated wave.

Cathode modulation is better than grid modulation and has the same advantage of economy in modulating-wave power; but the quality is inferior to that of anode modulation.

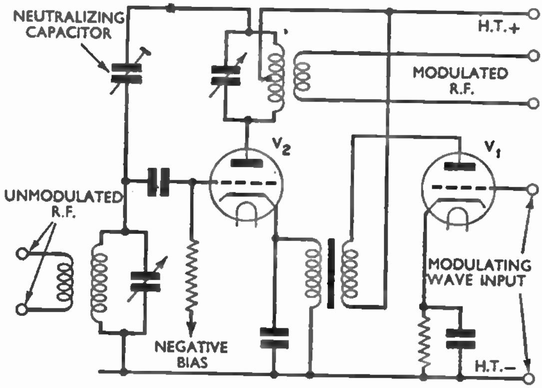


Fig. 19. Cathode-modulation circuit in which V_1 is the modulator valve and V_2 the modulated amplifier. The arrangement may be regarded as a combination of grid modulator and anode modulator.

CATHODE POTENTIAL. Difference of potential between the cathode electrode and earth. A positive bias voltage on the cathode when the grid is earthed produces the same conditions as when the cathode is earthed and a negative bias is applied to the grid. See CATHODE BIAS.

CATHODE-RAY DIRECTION-FINDER. Direction-finder in which the bearing of the distant sender is displayed directly on the screen of a cathode-ray tube. In its basic form, such a direction-finder receives signals from a pair of directional aerials at right angles and applies them to the X and Y plates of the tube. If care is taken to ensure that the signals remain in phase, the spot traces out a line which is the resultant of the two applied forces, and is in fact at an angle equivalent to the required bearing. See CATHODE-RAY TUBE.

CATHODE-RAY OSCILLOGRAPH. See OSCILLOGRAPH.

CATHODE-RAY OSCILLOSCOPE. See OSCILLOSCOPE.

CATHODE-RAY TUBE. Vacuum tube used extensively in industry and science for the investigation of mechanical, electrical and biological problems (see OSCILLOGRAPH). A beam of electrons from the cathode is focused on a screen inside the tube, and the point of the beam traces the wave form of the phenomenon being examined. The cathode-ray tube also plays an important part in television reception and in the application of radar.

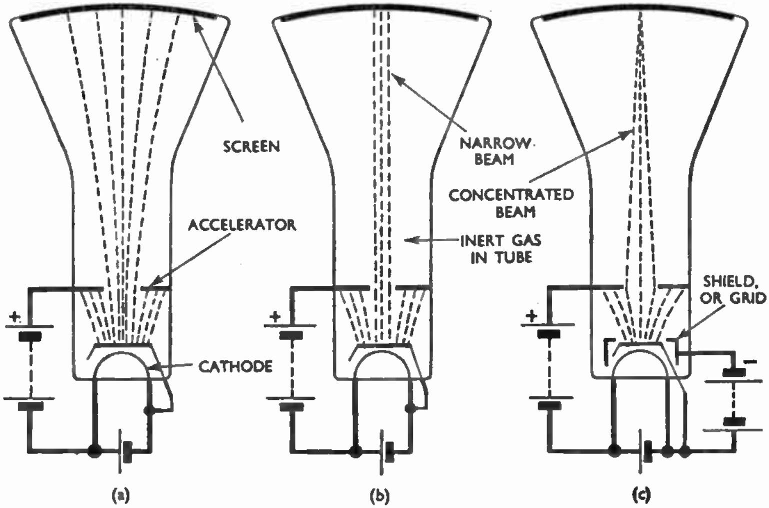


Fig. 20. Principles of electron emission in a cathode-ray tube; (*a*) a proportion of the electrons passes through the aperture in the positively charged accelerator to impinge on the fluorescent screen. In a soft-vacuum tube focusing is achieved (*b*) by the release of positive ions from an inert gas, and (*c*) by the additional effect of a negatively charged shield which surrounds the cathode.

In construction and operation, the cathode-ray tube resembles a multi-electrode valve. The cathode, when heated, emits electrons which are attracted to a positively charged anode or accelerator (Fig. 20a). A number of electrons pass through an aperture in the accelerator to the envelope of the tube.

If the accelerator potential is increased, more electrons pass through the aperture, and their velocity is increased. By coating the inside of the tube with a substance such as zinc sulphide, a screen is formed which becomes fluorescent when electrons fall upon it (see FLUORESCENT SCREEN).

If an inert gas, for example, argon, is introduced into the evacuated tube (see SOFT-VACUUM VALVE), the bombardment of the gas molecules by the electrons releases positive ions. These are reluctant to leave the central path of the beam and, by virtue of their positive charge, attract those electrons which spread out fan-wise from

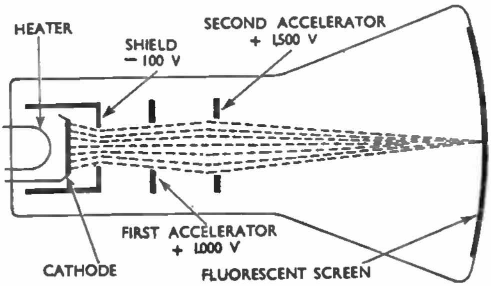


Fig. 21. Fundamentals of an indirectly heated hard-vacuum cathode-ray tube. Electron emission is controlled by varying shield voltage; focusing is effected by varying the positive voltage on one of the two accelerators.

the centre. The effect is to concentrate the electrons into a narrow beam (Fig. 20b), thus increasing the brilliance of the glow on the screen.

The concentration of the beam can be increased by surrounding the cathode with a negatively charged shield (Fig. 20c), the effect of which is to bend the rays inwards, producing a pencil of light on the screen. If the shield potential is adjustable, it has the additional function of controlling the intensity of the beam; if the negative potential is increased sufficiently, the beam can be extinguished entirely (see GRID BIAS).

A soft, or low-vacuum, tube produces a brilliant image for a relatively low accelerator voltage (50–500 volts), but it has a short life because the ionized gas causes deterioration of the cathode.

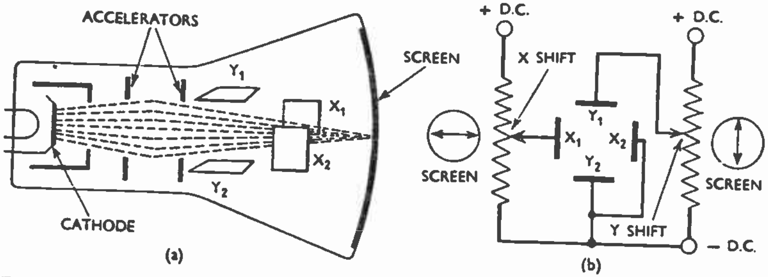


Fig. 22. Movement of the point of the beam over the screen of a cathode-ray tube is effected by two pairs of deflector plates (*a*). Adjustment of X-shift control (*b*) causes horizontal deflection, and of Y-shift control vertical deflection.

Another method of focusing is by using two or more accelerators, these having positive potentials of different values (Fig. 21). The electric fields created around these accelerators have the effect of bending the rays inwards, causing them to strike the screen at a focal point.

A stationary spot of light on a screen serves no useful purpose. If, however, it is deflected over the surface of the screen, it traces the wave form of the deflecting forces just as a recording thermometer traces the variations in temperature on a chart.

If two pairs of deflecting plates are placed in the path of the beam (Fig. 22a) the point of the beam can be deflected over the surface of the screen by varying the potentials applied to the plates (see DEFLECTOR PLATES). A voltage applied to the X plates causes horizontal deflection. If the Y plates are placed in a plane at right angles to that of the X plates, the Y plates cause vertical deflection.

When investigating a wave form, it is desirable for the initial operating point of the beam to be concentrated in the centre of the screen. This can be effected by connecting a source of D.C. potential to the plates as shown in Fig. 22b. The potential-divider controls are called the X shift and Y shift respectively. Varying the X shift causes the beam to move to the right or left; varying the Y shift causes it to move up or down.

The voltage to be examined is normally connected to the Y plates. Assuming no external voltage on the X plates (other than the X-shift voltage), an A.C. voltage having a frequency above about 10 c/s produces a vertical trace on the screen (Fig. 23), the length of the trace being proportional to the deflecting voltage. Such a trace indicates amplitude and not the wave form of the external voltage.

To examine a wave form, it is

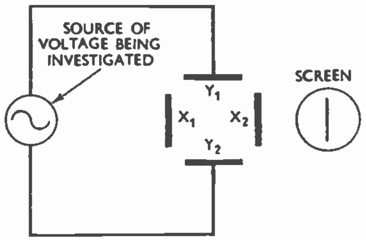


Fig. 23. A vertical trace is produced on the screen of a C.R.T. with an alternating voltage on Y plates and no alternating voltage on X plates.

necessary to indicate how the vertical movement varies with respect to time. For this purpose, a time-base voltage is applied to the X plates; the time-base voltage has a saw-tooth wave form (see RELAXATION OSCILLATOR). The effect of applying such a voltage to the X plates is to cause the beam to be deflected horizontally at comparatively low velocity and then to return almost instantaneously to the point at which deflection began. This sudden return is called the FLY-BACK (q.v.) and its motion is usually invisible.

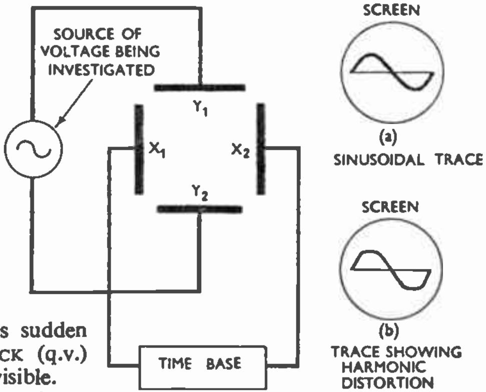


Fig. 24. Typical examples of the trace that may be produced on the screen of a cathode-ray tube when the voltage being examined is (*a*) sinusoidal, and (*b*) non-sinusoidal.

For a sinusoidal voltage on the Y plates and a saw-toothed voltage on the X plates, the trace of the screen takes the form of Fig. 24a. If the Y voltage is not sinusoidal (see HARMONIC DISTORTION), the nature of the distortion will be indicated on the trace (Fig. 24b).

For certain purposes, notably television reception, it is more usual to employ electromagnetic deflection instead of electrostatic deflection. In such cases, two pairs of deflector coils are placed outside the tube and so arranged that their respective electromagnetic fields produce horizontal and vertical deflection (see DEFLECTOR COILS). The principles of operation are similar to those appertaining to deflector plates.

A cathode-ray tube is termed an oscilloscope when used for measuring purposes; if permanent records of the trace are needed, a camera may be associated with the tube, in which case the instrument as a whole is known as an oscillograph, and the record thus obtained is called an oscillogram.

CATHODE SPUTTERING. Dislodgment from a cathode of particles of molecular size due to bombardment by positive ions of high energy. This eventually causes disintegration of the cathode, and is an anathema to valve makers and users.

CATHODE VOLTAGE. Synonym for CATHODE POTENTIAL.

CATION. Positively charged ion. A cation moves towards the negative electrode in an electrolytic cell (Fig. 25). See IONIZATION.

CAT'S WHISKER. Name given to the light spring contact used with certain types of CRYSTAL DETECTOR (q.v.).

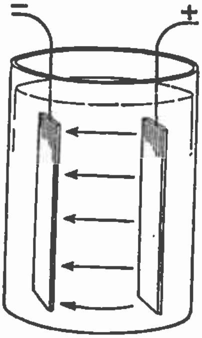


Fig. 25. In an electrolytic cell the cations, being positive, migrate to the negative electrode.

CAVITY RESONANCE. In an electro-acoustic device, for example, a loudspeaker or microphone, an artificial resonance produced by the formation of a cavity in the mechanical circuit to compensate for attenuation distortion in the circuit.

CAVITY RESONATOR. Space, usually simple in shape and enclosed by conducting surfaces, in which standing magnetic waves can be excited. See MAGNETRON, RHUMBATRON.

C-BATTERY. American term for GRID-BIAS BATTERY.

CELL. Device in which some action takes place to produce an electromotive force between electrodes forming the essential part of the cell. See ACCUMULATOR CELL, PHOTOCELL, PRIMARY CELL, SECONDARY CELL.

CENTIMETRE-GRAMME-SECOND SYSTEM OF UNITS. System which includes all units which are based on the centimetre as the measure of length, the gramme as the unit of weight, and the second as the time unit.

CENTIMETRIC WAVE. Radio wave of 1–10 cm. wavelength, that is, within a frequency range of 3,000–30,000 Mc/s. Centimetric waves are never refracted or reflected back to earth by the ionosphere and communication is established by means of the ground ray alone.

In general, reception is possible only within optical range of the sender, although signals have been received at distances considerably beyond the optical. Such reception appears to coincide with conditions of temperature inversion in the lower atmosphere.

The propagation characteristics of centimetric waves are similar to those of very high-frequency waves, the ground-ray attenuation increasing rapidly with frequency. See ABSORPTION, SUPER-FREQUENCY WAVE, VERY HIGH-FREQUENCY WAVE.

CERAMIC CAPACITOR. Form of capacitor having ceramic dielectric. See FIXED CAPACITOR, TRIMMER, VARIABLE CAPACITOR.

C.G.S. Abbreviation for centimetre-gramme-second. See CENTIMETRE-GRAMME-SECOND SYSTEM OF UNITS.

CHANNEL. Term based on a concept implying a frequency band wide enough to contain all or some of the frequencies of a group of waves representing a message transmitted by modulating a carrier wave, the frequency of which is not changed by the modulation.

When intelligence is communicated by electrical means, the communication is carried by a group of waves of different frequencies.

In order that several messages may be transmitted simultaneously through the same wave-transmitting medium, whether by radio, by physical conductors or by wave guides, each group of waves of comparable level must

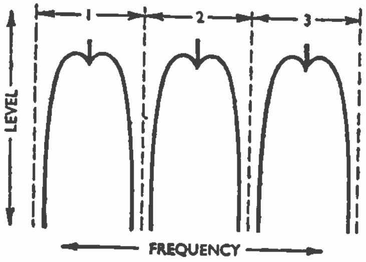


Fig. 26. Ideal arrangement of channels in a three-programme broadcasting system. Each curve represents the average level of sideband waves, and the centre line the carrier level.

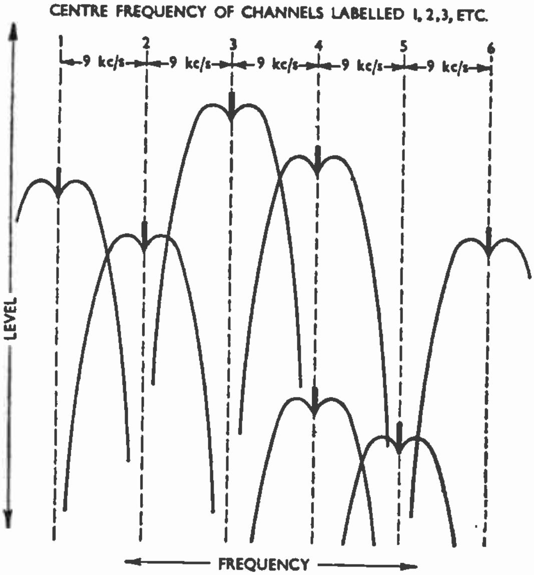


Fig. 27. Imaginary but typical illustration (in comparison with Fig. 26) of conditions in European broadcasting. In this case field strengths vary widely and, for example, channel 5 is occupied by a very low-power (or a very distant) sender which is blotted out by senders using channels 4 and 6.

occupy a different frequency band. In these circumstances, a selective receiver can pick up one group of waves and reject all other groups, and thus reproduce one message to the exclusion of all others (see SELECTIVITY). The different frequency bands occupied by the groups of waves representing different messages can be said to flow in different channels—in this case communication channels.

The terms "message" and "intelligence" can mean private telephone or telegraph messages on both sound and vision broadcast programmes, as well as the groups of waves used for the detection of otherwise invisible objects as in radar technique.

In the accompanying diagram of the diffusion of sound programmes in a broadcasting system (Fig. 26), field strength at any geographical location is plotted on a vertical axis, and wave-frequency on the horizontal axis. Fig. 26 illustrates an ideal state of affairs; but, in fact, the channels used by broadcasting stations in Europe are sometimes spaced too closely together and the sidebands overlap (Fig. 27). Because of this sideband overlap, the receiver must inevitably have a narrow band width and selects only those waves close to the carrier wave, cutting off those which represent the higher audio frequencies. The result is reproduction which lacks extreme "top." Only when a local station creates such an overwhelmingly strong field at the receiver that it dominates interference from the senders using frequency-contiguous channels, is it possible to get high-fidelity results. See CARRIER-WAVE TRANSMISSION, MODULATION, SIDEBAND, SIDEBAND WAVE.

CHANNEL DIVERSITY. See DIVERSITY SYSTEM.

CHARACTERISTIC DISTORTION. Distortion of the code units in a telegraphy transmission system. See MORSE CODE.

CHARACTERISTIC CURVE. Curve illustrating the manner in which the current of a valve electrode depends upon its potential or the potential of another electrode, all other potentials remaining constant.

CHARACTERISTIC IMPEDANCE. Iterative impedance of a quadripole when this has the same value at both pairs of terminals. Fig. 28 illustrates a quadripole, which may be either a

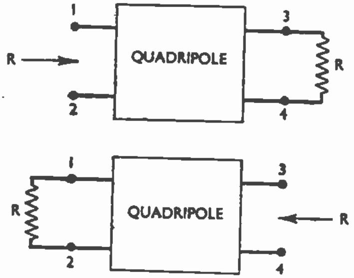


Fig. 28. When a quadripole has the same iterative impedance *R* measured at terminals 1 and 2 (terminals 3 and 4 being shunted by a resistance *R*) as measured at 3 and 4 (with 1 and 2 shunted), this equal iterative impedance is called the characteristic impedance of the quadripole.

network containing lumped reactance elements or a uniform transmission line, in which the iterative impedance measured at terminals 1 and 2 (with terminals 3 and 4 terminated in a resistance equal to the iterative impedance) is the same as that measured at terminals 3 and 4 (with terminals 1 and 2 terminated in a resistance equal to the iterative impedance). In this case, the iterative impedance is called the characteristic impedance of the quadripole to classify it as a particular form of iterative impedance (see ITERATIVE IMPEDANCE).

A quadripole which exhibits the same iterative impedance at both pairs of terminals must be symmetrical in itself; thus a filter section (Fig. 29) or a transmission line has a special iterative impedance, called its characteristic impedance. Fig. 30 illustrates the basic characteristics of a transmission line (see ARTIFICIAL LINE). Each series-inductive element and shunt-capacitive element, as well as the series-resistive element, is considered to be infinitely small; but there is an infinite number of elements.

As each shunt element subtracts a small current from the current flowing in the series arm, the series current will eventually be reduced to zero. There is thus no voltage across the conductors at the end of an infinitely long line. (In practice, infinite length can be considered to imply a line so long that the received voltage is substantively zero, although it must have some finite value, however small.)

Assuming a zero voltage at the end of the infinitely long line suggests that the sending-end impedance of the line will be the same whether the line end is short-circuited or open-circuited. In other words, the line is effectively terminated by a number of sections representing the line. Thus the infinitely long line is effectively terminated by its characteristic impedance, from which it may be concluded that the impedance of an infinitely long line is effectively isolated from its sending end by the infinite distance of separation. There can be no reflected wave from it; therefore, a line of finite length, terminated by a resistance equal to the characteristic impedance of the line, has no reflected wave to interfere with the sending-end impedance; apart from losses in the line itself, all the power fed into the sending end of a line, which is terminated in a resistance equal to the characteristic impedance of the line, is absorbed by this resistance.

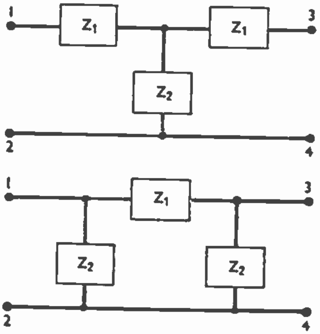


Fig. 29. Symmetrical filters having identical iterative impedance whether measured at terminals 1 and 2 or 3 and 4; this impedance is the characteristic impedance of the filter section.

It is, therefore, apparent that in feeding power to a load through a line, or through a cascade of symmetrical network sections, the best matching (i.e. maximum transfer of power to the load) occurs when the load has a resistance equal to the characteristic impedance of the line or network sections.

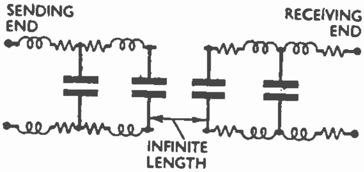


Fig. 30. Representation of a uniform transmission line of infinite length, consisting of series resistive and inductive elements and shunt capacitive elements. Voltage at the receiver is zero, impedance of the line being equal to its characteristic impedance.

The value of the characteristic impedance of a line or network depends upon the frequency of the waves passing through it. At frequencies for which the ratios of resistance per unit length to series reactance per unit length, and of leakance to shunt susceptance, are small, the characteristic impedance is $\sqrt{L/C}$, where L is the inductance and C the capacitance of the line per unit length. At very low frequencies (or D.C.), when the ratios specified are large, the characteristic impedance of the line approaches a value $\sqrt{R/G}$, where R is the resistance and G the leakance per unit length. In nearly all practical circumstances it is legitimate to take $\sqrt{L/C}$ as the characteristic impedance. See ITERATIVE IMPEDANCE, QUADRIPOLE, TRANSMISSION LINE.

CHARGE OF ELECTRICITY. Condition of electron excess or deficiency. If the number of "loose" electrons in a conductor is above the normal number, the conductor is said to be negatively charged; if the number is below normal, then the charge is called positive. The amount of an electric charge is measured in the unit of quantity, the coulomb. See COULOMB, ELECTROSTATICS.

CHARGING CURRENT. Current passed through an accumulator cell during the process of charging. The term may be used also to denote the direct current flowing into a capacitor; if there is danger of confusion, such a charging current should be described as a capacitor-charging current.

CHASSIS. Essential parts of a receiver or other apparatus, without cabinet or other container. It usually consists of a shallow metal tray, inverted as shown in Fig. 31, with large components such as variable capacitors mounted on the upper surface and small ones, such as resistors, underneath.

The metal tray, itself often described as a chassis, is customarily of mild steel with a non-rusting finish such as cadmium plating. Where large numbers are required to the same design, it is produced by stamping from sheet

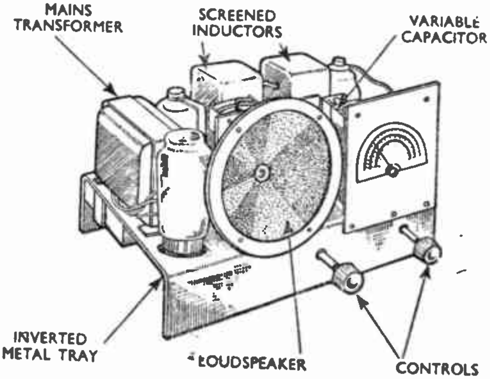


Fig. 31. Typical radio receiver chassis showing large components mounted on the upper surface of the metal tray, the smaller ones being accommodated underneath it.

metal. For smaller numbers, the metal blank is cut out with a guillotine and shaped on a bending machine.

CHECK RECEIVER. Receiver used to check the quality of a transmission, usually in close proximity to the sender.

CHEESE AERIAL. Reflector shaped as a sector of a paraboloid, as shown in Fig. 32, and containing a half-wave dipole; it is used at very high frequencies. The system produces a fan-shaped polar diagram, useful in radar and certain types of landing aids for aircraft, because it spreads out broadly in one plane but is narrowly defined in a direction at right-angles to the first.

CHOKE. Fixed inductor used generally in association with one or more capacitors to restrict alternating currents to a particular path. At audio frequencies the chokes used require high inductance, and have laminated-iron cores; but at radio frequencies a smaller inductance is adequate, and air or iron-dust cores are used.

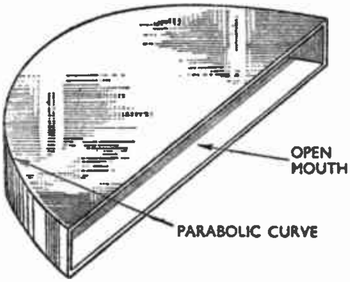


Fig. 32. Cheese aerial reflector as used for the production of narrow-beam radiation of centimetric waves from a half-wave dipole.

CHOKE COIL. Synonym for FIXED INDUCTOR.

CHOKE CONTROL. System of modulation. See ANODE MODULATOR.

CHOKE COUPLING. Synonym for INDUCTIVE COUPLING.

CHOKING COIL. Synonym for FIXED INDUCTOR.

CHOPPER. Device used for the production of A2 waves. The chopper

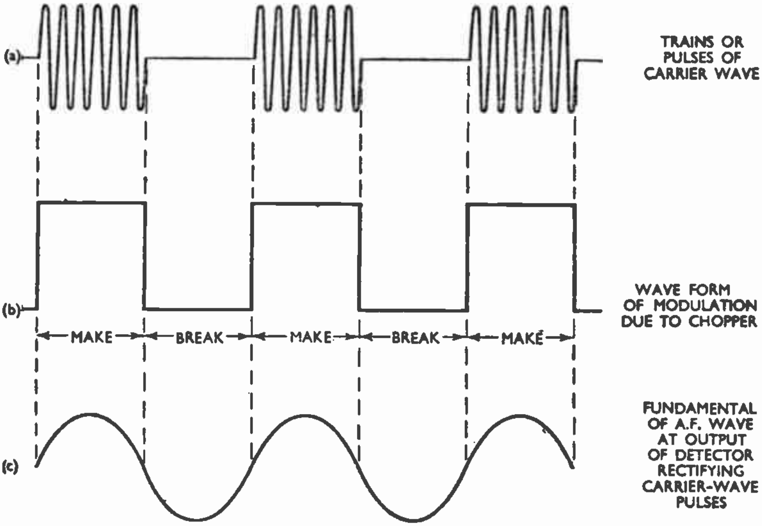


Fig. 33. Diagram showing a carrier wave (*a*) and the effect of a chopper (*b*). The audio-frequency wave (*c*), reproduced in the receiver, continues so long as the key is closed, thus messages may be transmitted by key and chopper in combination.

makes and breaks the circuit in which the carrier wave flows, so that the carrier wave is transmitted in periodic wave-trains. Fig. 33 illustrates the form of the carrier wave as transmitted; this is a form of pulse modulation because the time for which the carrier wave exists is the characteristic that is varied. See CARRIER-WAVE TRANSMISSION, MODULATION, PULSE MODULATION, TYPE A2 WAVE.

CIRCUIT. Path through which electricity flows continuously in a certain direction, or in which it flows alternately in one and then the other direction. A circuit may contain many branches but, if there is a single source of electricity, the current flowing from the source returns to the source and flows in a circuit connecting the terminals of the source. See ELECTROMOTIVE FORCE, NETWORK.

CIRCUIT-ELEMENT. Ideal resistor, inductor or capacitor considered as having respectively resistance, inductance and capacitance, and no other characteristic. In circuit theory it is desirable to assume that the circuit elements are "pure"—that a resistor has resistance but no reactance, and that a reactor has reactance but no resistance. It is not possible, however, to manufacture resistors that have no reactance, or reactors that have no resistance (see COMPONENT).

The reactance of a resistor becomes comparable with its resistance when the alternating currents flowing in it have very high frequencies. A resistor, whether it is wire-wound or of the carbon type, has both capacitance and inductance; and these can modify the impedance of the resistor when the wave frequency is high. All capacitors have resistance and inductance, although these are of relatively very small magnitude. The resistance of an inductor is often an extremely important characteristic of it (see Q-FACTOR).

Components which are used in practice as resistors and reactors may be considered as made up of circuit elements (Fig. 34). Naturally, in many cases—notably when the wave frequency is low—it is permissible to overlook the reactive properties of resistors and the resistive property of capacitors; it is, however, seldom permissible to overlook the resistive properties of inductors, except in dealing with simplified conceptions, for the Q-factors of inductors are usually lower than those of capacitors. See POWER FACTOR, Q-FACTOR, REACTANCE, RESISTANCE.

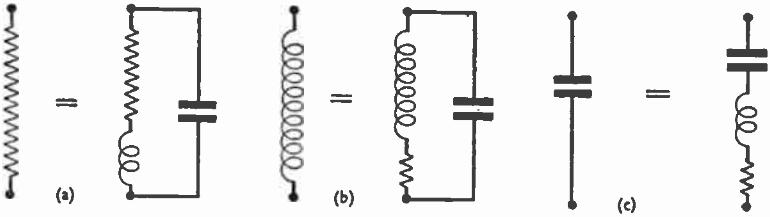


Fig. 34. Conventional representation of (*a*) resistor, (*b*) inductor and (*c*) capacitor as circuit components, together with their respective equivalent networks containing the reactive and resistive circuit elements which are inherent in them.

CIRCULARLY POLARIZED WAVE. Radio-wave whose plane of polarization is rotating from a vertical to a horizontal plane. Such waves are important only when the reception of short-wave stations at long distances is attempted. See CIRCULAR POLARIZATION, POLARIZATION.

CIRCULAR POLARIZATION. Polarization, the plane of which is rotating, of radio-waves after reflection in the ionosphere. It is found that, after reflection by an ionospheric layer, the plane of polarization is modified; nor is it a simple twist such as a vertically polarized wave emerging from the layer horizontally polarized. The plane of polarization is usually rotating; the first few waves may be vertically polarized, the next batch may be slightly off the vertical, and so on, until, after a brief interval, the waves are found to be horizontally polarized. The process goes on repeating itself, the time taken to complete a change of polarization depending upon the ionospheric conditions. Such waves are said to be circularly polarized.

More often than not, the amplitude of the wave varies with the direction of polarization; for example, the field strength of the wave may be greater when the polarization is vertical than when it is horizontal, so that there is a cyclic variation in amplitude as well as polarization. Waves of this nature are said to be elliptically polarized.

Rotation of the plane of polarization is produced by the effect of the earth's magnetic field on the ionized layers. The motion of electrons in the E- and F-layers, which is caused by the passage of the ionospheric wave, is affected to some extent by the earth's magnetic field.

The wave is split into two components, having different paths through the layer and attenuated to different degrees. They are found to be circularly polarized and rotate in opposite directions. When the two components combine, having been reflected by the layer, the wave is usually found to be elliptically or circularly polarized. This accounts for the fact that, when receiving long-distance, high-frequency transmission, equally good results are obtained with either horizontal or vertical receiving aerials. The nature of the sending aerial is unimportant. See PLANE OF POLARIZATION, POLARIZATION.

CIRCULAR SCANNING. Deflection of the beam in a cathode-ray tube so that the spot traces out a circular or elliptical path on the screen.

CIRCULAR TIME BASE. Circuit developing suitable potentials for application to the plates or deflector coils of a cathode-ray tube to produce circular scanning. In its most simple form, a circular time base may consist of a resistor and capacitor connected in series and fed from an A.C. source, one pair of plates (or deflector coils) being connected across the resistor and the other pair (or coil) across the capacitor. A circular trace is obtained when the reactance of the capacitor at the frequency of the supply equals the value of the resistor; otherwise the trace is elliptical.

CLASS-A, CLASS-AB, CLASS-B, CLASS-C AMPLIFIERS. See CLASS-A (ETC.) VALVE OPERATION.

CLASS-AB VALVE OPERATION. Method of working a valve in which the grid bias is somewhat greater than is required for operation at the midpoint of the straight-line portion of the characteristic curve which lies to the left of the grid-zero line.

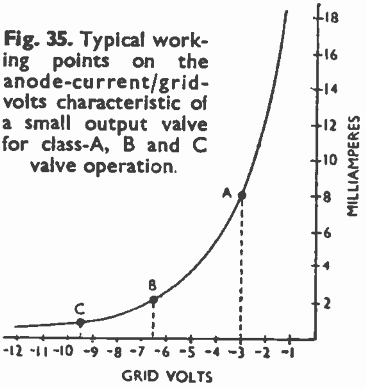


Fig. 35. Typical working points on the anode-current/grid-volts characteristic of a small output valve for class-A, B and C valve operation.

When the valve is working in the intended manner, the anode current of a class-AB amplifier is driven down to cut-off by each negative swing of the signal voltage. The standing, or no-signal, anode current is somewhat less than in class-A but not so low as that of class-B operation. See CLASS-A VALVE OPERATION.

CLASS-A MODULATION. Amplitude modulation in which the modulating-wave amplifier is a class-A type. See CLASS-A VALVE OPERATION.

CLASS-A VALVE OPERATION. Method of working a valve so that no grid current flows, and so that the operating point sweeps over the straight part of the characteristic curve (Fig. 35). In effect, this means adjusting the grid bias to a point near the middle of that straight part of the curve which lies to the left of the zero grid-volts line, and ensuring that the input voltages are not so great as to cause grid current or rectification at the lower bend of the curve. See CLASS-AB, CLASS-B, CLASS-C VALVE OPERATION.

CLASS-B MODULATION. Amplitude modulation in which the modulating-wave amplifier is a class-B type. See CLASS-B VALVE OPERATION.

CLASS-B VALVE OPERATION. Method of working a valve wherein the grid bias is sufficient to bring the standing anode current down to the cut-off point, that is, to or below the elbow at the bottom of the anode-current/grid-volts curve. Appreciable amounts of anode current therefore flow only when the valve is actually handling signals. See CLASS-A VALVE OPERATION.

CLASS-C VALVE OPERATION. Method of working a valve wherein the grid bias is sufficient to reduce the anode current well below the cut-off point. With a given signal input, the power output is then proportional to the anode voltage; this method of working a valve is chiefly of interest in sender circuits. See CLASS-A VALVE OPERATION.

C-LAYER. Ionospheric layer believed to exist at a height of between 15 and 20 miles above the earth. Pulse measurements indicate that a layer may be present at this height, but its characteristics appear to be very variable and, at present, no definite information in this connexion is available. See IONOSPHERE.

CLICK METHOD. Method used for finding the resonant frequency of an oscillatory circuit by means of a heterodyne wavemeter and a pair of headphones. The heterodyne wavemeter incorporates a calibrated oscillator which, when adjusted to the frequency of the circuit being tested, produces a single click in the headphones. The resonant frequency of the oscillatory circuit is then read from the dial of the wavemeter.

CLOSE COUPLING. Conditions existing when the coefficient of coupling between inductors is large. If a band-pass filter is formed by two inductively coupled tuned circuits, the circuits are said to be close-coupled when the mutual inductance between the two inductors has a relatively large value; that is, the coupling coefficient of the inductors exceeds, say, 0·5. The closer the coupling, the farther apart the peaks in the filter response curves (see BAND-PASS FILTER).

A more general definition of close coupling is applied to arrangements in which energy is passed from one circuit to another by inductive coupling. Thus, the greater the mutual inductance between the inductive elements by means of which the coupling is made, the closer the coupling is said to be, and the more complete the exchange of energy between the circuits. See BAND-PASS FILTER, COUPLING, COUPLING COEFFICIENT, INDUCTIVE COUPLING, MUTUAL INDUCTANCE.

CLOSED CIRCUIT. Oscillatory circuit in which an inductor is connected in parallel with a capacitor. In the early days of broadcasting, the term was used to describe a sender having its output terminals connected to a parallel-tuned circuit. This is chosen to simulate the electrical characteristics of the aerial normally used; the sender does not radiate energy connected to a closed circuit (see DUMMY AERIAL).

Programme executives employ the phrase "working on closed circuit," by which they mean that the programme is not radiated and not heard by listeners. See OSCILLATOR, RESONANCE.

CLOSED-CIRCUIT SYSTEM. In telegraphy, a system in which a continuous flow of current is maintained, signalling being available to any station by the control of this current.

CLOSED-CIRCUIT WORKING. Fire-alarm system in which a current is normally maintained in a line which passes through each of the call points. When the handle is operated at a call point, the current is interrupted and an alarm is sounded at the fire station. See OPEN-CIRCUIT WORKING.

C-NETWORK. Network composed of three impedances. The free ends of the series arms are connected to one pair of terminals, and the junctions of the two series arms and the single shunt impedance are connected to another pair of terminals. The C-network (Fig. 36) is the balanced form of the L-network. See NETWORK, QUADRIPOLE.

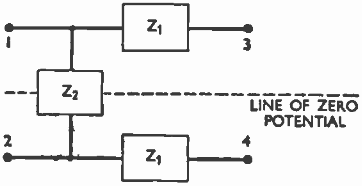


Fig. 36. Arrangement of the impedances forming a C-network; it is the balanced form of L-network.

COASTAL REFRACTION. Deviation of a radio-wave at the point where its path, having passed over water, becomes a path over land or vice versa. Radio-waves, being of an electromagnetic nature, are bent or refracted from their normal path when passing from one medium to another. A change in the conductivity of the surface over which a wave passes, or a change in the relative permittivity of the surface, is sufficient to constitute a change of medium and bring about some refraction of the wave.

The velocity of a radio-wave over sea water may be up to 5 per cent greater than that over land, as salt water, because of its higher conductivity, has less dragging effect on the "feet" of the wave. If a wave crosses the coast at an angle of less than 20 deg., refraction is appreciable and the bearing of the wave is no longer that of the sender. The effect varies with the frequency of the wave, but below about 150 kc/s the refraction appears to be independent of frequency.

As refraction of a radio-wave is almost always accompanied by a change of polarization, some form of fading may be experienced at the receiver.

The effect is of most importance when taking bearings by direction-finding methods, and ships at sea have to allow for errors introduced by coastal refraction. A bearing may be as much as 10 deg. in error and careful perusal of charts is necessary to determine whether refraction is likely to be important. Fig. 37 illustrates how coastal refraction occurs. See DIFFRACTION, DIRECTION-FINDING, POLARIZATION, REFRACTION.

CO-AXIAL CABLE. Cable containing one or more co-axial pairs. See CO-AXIAL PAIR.

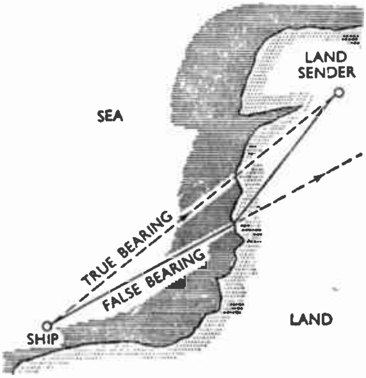


Fig. 37. Example of the false bearing obtained due to coastal refraction; the error may be as high as 10 deg.

CO-AXIAL PAIR. Pair of conductors, one surrounding but insulated from the other. Both conductors have the same axis, hence the term co-axial describes the form of the transmission line. A useful feature of the co-axial pair (Fig. 38) is that, at high wave frequencies, it gives less attenuation than an ordinary two-pair cable of the same length. Co-axial pairs are used for transmitting modulated carrier waves carrying intelligence: a great many messages can be transmitted by one co-axial pair, and television programmes involving a very wide frequency band may be carried over long distances. Repeaters are inserted in the cable at distances varying between five and ten miles. See CARRIER, CARRIER-WAVE TRANSMISSION, TRANSMISSION LINE.

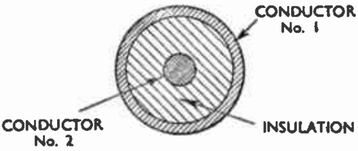


Fig. 38. Section through a co-axial pair, showing that the axes of the two circular conductors coincide.

CO-AXIAL TUBE FEEDER. Co-axial pair consisting of concentric tubes, used in connecting the aerials to the senders in short-wave radio stations (Fig. 39). See CO-AXIAL PAIR, FEEDER.

COEFFICIENT OF COUPLING. See COUPLING COEFFICIENT.

COEFFICIENT OF DETECTION. See DETECTION COEFFICIENT.

COEFFICIENT OF MUTUAL INDUCTION. Synonym for MUTUAL INDUCTANCE.

COEFFICIENT OF SELF-INDUCTION. See INDUCTANCE.

COGGING. Condition in which oscillations from an outside source cause an oscillator to synchronize with these oscillations, rather than oscillate at its natural frequency. If an oscillator is coupled to a source of oscillation, and the oscillations from the outside source are of invariable frequency, the effect of cogging is to drag the oscillator into synchronism with the oscillations flowing in the external circuit. If two oscillators are coupled together, cogging will cause both oscillators to oscillate at the same frequency although they would both oscillate at a different frequency if there were no coupling between them.

Cogging can occur only when an oscillator is producing a frequency not very different from that of the oscillations with which it cogs. The closer the coupling, the greater the change of frequency of the oscillator from its free to its cogged condition. Cogging may cause a local oscillator in a frequency-changer system to be dragged into synchronism with the other wave essential to the system; for example, the local oscillator in a superheterodyne may cog with the signal-wave frequency. See BEAT-FREQUENCY OSCILLATOR, BEAT OSCILLATOR, BEAT RECEPTION.

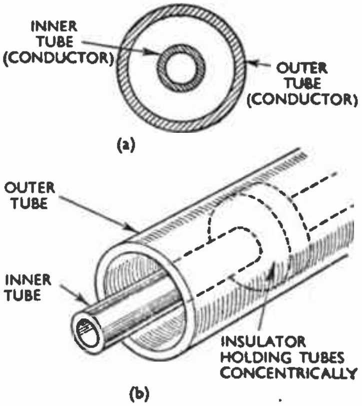


Fig. 39. Co-axial tube feeder shown (*a*) in section and (*b*) in perspective. A feeder of this type is frequently employed to conduct currents from a short-wave sender to its aerial.

COHERER. Early form of detector used in the first practical reception of wireless waves. It consists of a glass tube containing metal filings. This normally has a high resistance, but the passage of a radio-frequency current through the filings causes them to cohere and become conducting. It is necessary to re-set the device, after the passage of the R.F. current, by shaking up the filings again. This is achieved by tapping the glass tube, usually by means of an electromagnet operating a tapper.

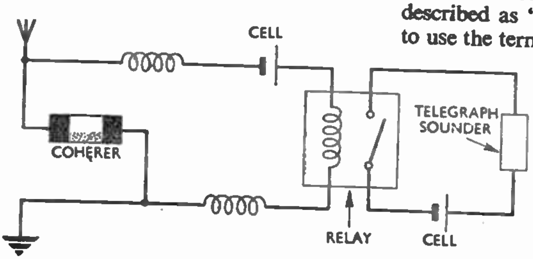


Fig. 40. Circuit diagram of the first Marconi receiver; the form of detector employed was a coherer.

The signal itself can be made to operate the tapper and, in this case, the device becomes self-restoring. The circuit of the first Marconi receiver, used in 1896, is shown in Fig. 40.

COIL. Number of turns of insulated and conductive wire, wound close to one another. The coil so formed may be of circular, rectangular or square form (Fig. 41). It is characterized in electrical work by having the property of inductance. An inductor is often described as "a coil"; but it is better to use the term "inductor" rather than "coil" when describing a component having predominantly the property of inductance. See CORE, INDUCTANCE, INDUCTOR.

COIL AERIAL. Synonym for LOOP-AERIAL.

COIL DRIVE. Synonym for inductive drive.

COIL LOADING. Synonym for inductance loading.

COLD CATHODE. Cathode electrode of a glow-tube. The term is used when the current in the tube is due to ionization of a gas and, therefore, when no primary electrons are available at the

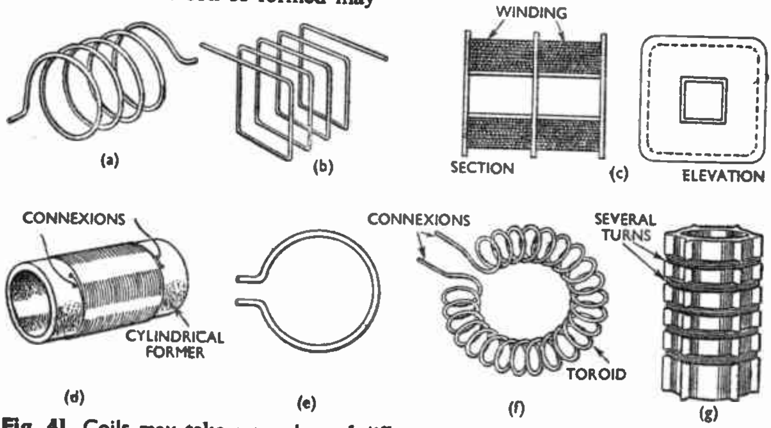


Fig. 41. Coils may take a number of different forms. Those illustrated are: (*a*) helical coil; (*b*) square coil; (c) two-section coil wound on a square-core former; (*d*) single-layer solenoid; (e) single-turn coil; (*f*) toroidal coil, and (*g*) sectionalized type of multi-layer coil which is wound on a ribbed and suitably slotted former.

cathode to start the process of conduction. See COLD-CATHODE VALVE, GLOW-TUBE.

COLD-CATHODE DETECTOR. Detector of the thermionic type in which the cathode is not heated. Certain types of valve have been developed for telephone circuits, such such as gas-filled triode, but with an unheated cathode. Such valves, however, are not employed in radio practice to any extent.

COLD-CATHODE VALVE. Valve containing a cathode which emits electrons without the application of heat. Such a valve needs no heater supply. Some rectifiers, voltage regulators and thyratrons are of this type.

The cold-cathode diode contains an inert gas under slight pressure; discharge begins when the anode-cathode potential reaches a certain value, usually between 60 and 180 volts, but the potential can be reduced slightly once the discharge starts. The stability of the discharge is improved by treating the cathode with metals or oxides of low work function.

If a third electrode is placed near the cathode in such a diode, any discharge occurring between these electrodes starts the main discharge between anode and cathode.

To use this type of cold-cathode triode thyratron, the anode/cathode potential is adjusted to just below the ionization potential, and a high resistance is connected in series with the grid or starter electrode to keep this electrode current low. A few volts applied to the starter electrode then initiates the main discharge. See COLD CATHODE, GAS-FILLED TRIODE.

COLOUR CODE. System of coloured markings frequently used on capacitors and resistors to indicate value.

Dots or bands of colour are placed nearer to one end of a capacitor and are read in order from that end, unless an arrow indicates otherwise. The respective values indicated by the different colours are shown in the table below.

The colours may be arranged in groups of one, two, three or five. One colour only indicates *tolerance*, the remaining designations being given numerically. Two colours only indicate *tolerance voltage* and *rating* respectively. When there are three colours, the first two indicate the first two significant *capacitance* figures and the third the decimal multiplier, the tolerance and rating being given in figures.

With five colours, the first three indicate *capacitance*, as with three colours, and the fourth and fifth indicate *tolerance* and *voltage rating* respectively. When five colours are

CAPACITOR COLOUR CODE

Colour	*Significant Figure*	*Decimal Multiplier*	*Tolerance Percentage*	*Voltage Rating*
Black	0	1	—	—
Brown	1	10	1	100
Red	2	100	2	200
Orange	3	1,000	3	300
Yellow	4	10,000	4	400
Green	5	100,000	5	500
Blue	6	10^6	6	600
Violet	7	10^7	7	700
Grey	8	10^8	8	800
White	9	10^9	10	1,000
No colour	—	—	20	500

used they may sometimes be arranged in two groups, in which case the three-figure group indicates capacitance and the two-figure group tolerance and voltage rating respectively. In all cases the capacitance is given in micromicrofarads.

RESISTORS. Two main systems are employed for the colour-coding of resistors (Fig. 42):

Three-band System. With this system the resistance value is indicated by three coloured bands; the bands are placed near one end of the resistor and, reading from this end, the first two bands indicate the first two significant figures and the third band the decimal multiplier, the colours having the values indicated in the table below. For example, a resistor having bands of red, green and orange in the order indicated above would have a nominal resistance of 25,000 ohms.

Single Spot or Band System. With this system, the first significant figure is indicated by the colour of the body, the second significant figure by the colour of the tip, and the decimal multiplier by the colour of the single band or spot on the body. In applying this system confusion may arise when the first significant figure is identical with the decimal multiplier, for, in this case, the colours of the spot and body are the same, and therefore no spot is seen.

Examples: Brown body, grey tip, yellow spot; value 180,000 ohms.

Red body, green tip; value 2,500 ohms.

It should be noted from the table that tolerance percentage is sometimes indicated by additional markings as follows: gold ± 5 per cent, silver ± 10 per cent. If no such marking appears on the resistor a tolerance of ± 20 per cent can be assumed.

COLPITT'S CIRCUIT. Thermionic-valve oscillator circuit consisting essentially of capacitive links between anode and cathode, and grid and cathode, and an inductive link between anode and grid, as shown in Fig. 43. The frequency of oscillation is given by $f = \frac{1}{2\pi\sqrt{LC}}$, where $C = \frac{C_1C_2}{C_1+C_2}$.

COMA. Distortion of the stationary spot on the screen of a cathode-ray tube, the image being pear-shaped instead of circular.

COMBINATION-TONE DISTORTION. See INTERMODULATION DISTORTION.

COMBINATION TONES. Tones produced by amplitude distortion in

RESISTOR COLOUR CODE

Colour	*Significant Figure*	*Decimal Multiplier*	*Tolerance Percentage*
Black	0	1	—
Brown	1	10	—
Red	2	100	—
Orange	3	1,000	—
Yellow	4	10,000	—
Green	5	100,000	—
Blue	6	10^6	—
Violet	7	10^7	—
Grey	8	10^8	—
White	9	10^9	—
Gold	—	0·1	± 5
Silver	—	0·01	±10
No colour	—	—	±20

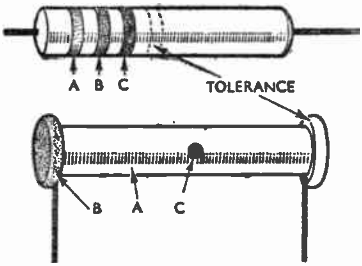


Fig. 42. Two forms of colour coding as applied to fixed resistors. The colours are "read" in the alphabetical order indicated, *A* and *B* representing the first two significant figures, and *C* the decimal multiplier. A fourth colour, which is sometimes added, refers to the percentage tolerance.

the human ear. They arise when the ear is subjected to more than one frequency at the same time, and have frequencies which are the sums and differences of the applied frequencies. See INTERMODULATION DISTORTION, SPEECH AND HEARING.

COMMON AERIAL. Aerial used in radar and other special applications for both sending and receiving. Some form of automatic switching, such as a gaseous spark-gap, is necessary to protect the receiver from the sending power. The gap breaks down at each sending pulse and short-circuits the receiving feeder line. If the short-circuit is located one quarter wavelength from the point at which the receiving line branches from the common feeder, it shunts a very high impedance across the sending line, and absorbs none of the sending power. See QUARTER-WAVELENGTH LINE.

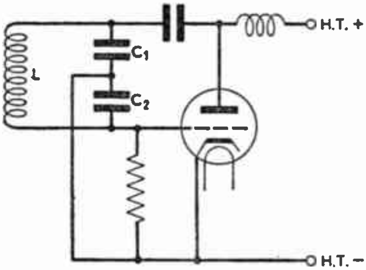


Fig. 43. Diagram which shows the fundamentals of Colpitt's circuit.

COMMON-FREQUENCY BROADCASTING. Synonym for SHARED-CHANNEL BROADCASTING.

COMMON-IMPEDANCE COUPLING. Coupling of two circuits by the inclusion of an impedor in both circuits. The term is sometimes abbreviated to "impedance coupling." See CAPACITIVE COUPLING, INDUCTIVE COUPLING, RESISTIVE COUPLING.

COMMON RETURN. A single conductor which in some way provides a return path for currents which have made part of their journey by separate paths, and which merge in the common return.

COMMON-WAVELENGTH BROADCASTING. Synonym for SHARED-CHANNEL BROADCASTING.

COMMUTATION MODULATION. Modulation in which switches, usually electronic, are used to cause periodic alterations of the circuit path of the carrier wave. There are many forms of commutator modulators, the most commonly used being the ring modulator (see RING MODULATOR). The basic principle lies in the changing of the path in which the modulating wave is flowing to produce a rectangular wave. Fig. 44 shows a form of this wave and the circuit which produces it. The frequency of reversal of circuit path is the frequency of the equivalent carrier wave.

It can be demonstrated that a commutation-modulated wave can be resolved into a number of waves. If f_c be the frequency of the reversals and f_m the frequency of the modulating wave, then the wave of Fig. 44b is composed of waves of frequency $f_c + f_m$, $f_c - f_m$, $3f_c + f_m$, $3f_c - f_m$, $5f_c + f_m$, $5f_c - f_m$ up to $nf_c + f_m$ and $nf_c - f_m$, where n is odd and theoretically infinity. The relative amplitude of the waves is 1, $\frac{1}{3}$, $\frac{1}{5}$, and so on up to $\frac{1}{n}$, so that if n

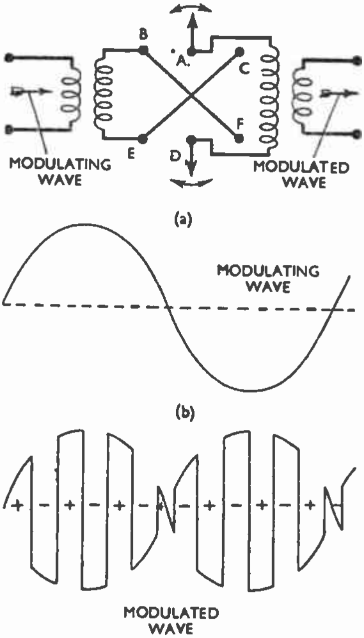


Fig. 44. Commutation modulation is effected if the switch (*a*) is changed over periodically so that the modulating wave (*b*) is altered to the modulated form shown below it; this contains a component wave representing a suppressed-carrier modulation.

is infinity, waves of frequency nf_c+f_m and nf_c-f_m have zero amplitude and infinite frequency. In practice, a filter can be used to transmit waves of frequency f_c+f_m and f_c-f_m to give a suppressed-carrier amplitude-modulated wave. If the filter passes waves of frequency f_c+f_m or f_c-f_m, single-sideband modulation is produced.

The frequency of reversal is the frequency of the reversals of the switch (Fig. 44). Electronic switches are generally used because the carrier frequency is, in most cases, too high to enable a mechanical switch to respond. If the carrier-wave frequency were of the order of 1,000–2,000 c/s, however, a rotating commutator could provide the reversals. Reversal of the circuit path may also be simulated by opening and short-circuiting the circuit path periodically. In this case, the carrier wave is not suppressed. See SUPPRESSED-CARRIER MODULATION.

COMMUTATOR. Cylindrical structure of copper bars insulated from one another and constituting the means of rectifying the current of a dynamo, or of reversing the current in the windings of a D.C. motor (see MOTOR). Commutators are also used on some types of A.C. motor.

COMMUTATOR MODULATOR. Modulator in which switches (usually electronic) are used to cause periodic alterations of amplitude (or reversal of direction) of the carrier wave. The commonest form of commutator modulator is the ring modulator. See COMMUTATION MODULATION, RING MODULATOR.

COMPANDER. In telephone speech transmission, a device combining the functions of an expander and a compressor. Its effect is to increase the volume of soft speech and reduce the loud components, thus reducing contrast and increasing the signal-to-noise ratio. See EXPANDER, COMPRESSOR.

COMPENSATED-LOOP DIRECTION FINDER. Device for avoiding errors in loop direction-finders owing to night effect by the use of a horizontal aerial which rotates with the loop. Night effect is caused by voltages induced in the horizontal members of the loop by horizontally-polarized downcoming waves which have been reflected at the ionosphere. These voltages can be partially neutralized and night effect eliminated to a certain extent by suitably combining with the loop output the output of the horizontal aerial mentioned. See DIRECTION-FINDING, NIGHT ERROR.

COMPLETE CYCLE. Synonym for CYCLE.

COMPONENT. Manufactured article which is used to form a part of an apparatus when connected to other components to form circuits. Generally speaking, a component does not of itself perform any function; a resistor is a component, but by itself, and without being connected in circuits to other components, it is of no functional significance.

Examples of what are called components include valves, inductors, capacitors, resistors, valve holders, terminals, switches, transformers and so on. On the other hand, a relay, calibrated attenuator, beat-frequency oscillator or signal generator are all examples of "apparatus," while a "broadcasting sender" is an "equipment." See APPARATUS, INSTRUMENT, MEASURING INSTRUMENTS.

COMPONENT OF ERROR. One of the many errors possible in readings obtained from a direction-finder. The term is generally used in referring to a specific type of error; for instance, quadrantal component of error.

COMPRESSOR. Electronic amplifier used in telecommunication and radio circuits for reducing contrast between extremes of speech or music volume. It permits the transmission of higher mean volume, thus increasing the signal-to-noise ratio. See COMPANDER, EXPANDER, LIMITER.

CONCENTRIC CABLE. Synonym for CO-AXIAL CABLE.

CONCENTRIC LINE. Synonym for CO-AXIAL PAIR.

CONCENTRIC TUBE FEEDER. Radio-frequency conductor which consists of a single wire centrally spaced in a metal tube or sheath. Feeders of this kind are sometimes used, on the higher frequencies particularly, to connect a receiving station to its distant aerial-system, and they are occasionally employed even to carry the output of a sender to the aerial.

Such a feeder system is, of course, well screened and will not radiate; moreover its impedance is fixed by the construction of the tubular conductors and does not require to be maintained by careful spacing and mounting of the two lines, which can be as near together or far apart as may be convenient. This is of some slight advantage at certain points in an aerial installation.

In a common form, a feeder of this type consists of a copper tube, perhaps half an inch in bore, with a single conductor of about 18 S.W.G. held in a central position by pointed ceramic-bead spacers (Fig. 45). For sending purposes, the tube would naturally be larger, perhaps 2 or 3 in. in diameter. In either case, the interior of the feeder system must be kept free from moisture, and it is sometimes filled with nitrogen or dried air under pressure.

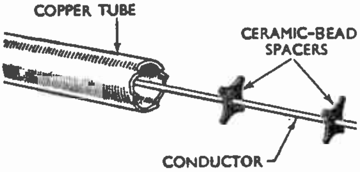


Fig. 45. Concentric-tube feeder in which ceramic beads are used to ensure central spacing of conductor.

CONDENSER. Obsolescent term for CAPACITOR.

CONDUCTANCE. Property of any material which allows it to pass an electric current. The possession of this property to a marked degree is the characteristic of those materials which are known as conductors; numerically, the conductance of a circuit is equal to the reciprocal of its resistance.

CONDUCTION. Process whereby an electric current is led along a definite path. The term conduction current is sometimes used to differentiate between a current in a conductor and one consisting of a stream of electrons projected across an evacuated space, as in a thermionic valve.

CONDUCTIVITY. Property, of a substance such as a metal, of being able to conduct an electric current with a particular degree of ease. More precisely, conductivity is a measure of the conductance of a given material under specified conditions, such as between the faces of a cube of standard size at a certain temperature. See CONDUCTANCE.

CONDUCTOR. Material capable of conducting an electric current with ease, as distinct from a non-conductor or insulator which does so with such difficulty that for all practical purposes it may be regarded as having zero conductivity or infinite resistance. Alternatively, a wire, cable or other path for currents (Fig. 46). See CABLE, WIRE GAUGE.

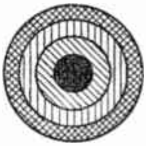


Fig. 46. In a power cable the conductor is the metal core (shown solid black in this section diagram). The core may be surrounded by a layer or layers of insulating material, a layer of armouring and, finally, a waterproof layer (shown cross-hatched).

CONE AERIAL. Synonym for CONICAL AERIAL.

CONE DIAPHRAGM. Diaphragm of a loudspeaker, taking the form of a cone, driven at its apex by a vibrating reed (moving-iron) or by an attached coil, moving at the frequency of the applied signals (moving-coil). See LOUDSPEAKER.

CONE LOUDSPEAKER. Any loudspeaker using a cone diaphragm.

CONICAL AERIAL. Wide-band aerial; that is, one which is designed to cover a considerable band of frequencies. The cone is a half-wave dipole consisting of two wire cages, each tapering to a point at the dipole centre; thus there are in fact two skeleton cones with points towards each other, as in the diagram (Fig. 47). In some cases, and for centimetric wavelengths, sheet-metal cones are used.

CONICAL-HORN AERIAL. Aerial used at centimetric wavelengths, much resembling a loudspeaker horn with exponential flare; when suitably proportioned such an aerial is strongly directive. It is normally fed with energy from a wave-guide leading into its throat. See WAVE-GUIDE.

CONJUGATE IMPEDANCES. Impedances each having equal resistance, and reactance of equal magnitude but of opposite sign. Reactances which have the same magnitude but opposite sign are capacitive and inductive reactances of equal reactance value. For example, the reactance of an inductor of inductance L is ωL, and the reactance of a capacitor is $\frac{1}{\omega C}$, ω being $2\pi f$ where f is the frequency of the wave passing through the reactors. At some value of ω, $\omega L = \frac{1}{\omega C}$ and the numerical values of the reactances of inductor and capacitor are equal. But, if the same current flows through both reactors, the voltages across them, assuming there is no resistance, are 180 deg. out of phase, and so cancel; thus the reactances are said to have "opposite signs." See IMPEDANCE, REACTANCE, VECTOR.

CONSTANT-AMPLITUDE RECORDING. In electrical recording, a term used when the amplitude of the recorded wave form is constant at all frequencies for a constant-voltage, variable-frequency input to the equipment. See CONSTANT-VELOCITY RECORDING.

CONSTANT-CURRENT MODULATOR. Synonym for ANODE MODULATOR.

CONSTANT-FREQUENCY OSCILLATOR. See FREQUENCY-STABILIZED OSCILLATOR.

CONSTANT-VELOCITY RECORDING. In electrical recording, term used when the velocity of the recorded wave form remains constant for a constant-voltage, variable-frequency input to the equipment. Velocity and amplitude are related: Velocity (r.m.s.) = $4{\cdot}44\,fa$ cm/sec., where f is the recorded frequency and a the amplitude of the waves. Therefore, with constant velocity, the amplitude is inversely proportional to frequency.

CONTACT POTENTIAL. Difference in the characteristic affinity for electrons of the various parts of the structure of a thermionic valve, such as the anode and cathode. The contact potentials of grid and cathode affect the position of the cut-off point on the characteristic of the valve.

CONTACT VOLTMETER. Voltmeter in which the movement of the instrument actuates contacts for alarm and other purposes.

CONTINUITY CONTROL. Function of keeping a watch on the programme presentation as a whole and smoothing over gaps between programme items; or the stage management of a programe when schedules are upset.

Each programme item is generally introduced by an announcer. On changing from one item to another, new studios come into use, and the new item will most probably be introduced by a new announcer and a short delay may take place. Continuity control ensures that there shall be a smooth change-over. Thus, while flashing of warning lights, hushing of performers and so forth goes on in the studio about to go on the air, the continuity-control announcer makes the fade-outs and fade-ins, while placing his own microphone in circuit to announce the programme.

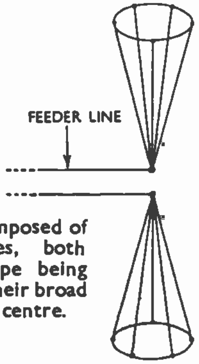


Fig. 47. Form of wide-band half-wave dipole, using a pair of tapering cage structures, known as a conical aerial. A diamond aerial is composed of similar structures, both cages in this type being inverted so that their broad ends are at the centre.

The circuits are further arranged so that the continuity controller can fade out any studio and put himself in control through his own microphone. This, when it has been used, is faded out as the new item starts. See FADER, STUDIO-CONTROL CUBICLE.

CONTINUOUS CURRENT. Synonym for DIRECT CURRENT.

CONTINUOUS WAVE. Synonym for TYPE A0 WAVE.

CONTRAST AMPLIFICATION. Form of amplification by which the contrast between soft and loud passages in a radio-broadcast programme is accentuated. The gain of the amplifier is automatically reduced on soft, and increased on loud passages. It is designed to counteract the compression of the volume range introduced into the transmitting system for the purpose of maintaining adequate signal-to-noise ratio. See COMPANDER, COMPRESSOR, EXPANDER, LIMITER.

CONTRAST CONTROL. Control of the variation of brightness of a television picture for a given change in signal amplitude.

Change in the brightness of any part of a picture is judged, not by the actual magnitude of the change, but by the magnitude in relation to the original brightness. Therefore, the initial brightness of the cathode-ray tube must be taken into account when contrast control is required.

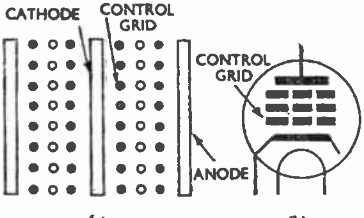
If contrast in a picture is to be increased, the method adopted is to increase the gain of the amplifier, but this in itself will not completely provide the required contrast because the brightness control must be adjusted also. In general, the brightness must be reduced when the contrast is increased, and the brightness increased when the contrast is reduced.

CONTROL ELECTRODE. Any electrode the potential of which controls the current flowing between two other electrodes. In a valve the usual controlling electrode is known as the CONTROL GRID (q.v.); in a cathode-ray tube it is known as the MODULATOR ELECTRODE (q.v.).

CONTROL GRID. Electrode of the grid type nearest to the cathode (Fig. 48). The control grid is the electrode which, for a given change of its potential, produces the largest change of anode current. In most amplifier circuits the wave to be amplified varies the potential of the control grid with respect to the cathode.

The anode current in an ordinary amplifying hard-vacuum valve is determined by the potential gradient at the cathode. Since the control grid is nearly always very close to the cathode, its potential has a predominating influence in determining the potential gradient at the cathode.

The term "grid" is constantly used instead of control grid; this is partly a survival from the days before the tetrode, pentode, hexode and other complex valve types came into use, when only the triode with its single grid was available. Moreover, as the other grids are distinguished by the terms screen grid, suppressor grid and so on, there is no need to give the control grid its full name. The control grid is usually a spiral of wire of constant pitch. The closer the spiral the greater the mutual conductance. In a variable-mu valve, the pitch of the spiral varies along its length.



(a) (b)

Fig. 48. Diagram of electrodes (*a*) and the usual symbolic representation (*b*) of a pentode, showing the control grid to be that nearest to the cathode.

Associated with the control-grid electrode is the mutual conductance of a hard-vacuum valve, an extremely important quantity (see AMPLIFICATION FACTOR, ANODE SLOPE-CONDUCTANCE, MUTUAL CONDUCTANCE, TRANSCONDUCTANCE).

In class-A amplification, the control grid is biased negatively with respect to cathode and the variation of potential due to the wave applied to the control grid never causes it to have a positive potential with respect to cathode (Fig. 49). In class-B amplification, the control grid does become positive with respect to the cathode, and current flows between it and the cathode.

In a gas-filled triode or tetrode, the grid bias determines the anode voltage at which ionization takes place. Once current flows, the control-grid potential has no effect upon the anode current. See GAS-FILLED TRIODE, GRID BIAS, GRID CURRENT, GRID POTENTIAL, GRID SWEEP, MUTUAL CONDUCTANCE, TRIODE, VARIABLE-MU VALVE.

CONTROLLED-CARRIER MODULATION. Synonym for FLOATING-CARRIER MODULATION.

CONTROLLED SENDER. Sender in which a controlling device is employed to keep the radiated frequency within narrow limits.

CONTROLLED TRANSMITTER. See CONTROLLED SENDER.

CONTROL RATIO. Term used in connexion with a gas-filled triode or tetrode. It is a number expressing the ratio of the anode voltage at which ionization takes place, to the grid voltage existing when the ionization takes place. If a gas-filled triode is not passing current, and the grid has a potential of $-E_g$ volts, then the anode voltage must be raised to E_a volts before current starts to flow. The more negative the grid is made, the more positive E_a must be to start ionization. The ratio E_a/E_g is the control ratio. As will be seen from Fig. 50, it tends to remain constant over a wide range of values. See GAS-FILLED TRIODE, IONIZATION POTENTIAL.

CONTROL ROOM. Room in which all transmission-line links are centralized, and in which switching and fading

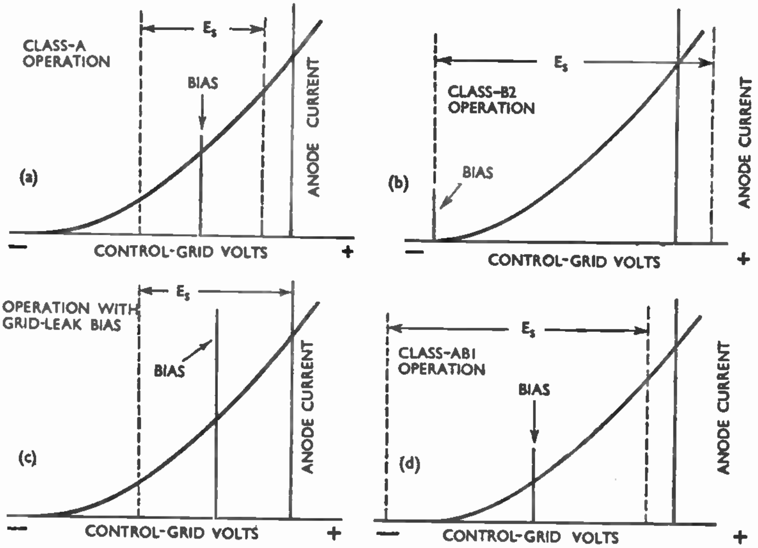


Fig. 49. Grid-volts/anode-current characteristic of an amplifier valve, E_s being the grid sweep: (*a*) with bias for class-A operation; (*b*) the valve biased to cut-off; (*c*) zero bias, the condition for automatic grid-bias using the grid-leak principle, and (*d*) the condition which exists in class-AB1 valve operation.

operations are carried out and the level of the input to the modulation circuits of senders is regulated. The links carry the audio-frequency currents representing the output from the microphone; that is to say, "carrier" systems in which modulated waves are sent through the transmission lines are not used. A diagram of a broadcasting system comprising several senders is shown in Fig. 51. It may be compared with Fig. 31 on page 79 (BROADCASTING) which shows the basic principles of a single-sender system.

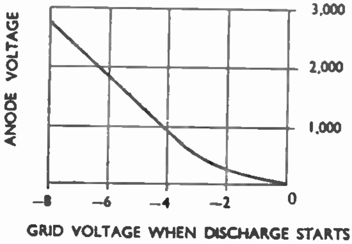


Fig. 50. Graph showing that the control ratio—that is, the ratio of anode voltage to grid voltage at which discharge begins—is constant over a considerable part of the working characteristic of a representative gas-filled triode.

Each control room centralizes the links which join all the control rooms together (Fig. 51) and each control room is at the junction of lines from places in which outside broadcasts are made. Lastly, each control room is connected by a short line to a local sender (Fig. 52). This system, however, is not invariable; cases may arise where a sort of sub-control room in a town or city may not be directly connected to a local sender.

The network of transmission lines makes it possible to route any programme, wherever it takes place in the area, to any sender via its local control room. Lines coming from other countries may be used to accept programmes made in other countries

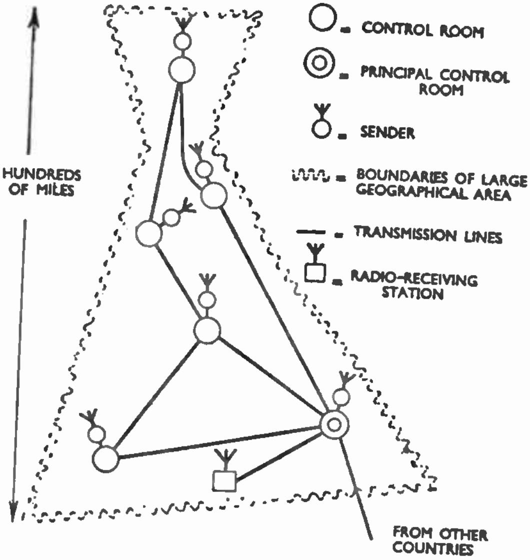


Fig. 51. Formal diagram showing how a control room forms the junction of lines from and outgoing to other control rooms and to local senders.

or areas, and form part of the public-telephone system. In Britain, the B.B.C. hires local and trunk lines from the Post Office; these trunk lines are specially treated to pass frequencies of up to 8,000 c/s without serious distortion. When the programme to be broadcast is made in another continent, separated from the area considered by a large ocean so that a transmission line cannot be used to convey the programme, a radio link is set up and the receiving end is linked to a principal control room.

Apart from the switching gear, which can be operated in each and every control room to form a flexible system, the function of regulating the level of the audio-frequency currents sent to the local sender is also centralized. A sender has a certain maximum power, and so the power in the modulated wave has a maximum limit which cannot be exceeded without creating harmonic distortion. At the other end of the scale, the power in the modulated wave must exceed a certain minimum, otherwise it will not be sufficiently great to overcome noise (see SIGNAL-TO-NOISE RATIO, SERVICE AREA).

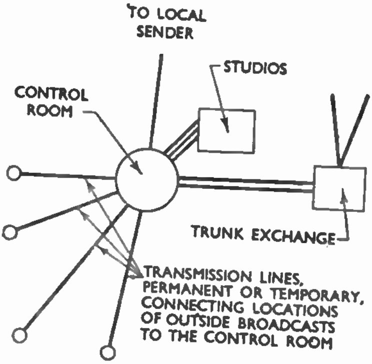


Fig. 52. Schematic diagram of the various lines radiating from the control room of a broadcasting system.

The contrast of volume in orchestral playing might be of the order of 60 to 70 db.; if the average power in the modulated wave coming from a sender fell much more than 30 db. below a (limited) maximum, the noise level would become predominant. Thus a contrast level of 60 db., which represents reality, has to be made into a contrast level of 30 db. when broadcasting gives us its synthesis of music.

To do this, a skilled person must operate a gain control in order to level out the dips and round off the peaks that occur in the microphone output. This function of controlling must be dictated by one person; it is useless to have two with different ideas. This one person is given an apparatus and a position which may be considered as part of the control room.

The control room contains racks to hold the many line amplifiers which are set to raise the level of the power fed into the lines to a value sufficient to overcome noise; or amplifiers which raise the level of incoming signals to a sufficient value. See SIMULTANEOUS BROADCASTING, STUDIO, STUDIO-CONTROL CUBICLE, TRANSMISSION LINE.

CONTROLS. Generic term applied to devices used in an electrical circuit for varying the constants of individual elements, for example, volume control, rheostat, switch.

CONVERSION. Synonym for FREQUENCY-CHANGING.

CONVERSION CONDUCTANCE. Quantity associated with a frequency-changer valve. It is the equivalent of mutual conductance or transconductance for a valve where the frequency of the amplified wave is not changed in the process of amplification. If a wave of a certain voltage and frequency f_1 is applied to one electrode of a frequency-changer valve, then, from another electrode, a current I, alternating at a frequency f_2, can be drawn. The maximum value of this current occurs when the electrode path which completes the circuit has zero resistance.

Conversion conductance is the ratio of the short-circuit current of changed frequency f_2 drawn from one electrode, to the voltage of frequency f_1 applied to the other electrode. This quantity is usually expressed as so many milliamperes per volt. See CONVERSION GAIN, FREQUENCY-CHANGER VALVE, MUTUAL CONDUCTANCE.

CONVERSION DEMODULATION. Synonym for FREQUENCY-CHANGING.

CONVERSION DEMODULATOR. Synonym for FREQUENCY-CHANGER.

CONVERSION DETECTION. Synonym for FREQUENCY-CHANGING.

CONVERSION DETECTOR. Synonym for FREQUENCY-CHANGER.

CONVERSION GAIN. Term used to express the voltage gain of a frequency-changer valve. It is the equivalent of stage gain in an amplifying valve when the frequency of the wave is not changed in the process of amplification. If a voltage E_1 at a frequency f_1 is applied to the input of a frequency-changer and produces at the output a voltage E_2 at a frequency f_2, the ratio of E_2 to E_1 is the conversion gain. See CONVERSION CONDUCTANCE, STAGE GAIN.

CONVERSION RESISTANCE. Reciprocal of CONVERSION CONDUCTANCE (q.v.).

CONVERSION TRANSCONDUCTANCE. Term analogous to MUTUAL CONDUCTANCE (q.v.) but applicable only to frequency-changer valves. Conversion transconductance is given by the current at the difference frequency flowing in the anode circuit, for zero anode load, divided by the signal voltage at the control grid. It is expressed in milliamperes per volt. See FREQUENCY-CHANGER.

CONVERTER. Machine for converting alternating current to direct current, or vice versa. See MOTOR CONVERTER, MOTOR GENERATOR, ROTARY CONVERTER.

COOLED VALVE. Valve which is operated in conjunction with some auxiliary means of cooling. Owing to the generation of heat by electron bombardment, particularly of the anode, it is necessary, when valves handle high power, to provide some extra cooling.

Air and water cooling are used. Air may be blown on to the bulb or on to an exposed anode with fins on it to assist cooling. Water is used to cool the anode by passing it over the surface of the anode. The extra capacitance induced by the air-cooling of a finned anode limits the use of such valves for ultra-high-frequency work. See AIR-COOLED ANODE, AIR-COOLED VALVE, SILICA VALVE, WATER-COOLED VALVE.

CO-PLANAR GRID VALVE. See WUNDERLICH VALVE.

COPPER-OXIDE DETECTOR. Detector using the rectifying properties of copper oxide in contact with copper (see METAL RECTIFIER). Rectifiers of this type may be used for the detection of radio-frequency signals up to frequencies of a few megacycles per second, provided that the physical size of the disc is reduced to the minimum. This is to keep down the self-capacitance between the discs which would otherwise short-circuit the radio-frequency currents.

As the frequency is raised, the by-passing action due to the self-capacitance begins to come into play even with the smallest practicable size of disc (about 2 mm. in diameter). Up to this point, however, the copper-oxide detector is both efficient and stable.

COPPER-OXIDE MODULATOR. Commutator modulator using copper-oxide rectifiers. See COMMUTATION MODULATION, COPPER-OXIDE RECTIFIER, RING MODULATOR.

COPPER-OXIDE RECTIFIER. Form of metal rectifier in which the rectifying action takes place between copper oxide and copper. If the surface of a clean piece of copper is oxidized, then the conduction between the copper and the oxide depends upon the sense in which voltage is applied. This rectifying action is thus between two hidden surfaces, that is to say, that of the clean copper and the inner surface of the covering oxide. The molecular action which causes this asymmetrical conduction is not completely understood, but that it takes place between the underside of the oxide and the clean copper is certain.

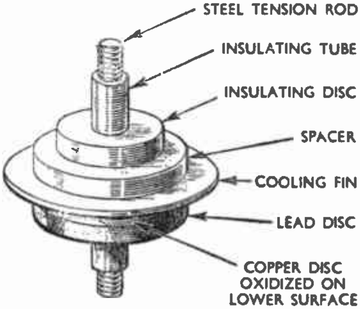


Fig. 53. Assembly details of a copper-oxide rectifier element.

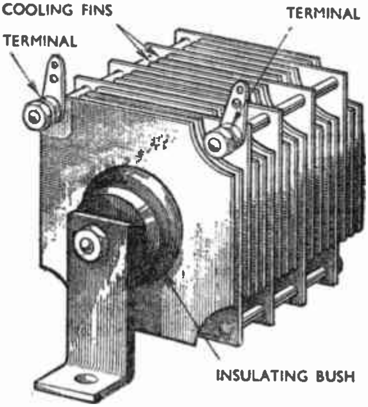


Fig. 54. Typical series-parallel arrangement of copper-oxide-rectifier units incorporating cooling fins.

Contact must be made to the copper on the one hand and the outer surface of the oxide on the other in order to establish the circuit of this rectifier.

Practical advantage of this effect has been taken by constructing rectifiers which can handle a wide range of power, and which, because no chemical action takes place, have a virtually unlimited life.

Fig. 53 illustrates the construction of a typical copper-oxide rectifier, such as is used for rectifying alternating currents in mains units and, in general, for converting alternating to direct current. It will be noted that a lead disc makes contact between the oxidized surface and the terminal of the rectifier.

Fig. 54 shows how the units of Fig. 53 may be assembled with cooling fins to dissipate the heat. This design is essential when power efficiency is important. A series-parallel arrangement is used, that is, a number of units may be in series but the groups made from these units are in parallel.

It is not uncommon to find copper-oxide rectifiers assembled as voltage-doublers, when the application of a single-phase alternating current to one pair of terminals results in a unidirectional current at the other (see VOLTAGE-DOUBLER). The internal impedance of a copper-oxide rectifier is greater for a given output than that of a valve-rectifier system.

Apart from its uses in converting alternating to direct current where considerable power is involved as, for example, with accumulator-charging equipment, the copper-oxide rectifier is made in very small sizes for applications as an instrument rectifier, electronic switch (in the ring modulator) and as a detector in radio receivers. The copper-oxide rectifier is only one form of metal rectifier; the selenium rectifier is another and has basically similar properties. See METAL RECTIFIER, RECTIFIER INSTRUMENT, SELENIUM RECTIFIER.

COPPER WIRE DATA. Details of diameter, cross-sectional area, weight, working current, resistance, turns per inch, etc., applicable to each standard wire-gauge size of copper wire. Information of this nature is to be found from a table appearing in the Reference Section at the end of this book.

CORE. Of an inductor, the space enclosed by the turns of the coil (Fig. 55). Any means of increasing the flux linkages between the turns of a coil increases the inductance of the coil (see INDUCTOR, MAGNETIC FLUX). Thus iron, which has a permeability greater than unity, is frequently placed in the core of a coil, and the inductor is then described as iron-cored.

In order to avoid losses in the iron when the wave frequency is high, the iron may be laminated. For use at radio frequencies, the core is filled with a mixture of iron powder and some insulating "binder" which holds the iron particles firmly in position yet insulates them electrically. This diminishes eddy-current losses in the iron, but leaves the core with a permeability greater than unity. Air cores are used when, even with dust-iron cores, the losses are excessive. See DUST-CORED INDUCTOR, EDDY CURRENT, INDUCTANCE, LAMINATION, PERMEABILITY.

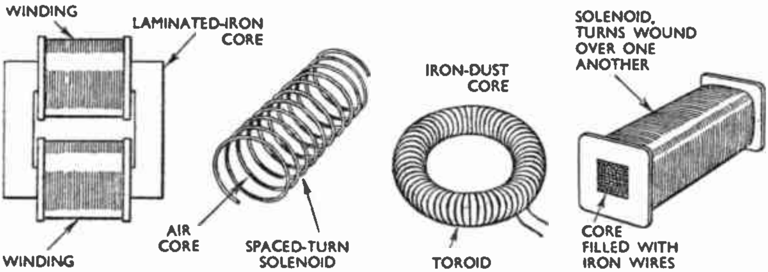


Fig. 55. The core of an inductor is the space enclosed by the turns of the coil; it may be filled by laminations of iron, by iron wires, by an iron-dust composition or by air. An air-cored inductor is generally to be prefered when the inductor is to operate at high radio frequencies and the losses in a ferro-magnetic core may be so great as to reduce rather than increase the Q-factor of the coil.

CORNER REFLECTOR. Device consisting of reflecting plates at right angles to one another designed to return radar pulses along their original path and thus increase the range at which the object incorporating the corner reflector can be detected.

CORONA. Visible discharge of electricity from a conductor into the surrounding air which occurs when the potential gradient at the surface exceeds a certain value, the value being, nevertheless, short of that necessary for a spark. See ATMOSPHERICS.

CORRECTED BEARING. Bearing obtained when the reading obtained experimentally from a direction-finder equipment has been corrected for all known errors.

COSINE CURVE. Synonym for COSINE GRAPH.

COSINE FUNCTION. Quantity or factor related to some other factor in such a way that one is equal to or proportional to the cosine of the other. Thus, A is a cosine function of B if $A = \cos B$.

COSINE GRAPH. Graph obtained by plotting the cosine of an angle against the angle (Fig. 56). It has the same shape as a SINE GRAPH (q.v.) but for angles between zero and 360 deg. begins and ends at unity. In other words, the cosine graph is obtained by displacing the sine graph to the left by 90 deg. An example of the use of the cosine graph is in expressing as an angle the lag or lead of alternating current.

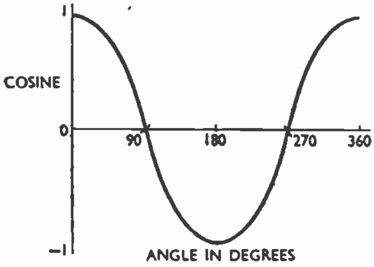


Fig. 56. Cosine graph; the curve is obtained by plotting the cosine of each angle against the angle.

COSINE WAVE. Wave having the form of a COSINE GRAPH (q.v.). The idea of the cosine wave is a useful conception, as the following examples show. If a voltage of cosine wave form is applied to an inductive circuit, the current which flows has a sinusoidal form, and if a voltage of sine wave form is applied to a capacitive circuit, the current has a cosine wave form. See SINE WAVE.

COSMIC NOISE. See ATMOSPHERICS.

COSMIC RAY. Path traversed by waves thought to enter the atmosphere from outer space. Such waves are shorter than gamma rays and have a high degree of penetration.

COULOMB. Practical measure of electrical quantity. It is defined as that quantity of electricity which is delivered by a current of one ampere flowing for one second.

Fig. 57. Coulomb's law states that, where two charges Q_1 and Q_2 are separated by a distance d, the physical force of attraction or repulsion is proportional to the product of Q_1 and Q_2 divided by d squared.

COULOMB'S LAW. One of the basic relationships of electrostatics. It states that the forces of repulsion and attraction, which exist when charged objects are in proximity to each other (Fig. 57), obey the fundamental law of inverse squares; this law states that an electrical force is inversely proportional to the square of the distance between the component charges, and that the attraction or repulsion of these charges is in direct proportion to the product of the values of the charges.

COUNTERPOISE. Arrangement of insulated conductors placed a few feet above the ground and used in conjunction with an aerial system instead of, or as well as, a direct connexion to earth (Fig. 58). The arrangement commonly takes the form of stretched wires running out fanwise, or as a parallel network under the aerial.

COUPLED ADCOCK DIRECTION-FINDER. Adcock direction-finder in

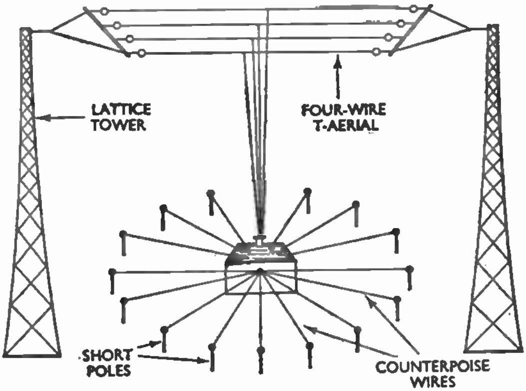


Fig. 58. Radial form of counterpoise or capacitive earth. Wires, only a few of which are shown, radiate from distribution points on each side of the sender building to a ring of short poles.

which signals are transferred from the aerial circuit to the receiver by means of suitably arranged inductive couplings. In this way, the effect of energy picked up by the horizontal portion of the aerial-system is minimized, with the consequent reduction of certain errors. See U-TYPE ADCOCK DIRECTION-FINDER.

COUPLED CIRCUIT. Circuit which receives energy from another circuit by electromagnetic induction (Fig. 59). The term is generally used in a specialized sense; to describe, for instance, the coupling between circuits when there is no metallic connexion. Circuits can be coupled by including a common reactance, resistance or impedance in both circuits.

Another form of coupling is made by using the proximity of two inductors, one in each circuit, to ensure the transfer of energy from one circuit to another. The distinction is, perhaps, too fine, as the mutual inductance in the case of inductive coupling is, in effect, an impedance common to the two circuits. See CAPACITIVE COUPLING, COUPLING, INDUCTIVE COUPLING, RESISTIVE COUPLING.

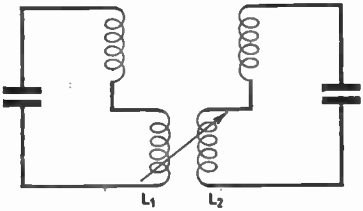


Fig. 59. Example of coupled circuits; mutual inductance between L_1 and L_2 forms the coupling by which energy passes to and fro between the circuits.

COUPLING. The condition in which electrical energy may be transferred from one circuit to another, whether the circuits are physically connected or not. The use of the term varies according to the aspect of the electrical circuits seen by different people in different circumstances. For instance, if transmission problems are considered in terms of filters and networks, the system shown in Fig. 60 is a form of band-pass filter; while from another point of view, the system might well be described as two coupled tuned circuits. Again, a theorist analysing filters would disregard Fig. 60a and redraw it as in Fig. 60b. The term coupling would not be used.

Similarly, from a radio-engineering point of view, the aerial is coupled to the closed circuit in Fig. 60c; but from the more general aspect of transmission, the same diagram might be said to show a transformer, in which the inductive reactance of the leakage inductance is neutralized by the inclusion of a capacitive reactance of opposite sign (Fig. 60d).

Common-impedance coupling (Fig. 61a) implies that an impedance is common to both circuits, so that energy is transferred from one circuit

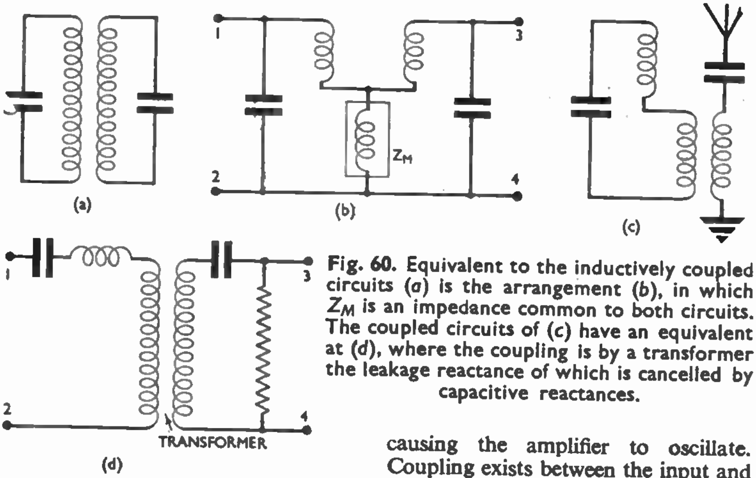
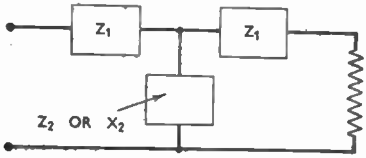


Fig. 60. Equivalent to the inductively coupled circuits (*a*) is the arrangement (*b*), in which Z_M is an impedance common to both circuits. The coupled circuits of (*c*) have an equivalent at (*d*), where the coupling is by a transformer the leakage reactance of which is cancelled by capacitive reactances.

to the other. But each of the circuits shown in Fig. 61b, in which an impedor is replaced by a reactor, are filter circuits. But here, again, by one person they may be described as coupled circuits, by another, as filter circuits. A distinction might be drawn involving the conception that filter elements have to be given exact values if their response characteristics are to conform to a calculated value, whereas "coupling" is conceived in a more casual way.

There can be no argument, however, about the use of the term to describe unwanted interconnexion of circuits. Thus an exposed connexion in the input circuit of a sensitive valve amplifier may pick up energy from an exposed connexion in the output, causing the amplifier to oscillate. Coupling exists between the input and output of the amplifier, just as it may exist between unscreened stages of an amplifier. The oscillators of a beat-



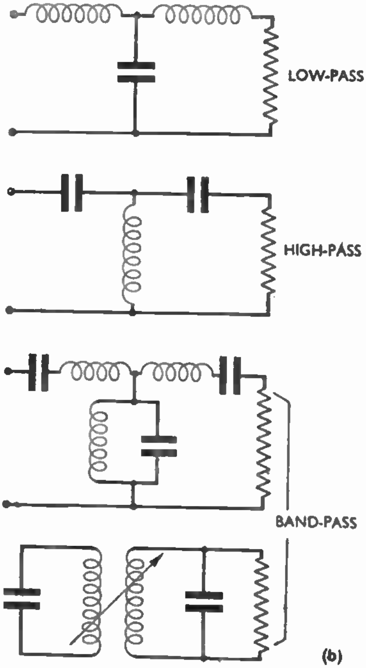


Fig. 61. The schematic diagram (*a*) is that of a common-impedance- (or reactance-) coupled circuit. Its exact equivalents (*b*) may, however, be correctly described as filter circuits.

frequency oscillator may be coupled, due to incomplete screening, and, in consequence, tend to cog. In describing such spurious couplings as these, the term seems to have found a common usage.

There is, furthermore, a common use of the term to describe different forms of amplifier, such as "resistance-capacitance coupling," "transformer coupling." See BAND-PASS FILTER, CAPACITIVE COUPLING, CLOSE COUPLING, COMMON-IMPEDANCE COUPLING, COUPLED CIRCUIT, INDUCTIVE COUPLING, LOOSE COUPLING, RESISTIVE COUPLING, TRANSFORMER.

COUPLING CAPACITOR. Capacitor forming a part of a common impedance in coupled circuits (see CAPACITIVE COUPLING); or a blocking capacitor; or, typically, the capacitor in a resistance-capacitance amplifier which prevents the steady voltage component at the anode of one valve affecting the grid bias of the valve in the following stage. See BLOCKING CAPACITOR, CAPACITIVE COUPLING, COUPLING, RESISTANCE-CAPACITANCE AMPLIFIER.

COUPLING COEFFICIENT. Number expressing the closeness, or tightness, of coupling. In general, the term expresses the amount of energy transferred from one circuit to another when the circuits are coupled. In an inductively coupled circuit (Fig. 62), the coefficient is given by $\frac{M}{\sqrt{L_1L_2}}$, M being the mutual inductance, and L_1 and L_2 the inductances in the two circuits which are coupled.

Thus, when $M = \sqrt{L_1L_2}$, the coupling coefficient is unity; if $L_1 = L_2 = L$, then, when $M = L$, the coefficient is unity. As M, the mutual inductance, is reduced so the coupling is not so tight, or is looser. If M is very small, the circuits are loose-coupled; and if large, tight-coupled.

The term applies not only to inductive, but also to capacitive and resistive coupling. The formal definition of the coupling coefficient, to embrace all forms of coupling, is: "the ratio of the mutual- or common-impedance component of two circuits, to the square root of the product of the totals, in the two circuits, of the impedance components of the same kind." The impedances referred to may be preponderantly inductive, capacitive or resistive. See CAPACITIVE COUPLING, COMMON-IMPEDANCE COUPLING, COUPLING, INDUCTIVE COUPLING, RESISTIVE COUPLING.

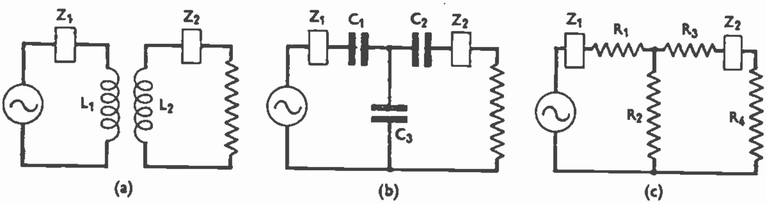


Fig. 62. Coupling coefficients in the above circuits are: (*a*) $M/\sqrt{L_1L_2}$, where M is the mutual inductance of L_1 and L_2; (*b*) $\sqrt{C_1C_2}/\sqrt{(C_1+C_3)(C_2+C_3)}$; and (*c*) $R_2/\sqrt{(R_1+R_2)(R_2+R_3+R_4)}$. Impedances Z_1 and Z_2 do not affect coupling coefficient.

COUPLING COIL. Term which may be employed to describe either of the coils in a variable mutual-inductance arrangement, sometimes termed a "variometer." The feedback coil of an oscillator, often called the "reaction" or "retroaction" coil, might be called a coupling coil; and the coil used to couple an aerial to the closed circuit of an oscillator could be called a coupling coil. See COUPLING.

COUPLING CONDENSER. Synonym for COUPLING CAPACITOR.

COUPLING FACTOR. Synonym for COUPLING COEFFICIENT.

COUPLING RESISTOR. Resistor which forms the common part of resistive-coupled circuits. See COUPLING COEFFICIENT, RESISTIVE COUPLING.

COUPLING SYSTEM. That part of a coupled circuit in which coupling takes place. See COUPLING.

COURSE-INDICATING BEACON. Automatic radio sender which radiates characteristic signals in one or more distinct directions, for the guidance of ships or aircraft. Such beacons may be arranged to cover a particular route and thus provide navigational assistance from point to point.

COVERAGE. Term, of American origin, for the area covered by strong signals from a broadcasting station, the service from which is defined in terms of its coverage. British usage prefers the synonymous term, SERVICE AREA (q.v.).

c.p.s. Abbreviation sometimes used instead of c/s for CYCLES PER SECOND.

CREST VALUE. Synonym for PEAK VALUE.

CRITICAL ANODE-VOLTAGE. See IONIZATION POTENTIAL.

CRITICAL COUPLING. Smallest degree of coupling existing between two tuned circuits, sufficient to give a just detectable band-pass, as compared with a peak-tuned response curve. Two tuned circuits tightly coupled together give a response curve which is substantially flat over a band of frequencies. Critical coupling is that small value of coupling which makes the band-pass characteristic just begin to flatten over a small band of frequencies. See BAND-PASS FILTER, COUPLING COEFFICIENT, INDUCTIVE COUPLING.

CRITICAL DISTANCE. Distance between the screen-grid and anode electrode of a tetrode which, when correct, ensures that the effects of secondary emission are nullified.

CRITICAL FREQUENCY. Highest frequency that an ionospheric layer can reflect to earth when the ray enters the layer at vertical incidence. The maximum electron density of an ionospheric layer is usually expressed in terms of the critical frequency, and if this frequency is determined, it is possible to estimate with a fair degree of accuracy the best short wavelengths to use for reliable long-distance communication between any two points.

The critical frequency is higher during the day than at night, and lower during the winter than in summer. Because of these characteristics, it is possible to use much shorter wavelengths during the day than at night. For instance, a communication over a distance of 6,000 miles during the daytime could be effected with a wavelength of 14 or 15 metres; but at night it might be necessary to use a wavelength as long as 30 metres. See IONOSPHERE, IONOSPHERIC RAY, IONOSPHERIC REFLECTION, IONOSPHERIC REFRACTION.

CRITICAL GRID-VOLTAGE. Value of the grid voltage in a gas-filled triode at which grid current just starts to flow, the potential of other electrodes being specified. See GAS-FILLED TRIODE.

CROSSED-DIPOLE AERIAL. System of two or more horizontal half-wave dipoles, set at right-angles, with each pair or group symmetrically disposed about a centre point. The system may be used in conjunction with a goniometer, in a similar manner to the crossed loops of the Bellini-Tosi direction-finder, for work on the higher frequencies. See BELLINI-TOSI DIRECTION-FINDER.

CROSS-MODULATION. Modulation of the carrier of a wanted signal by an unwanted, or interfering signal. In any communication system designed to transmit several messages simultaneously, we may, in considering the clear transmission of one message, call this message the "wanted" message or signal. In other words, it is necessary that each message shall be transmitted independently of all the others. It is undesirable, for instance, in a public telephone system that a person intended to receive one message shall hear another. Thus any one message or signal is the wanted signal or message, and any other, with respect to this wanted signal, is "unwanted."

An understanding of cross-modulation can be gained from the dynamic characteristic of a valve amplifier (Fig. 63). Consider two waves of different frequencies added together and applied to the grid. When the feebler wave is "riding" on the stronger, it is applied to the steep or the shallow parts of the dynamic characteristic depending on the instantaneous value of the stronger signal. Thus the weak signal is alternately subjected to low and high amplification. This is the mechanism of non-linear modulation, by which the stronger wave modulates the amplitude of the other (see NON-LINEAR MODULATION).

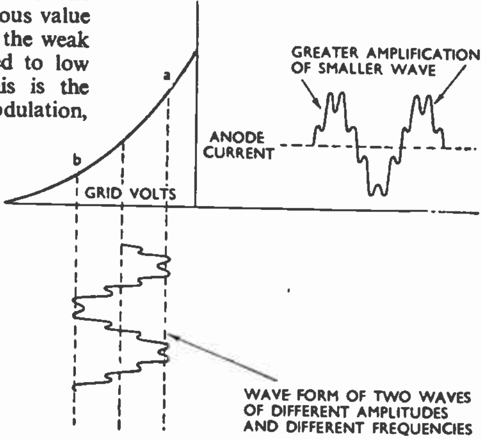


Fig. 63. Cross-modulation results when the wave which is produced by adding the voltages of two waves is applied to the grid of an amplifier valve. When working over a part *a* of the dynamic characteristic, amplification of the smaller-amplitude wave is greater than when working over the less steep part *b* of the characteristic.

In normal modulated carrier-wave transmission over lines, several messages are carried by carrier waves of different frequency. These waves are all grouped together in one conductor and pass, within a wide frequency band, through amplifiers or repeaters. Non-linear response of such amplifier will cause cross-modulation and it is usual to employ a very large amount of negative feedback in repeaters to reduce such effects. See CARRIER, GROUP MODULATION, MODULATED AMPLIFIER.

CROSSTALK. In a multi-pair cable, the induction of signals in one circuit from a neighbouring circuit; in a carrier system, the interference between two channels caused by intermodulation.

Numerous precautions are taken in the construction of a multi-pair cable to minimize crosstalk; for example, each pair of conductors is twisted and balanced and the power fed to each circuit is limited to a few milliwatts. Any faults which cause unbalance or excessive power may result in crosstalk.

The mechanism causing crosstalk in carrier systems is different. Repeaters are used to amplify several signals simultaneously, each signal consisting of a modulated carrier wave. If any one signal is large enough to drive the repeater off the linear part of its characteristic, rectification occurs and the modulation of one carrier is, in effect, transferred to other carriers. To minimize this cross-modulation the repeaters must have great linearity; this is achieved by the use of a high degree of negative feedback. See BALANCED TRANSMISSION LINE, SIMULTANEOUS BROADCASTING.

CROSSTALK ATTENUATION Attenuation between the sending terminals of the circuit causing crosstalk and the receiving terminals of the circuit in which crosstalk is caused. The attenuation can be measured directly by a volume indicator and expressed in decibels if the two pairs of terminals have the same impedance; but, if the impedances differ, a correction must be applied before the attenuation can be correctly stated.

Crosstalk volume cannot be evaluated from crosstalk attenuation unless the volume on the circuit causing the crosstalk is known. See CROSSTALK, CROSSTALK VOLUME.

CROSSTALK FACTOR. Ratio of the depth of modulation of the crosstalk in a second carrier to the depth of modulation of the first carrier when the modulation on a carrier is transferred by cross-modulation to a second carrier. See CROSSTALK.

CROSSTALK VOLUME. Volume of crosstalk speech expressed in decibels with respect to Reference Telephonic Power. See CROSSTALK, REFERENCE TELEPHONIC POWER, S.F.E.R.T. VOLUME INDICATOR.

C.R.T. Abbreviation for CATHODE-RAY TUBE.

CRYSTAL DETECTOR. Detector using the non-linear conductivity of certain crystals placed in contact with each other, or in contact with a suitable metal. Such contacts permit current to flow across the junction more readily in one direction than in the other, so that the arrangement acts as a rectifier and may thus be used for the detection of radio-frequency signals.

Examples of crystal-to-metal contacts are the galena and carborundum detectors. The former uses a crystal of galena in association with a light spring of copper or brass, as shown in Fig. 64. The sensitivity varies considerably with the actual spot on the crystal and with the pressure, so that frequent adjustment of the "cat's whisker," as it is called, is necessary.

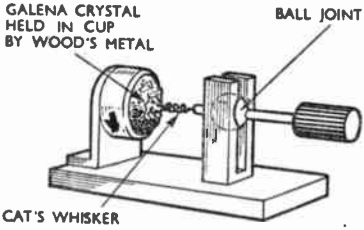


Fig. 64. Crystal detector comprising an adjustable spring of copper or brass in contact with galena crystal.

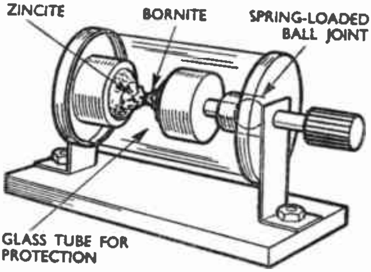


Fig. 65. Perikon detector, in which a spring-loaded bornite crystal is held in contact with a zincite crystal.

An alternative crystal-to-metal contact is the carborundum-steel arrangement (see CARBORUNDUM DETECTOR), which is not so sensitive as the galena crystal, but is more stable mechanically.

An example of the crystal-to-crystal contact is the zincite-bornite combination known as the Perikon detector. Here again the action is dependent upon finding the right points of contact, and the sensitivity is also dependent upon the pressure, so that one of the crystals is usually mounted in a spring-loaded holder (Fig. 65). A characteristic of a Perikon detector is illustrated in Fig. 66.

CRYSTAL DRIVE. See CRYSTAL-OSCILLATOR DRIVE.

CRYSTAL FILTER. Filter in which certain of the elements or arms of the filter are formed by quartz crystals. A quartz crystal is the equivalent of a series-tuned resonant circuit; it has a low resistance to waves of one frequency and a comparatively high reactance to waves of other frequencies. The notable point is that the crystal is equivalent to a series-tuned circuit with an inductor having a very large Q-factor. See QUARTZ CRYSTAL.

Certain filters give a more nearly ideal performance, as their elements are more like pure reactances; they absorb no power from currents passing through them. Thus a crystal is like a series combination of inductor and capacitor with very large Q-factors, and can be used with advantage in a filter for that reason. The practice of using crystal filters is expensive, and is only justified when the filter is required to give a very large attenuation for waves of certain frequency. See FILTER, Q-FACTOR.

CRYSTAL-GATE RECEIVER. Superheterodyne receiver of extremely high selectivity, this quality being due to the introduction of a quartz-crystal resonator at some suitable point in the intermediate-frequency amplifying circuits, usually in the second-detector grid circuit.

The quartz crystal is cut to the exact intermediate frequency, and its extremely sharp resonance properties cause it to act as a narrow "gate," excluding frequencies differing by only small amounts from the true intermediate frequency. Considerable attenuation of the sidebands of a type A3 transmission may result, calling for a suitable rising characteristic in the audio-frequency amplifying circuits.

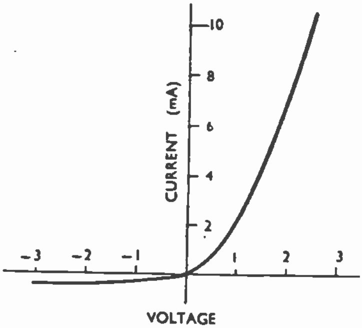


Fig. 66. Voltage/current characteristic of the zincite-bornite type of crystal detector shown in Fig. 65.

CRYSTAL HEADPHONE. Headphone with a diaphragm actuated by the expansion and contraction of a crystal plate or pair of plates, such expansion and contraction being caused by the application of electric potentials from a receiver or amplifier. See CRYSTAL MICROPHONE, HEADPHONE, PIEZO-ELECTRIC EFFECT.

CRYSTAL LOUDSPEAKER. Loudspeaker operating on the same principles as the crystal headphone. See CRYSTAL HEADPHONE, CRYSTAL MICROPHONE, LOUDSPEAKER, PIEZO-ELECTRIC EFFECT.

CRYSTAL MICROPHONE. Microphone which depends for its action upon the piezo-electric effect of certain crystals. The crystals used in microphones are generally of Rochelle salt because this exhibits the piezo-electric effect to a greater degree than quartz and other crystals.

If a slice of Rochelle salt is placed between two conducting plates, it will expand or contract, depending on the type of crystal, when potentials are applied between the plates. If an expanding type and a contracting type of crystal are rigidly cemented together, the combination, known as a *bimorph*, will twist or bend when potentials are applied to the plates. Conversely, if the bimorph is bent or twisted, e.m.f.s are developed between the plates. Both bending and twisting types of bimorph are used in crystal microphones.

In one type of crystal microphone a crystal slice is held at three corners, and the centre of a diaphragm is attached by a short reed to the fourth corner (Fig. 67). Thus any movement of the diaphragm caused by sound waves is communicated to the crystal, giving rise to a reciprocating motion of the corner, and alternating e.m.f.s are generated between the plates.

This type of microphone suffers from a number of defects because, to give a reasonably large output, the diaphragm must be at least two or three inches in diameter and its size is thus comparable with the wavelength of high-frequency sound waves. Such a diaphragm offers an impedance to the passage of high-frequency sound waves and may be likened to a breakwater which prevents the passage of sea waves. This "obstruction effect" causes the waves to exert more pressure than if the diaphragm were absent, the microphone tending to give an output which increases with increase in frequency.

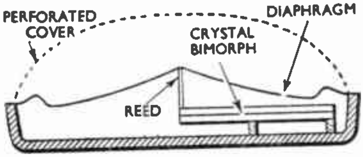


Fig. 67. Form of crystal microphone, shown in section, in which a crystal slice, held at three corners, has its fourth corner attached by a short reed to the centre of the diaphragm.

The diaphragm also causes the microphone to have a poor response to those high-frequency sound waves that strike the instrument at oblique angles of incidence, the response to low-frequency sounds being more or less independent of the angle of incidence. This tends to counteract the obstruction effect but also makes the microphone somewhat directional.

This type of microphone is very useful where the highest possible quality is not required and where the increased output due to use of a diaphragm is an advantage.

In another type of crystal microphone, two bimorphs of the bending type are mounted back-to-back to form a unit, known as a sound cell, which generates e.m.f.s when subjected to pressure (Fig. 68). If the pressures are alternating, as in sound waves, alternating e.m.f.s of the same frequency as the sound wave are generated between the plates. Thus the simplest type of crystal microphone may consist of a single sound cell which is mounted within a protective perforated cover.

No diaphragm is necessary and the dimensions of a sound cell can be made small enough to avoid the defects commonly experienced with microphones which have diaphragms. The output of such a microphone, though free from distortion, is very small; if a larger output is required, however, a number of sound cells may be connected in series or in parallel.

Over the audio range the impedance of a crystal microphone is predominantly capacitive and varies greatly with frequency. For this reason, matching transformers cannot be used to convey the microphone output to the following amplifier; it is usual, therefore, to connect the output of the microphone directly in the grid circuit of the first valve.

The impedance of a single-cell microphone is extremely high and the capacitance of even a short microphone cable would cause a serious loss in the already small output. Thus it is customary to eliminate almost completely the output lead by mounting the microphone amplifier, or the first stage of it, only a few inches from the microphone. The amplifier is then known as a head amplifier and is often housed in a tubular casing built into the microphone stand.

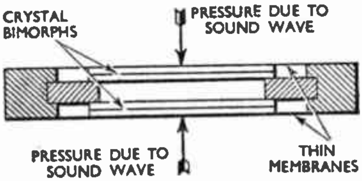


Fig. 68. Section through the type of crystal microphone in which there is a sound cell comprising two bending bimorphs mounted back-to-back.

A multi-cell microphone has a lower impedance and a greater output than a single-cell type and may be used successfully with cables many feet in length. See MICROPHONE, PIEZO-ELECTRIC EFFECT.

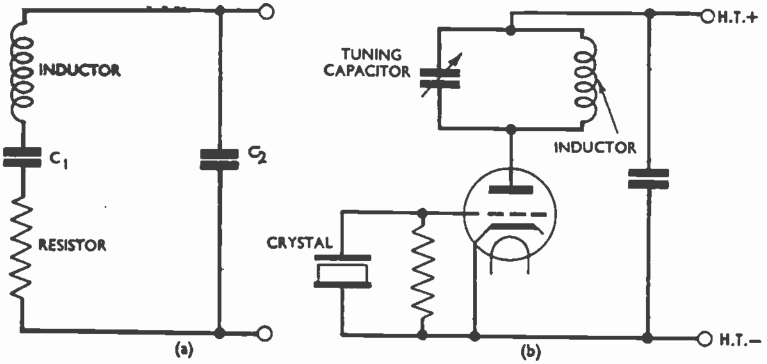


Fig. 69. In a crystal oscillator the frequency-determining element, having the equivalent tuned electrical circuit shown at (*a*), is a vibrating quartz crystal. The circuit diagram (*b*) is that of a simple form of crystal oscillator.

CRYSTAL OSCILLATOR. Term applied to a valve-maintained oscillating system in which the frequency-determining element is a quartz crystal.

The vibrating crystal in its mounting is equivalent to the tuned electrical circuit shown at Fig. 69a. In this circuit, the inductor, the capacitor C_1 and the resistor represent the equivalent mass, compliance (the reciprocal of stiffness) and frictional loss, respectively, of the vibrating crystal. C_2 represents capacitance of the holder.

The equivalent circuit has a frequency of parallel resonance, also one of series resonance. The Q value of the circuit is generally very high.

There are many varieties of crystal oscillator circuits, some utilizing the parallel resonance of the crystal, others the series resonance. A simple circuit is shown in Fig. 69b. Here the crystal replaces the normal tuned-grid circuit of a tuned-anode-tuned-grid oscillator, and operates very close to the parallel resonant condition of the crystal.

In order that continuous oscillations be maintained, it is necessary that there shall be a feedback of energy from the anode circuit to the grid circuit of such phase and magnitude as to meet the damping losses of the crystal and associated components. This implies that there must be a negative-resistance component in the input impedance of the valve, a condition which is obtained by tuning the anode circuit to a frequency slightly higher than that of the crystal.

The frequency stability of a crystal oscillator is much higher than that of normal tuned-circuit oscillators, even without temperature control. For frequency stability of very high order, it is usual to fit the crystal in a thermostatically controlled heat chamber and to employ stabilized supplies. See PIEZO-ELECTRIC EFFECT, QUARTZ CRYSTAL.

CRYSTAL-OSCILLATOR DRIVE. Master oscillator, suitable for controlling a chain of R.F. amplifiers, and in which the frequency-determining element is a piezo-electric crystal. The drive equipment usually includes a limiter stage which keeps the oscillator amplitude low to preserve a good wave form, and a buffer or separator stage which isolates the oscillator proper from the drive output circuit so that the oscillator frequency is not affected by connecting the drive equipment to the sender or any other circuits. See BUFFER STAGE, LIMITER

CRYSTAL OVEN. Temperature-controlled heat chamber containing a piezo-electric crystal. By maintaining the crystal within very close limits of temperature, a high degree of frequency stability is obtained.

CRYSTAL RECEIVER. Radio receiving equipment in which the function of detection is performed by the rectifying property of a light contact on the surface of a crystalline mineral substance (see CRYSTAL DETECTOR).

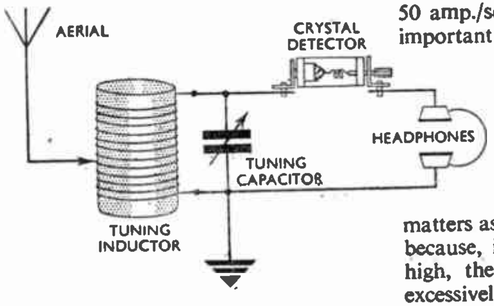


Fig. 70. Circuit connexions of a simple form of crystal receiver suitable for the reception, on headphones, of a local broadcast sender.

Such receivers, much used before thermionic valves were introduced, are usually simple in design, using only one or, at most, two tuned circuits, and consequently are of comparatively low selectivity. Lacking the amplifying power of the valve, they are suitable only for use at relatively short distances from the sender; but, for local reception on headphones where high selectivity is not needed, they are still the cheapest and simplest form of receiver. Fig. 70 shows the circuit of a typical crystal receiver.

CRYSTAL RECTIFIER. See CRYSTAL DETECTOR.

CRYSTAL SET. Synonym for CRYSTAL RECEIVER.

CRYSTAL TELEPHONE. See CRYSTAL HEADPHONE.

c/s. Abbreviation for CYCLE(S) PER SECOND.

C-SERVICE AREA. Area surrounding a broadcast sender in which the field strength is between 2·5 and 5 mV per metre.

CURRENT. See ELECTRIC CURRENT.

CURRENT DENSITY. Measure of current intensity in relation to the cross-sectional area of the conductor in which the current is flowing. Current density is commonly expressed in amperes per square inch. For example, if a current of 5 amp. flows in a conductor having a cross-sectional area of a tenth of a square inch, this is equivalent to a current density of 50 amp./sq. in. Current density is an important factor in deciding such matters as the diameter of a conductor because, if the current density is too high, the conductor may be heated excessively. Thus, to keep the temperature rise within specified limits, the current density must be kept below a certain value.

CURRENT-FED AERIAL. Aerial in which the driving energy is introduced at a current-maximum point, such as the centre of a half-wave dipole; hence the alternative term *centre-fed* aerial. See VOLTAGE-FED AERIAL.

CURRENT FEEDBACK. Negative feedback in which the voltage fed back to the input of the amplifier is directly proportional to the current in the load. Such a circuit arrangement is extensively used in the design of electronic amplifiers to obtain low harmonic distortion, improved frequency response and greater constancy of amplification with change in the supply voltages.

The basic circuit for providing current feedback is that illustrated in Fig. 71. A small resistor is connected in series with the load, and the p.d. developed across it is returned to the input of the amplifier. Here it is connected in series with, but so as to oppose in phase, the normal signal input of the amplifier. The effects of current feedback on gain and distor-

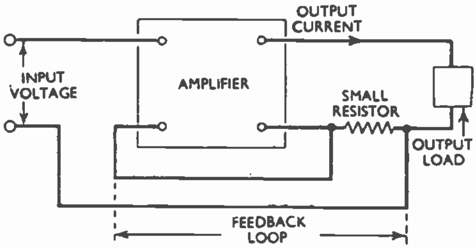


Fig. 71. Schematic diagram of the basic circuit for the provision of current feedback, showing what may be regarded as the feedback loop.

tion are similar to those of VOLTAGE FEEDBACK (q.v.), but its effect on output impedance is different.

When current feedback is applied to a single valve, as it usually is, it increases the output impedance, that is to say, it tends to make a triode behave as a pentode. Consider, for instance, the circuit shown in Fig. 72, where the negative feedback results merely from the omission of the customary by-pass capacitor across the bias resistor *R*; the voltage fed back to the grid will obviously be proportional to the amplitude of the signal current through *R*, which is in fact the anode current.

Suppose now that some change occurs in the anode load. If the load resistance increases, the signal current through *R* will diminish, and so will the voltage fed back to the grid circuit. Since the feedback is negative, its reduction will lead to an increased grid input and so tend to counteract the effect of raising the load resistance by keeping the anode-circuit signal current constant.

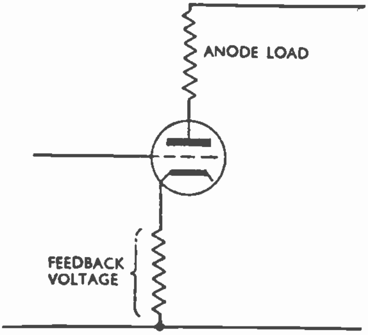


Fig. 72. Current feedback applied to a triode; when the usual by-pass capacitor across the bias resistor is omitted, the result is negative feedback proportional to the amplitude of the current that is flowing in the resistor.

If the anode load is *reduced*, the alteration in the feedback effect will oppose the change of signal current in the anode circuit. Thus changes in the anode load resistance have less effect on the amplitude of the signal currents than they would have in the absence of feedback. The effect is much as though the valve impedance had been considerably increased.

If applied to an output stage, current feedback would exaggerate the attenuation distortion occurring at the frequencies of mechanical resonance, and it is customary, therefore, to restrict its use to so-called voltage-amplifying stages where the increase in output impedance is of no consequence.

In the circuit of Fig. 72 the resistor *R* provides grid bias in addition to current feedback, and, if the value of the resistor is chosen to give correct bias, the current feedback is fixed. It is often desirable to have more or less current feedback than is provided by the bias resistor, and Figs. 73a and 73b show how this can be obtained.

In Fig. 73a the grid circuit is returned to the junction of R_1 and R_2, and the steady potential between grid and cathode is equal to the product of the anode current and R_1, which is therefore the bias resistor. Current feedback is, however, caused by the A.C. component of the anode current in flowing through R_1 and R_2, which together can be termed the feedback resistor. For example, if a cathode resistor of 5,000 ohms is necessary for feedback purposes, and if the bias-resistor value is 1,500 ohms, both requirements can be met by making R_1 equal to 1,500 ohms and R_2 equal to 3,500 ohms.

In Fig. 73b R_1 and R_2 in series determine the grid bias, since the steady potential difference between grid and cathode is due to the anode current in flowing through them. R_1 is shunted by a capacitor C_1, which is chosen to have a very low reactance over the frequency range of the amplifier. Thus the impedance of R_1 and C_1 in parallel is very small and the p.d. developed across them by the A.C. component of the anode current is very small; in other words, R_1C_1 produce negligible feedback. Only R_2 therefore is effective in providing current feedback.

As a numerical example, if the bias-resistor value is 1,500 ohms and only 1,000 ohms are necessary to provide the required current feedback, R_1 should be 500 ohms and R_2 1,000 ohms.

If the full gain of an amplifier is not always required, it is advantageous to "use up" the excess gain as feedback, since by this means distortion, hum, noise, etc., are reduced to their lowest possible level for a given output. This can be achieved by making the feedback variable and setting the gain to the desired value by adjustment of the feedback control. In this way feedback is always at a maximum and distortion at a minimum.

Fig. 73c shows one method of obtaining variable current feedback. This circuit is similar to that of diagram (a) in that R_1 provides bias and $R_1 + R_2$ provide feedback but the secondary winding of the input transformer is returned to the slider of the feedback control R_4. When the slider is at earth potential, circuits (a) and (c) are similar, feedback is a maximum and gain a minimum. At the opposite extreme of its travel, feedback is zero and gain the maximum that the valve can deliver. Between these extremes, intermediate degrees of feedback and gain are obtained.

It is not usually possible, by this means, to obtain more than about 30 db. variation in gain because this is approximately the maximum degree of feedback obtainable with a single valve. But 30 db. of variation is insufficient for many purposes, and often the feedback control is ganged with a conventional gain control in, say, the grid circuit of the following valve. The

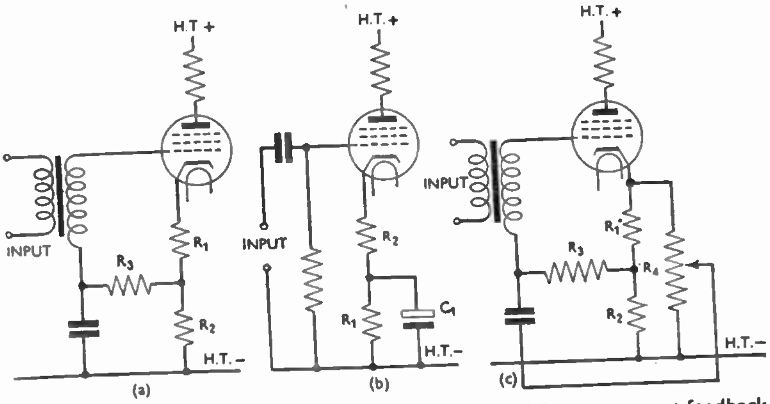


Fig. 73. Circuits which illustrate methods of obtaining (*a*) more current feedback and (*b*) less current feedback than is given by the bias resistor. The third arrangement, illustrated at (c), provides variable current feedback.

arrangement is such that, to increase gain from zero, the composite control first advances the grid potential divider to its maximum, the feedback remaining constant at its maximum value, after which continued rotation of composite control reduces the feedback to zero to give maximum gain.

By use of reactances in the feedback chain, it is possible to alter the frequency response of an amplifier to conform to a desired shape. Often, for example, a slight bass lift or treble lift is obtained by means of feedback to offset losses in bass and treble occurring elsewhere in the amplifier.

Top lift can be obtained very simply by connecting a capacitor in parallel with the feedback resistor, the value of the capacitor being chosen so that its reactance is comparable with the value of the resistor at high frequencies. If a larger capacitor is used the effect becomes a loss at the lower end of the amplifier pass-band, and if a very large capacitor is used the feedback is removed entirely, and the amplifier gives maximum gain at all frequencies.

Bass lift can be obtained by connecting an inductor in parallel with the feedback resistor, the inductance being chosen so that its reactance at low frequencies is comparable with the value of the feedback resistor. This is not a good method to use with a valve amplifying very small audio signals because hum may be introduced into the cathode circuit of the valve by induction in the inductor core. The amount of top lift or bass lift obtainable with these two circuits is, of course, limited by the amount of feedback used; if the feedback reduces the gain by 10 db. the maximum lift obtainable is 10 db.

CURRENT TRANSFORMER. Transformer used to measure or register current flowing in a circuit without disturbing the circuit conditions. Three uses of a transformer are shown in Fig. 74; in (a), the turns ratio is chosen so that maximum power is transferred from one circuit to another. If there is no loss, only the voltage and current values are changed between the two circuits, the product of current and voltage being the same on both sides of the transformer.

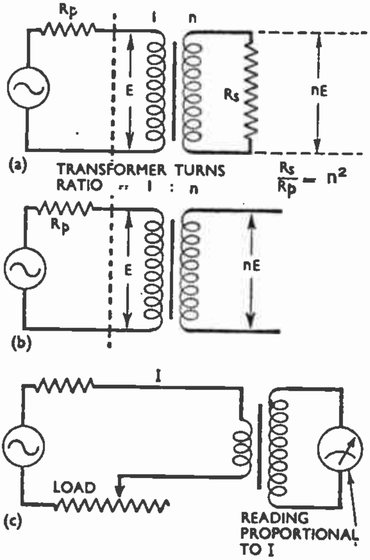


Fig. 74. Functions of the transformer: in (*a*) power is passed from a source to a load (of resistance R_s): (*b*), with load omitted, shows a voltage transformer, and (*c*) a current transformer.

Fig. 74b shows a voltage transformer, so-called because secondary voltage is greater than the primary; in this case, there is no secondary load, therefore no secondary current and no transfer of power. A transformer-coupled amplifier uses voltage transformers.

In Fig. 74c, matching does not take place and the current in the circuit is substantially unaffected by the series connexion of the primary of the transformer. It may be assumed that the instrument connected across the secondary of the transformer absorbs negligible power, but it does indicate a current which is proportional to the primary current. The primary current is almost wholly determined by the

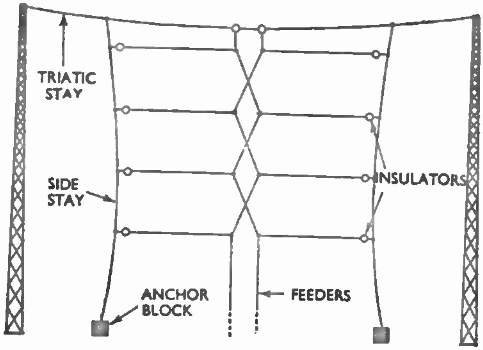


Fig. 75. Simplified representation of an elementary form of curtain array hung from a triatic stay between two masts. The aerial proper consists of four centre-fed half-wave dipoles arranged in a vertical tier.

load impedance and is measured by the current transformer. See TRANSFORMER.

CURTAIN ARRAY. Aerial-array consisting of a system of stretched-wire elements, hung between suspension members also made of wire or cable. In a typical form, the whole assembly is hung from a triatic stay between two masts or towers (Fig. 75). It may be backed with a second curtain consisting of passive aerials acting as reflectors to increase the directive properties of the active curtain. This arrangement is valuable on the higher frequencies, when the aerial elements commonly take the form of half-wave dipoles.

CURVE. Synonym for GRAPH.

CUT-OFF BIAS. Grid or modulator-electrode bias voltage required to reduce the anode current of a valve or the beam current of a cathode-ray tube to a negligible value, the potentials of the other electrodes being specified. The term must not be defined as the control-grid bias at which the anode current is zero, because this would be indefinite; for example, the anode current might be zero for a grid bias between 10 and 20 volts negative. See BIAS, CONTROL GRID.

CUT-OFF FREQUENCY. Term used to denote the frequency of the wave at which the attenuation of an ideal filter is zero, but at which an infinitesimal increase or decrease of frequency of the wave causes its attenuation to be finite. Fig. 76a illustrates the meaning of cut-off frequency for a low-pass filter; a band-pass filter has two cut-off frequencies.

The illustration shows attenuation curves of an ideal filter, which uses ideal elements having zero resistance. Assuming the filter elements have zero loss and that the filter is terminated in its image impedance, it can

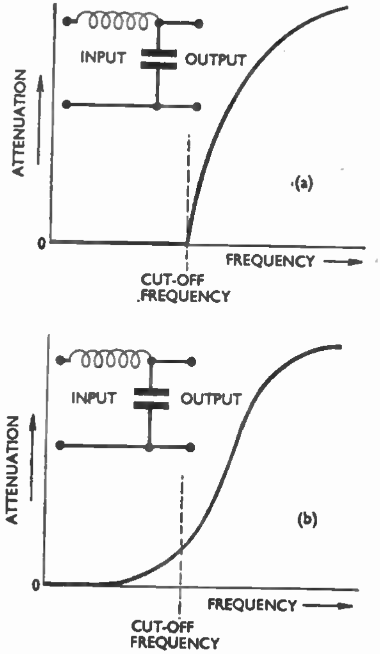


Fig. 76. Attenuation/frequency characteristic curves for filters terminated in their image impedances; (*a*) is that of a theoretical filter with elements having no loss. In practice the rate of change of attenuation at the cut-off frequency is gradual, as in (*b*).

be shown that the attentuation of the filter changes abruptly with frequency from zero to a finite value.

In practice, this does not happen; instead, there is a gradual change in attenuation with frequency around the cut-off frequency (Fig. 76b) because the filter elements are not pure reactances and because the filter cannot be ideally terminated. Nevertheless, the cut-off frequency is an extremely important parameter of a filter, since it is used in making calculations to determine the correct relative values of the filter elements. In other words, the cut-off frequency is a quantity relating the constants of the filter, and forms one of the bases for filter design. The attenuation at the cut-off frequency may be quite considerable, but allowances are made for this in design. See FILTER.

C.W. Abbreviation for continuous wave. See TYPE AO WAVE.

CYCLE. One complete positive, and one complete negative, alternation of a current or voltage. If a simple loop of wire is rotated in a fixed magnetic field, the voltage output across the ends of the loop starts from zero, and gradually builds up in one direction until it reaches a maximum; it then falls back to zero, again builds up to a maximum in the opposite direction, and finally returns to zero. Thus one cycle of alternating voltage is generated in each complete revolution of the simple loop.

The currents and voltages in an oscillatory circuit vary in a similar manner; the frequency, or number of cycles per second, depending on the inductance and capacitance values present in the circuit. If the oscillatory circuit is coupled to a radiating aerial-system it is found that the electric and magnetic fields associated with the radiated wave also vary in a cyclical manner. The electric field builds up to a maximum in one direction, then decays to zero, builds up to a maximum in the opposite direction and finally returns to zero again. See ALTERNATING CURRENT, OSCILLATING CURRENT, WAVE, WAVELENGTH.

CYCLES PER SECOND. Standard unit of frequency expressing the number of repetitions of an alternating voltage or current which takes place in an electric circuit during a period of one second. Convenient multiples of the unit have been evolved for the measurement of electromagnetic-wave frequencies; thus the frequencies of medium- and long-wave radio sending stations are expressed in kilocycles per second, a unit equal to 1,000 c/s; and megacycles per second, equal to 1,000,000 c/s are used to evaluate wavelengths that are shorter than 100 metres.

CYCLOTRON. Machine in which R.F. energy is used to separate electrically charged particles according to their mass. It is practically the only method of separating isotopes, and is used in preparing the uranium isotope from which atomic energy is obtained.

CYLINDRICAL AERIAL. Aerial, designed to cover a considerable band of frequencies, consisting of a half-wave dipole in which each element is composed of a cage. See CAGE AERIAL.

D

D.A.G.C. Abbreviation for delayed automatic gain-control. See DELAYED A.G.C.

DAMPED OSCILLATIONS. Oscillations of which the amplitude progressively decreases with time, as shown in Fig. 1. They may occur in a mechanical system, such as a pendulum, or in an electrical circuit, for example, oscillations produced in a resonant circuit by a spark discharge. See OSCILLATION.

DAMPED WAVES. See TYPE B WAVE.

DAMPING. That property of a circuit which tends to cause decay in the amplitude of oscillation. Examples are friction and viscosity in mechanical systems, and resistance in electrical circuits. If no energy is supplied to the system, the oscillation dies away at a rate dependent on the degree of damping. Damping reduces the sharpness of resonance of tuned systems and slightly decreases the natural frequency of parallel-tuned circuits.

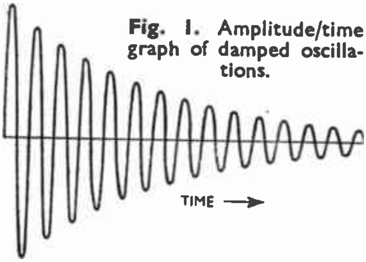


Fig. 1. Amplitude/time graph of damped oscillations.

DAMPING COEFFICIENT. Logarithmic decrement of an oscillation divided by the periodic time (see LOGARITHMIC DECREMENT). It is sometimes called the decay factor.

DARK CURRENT. Current passed by a photocell when no light falls upon it. If the cell is connected, as shown in Fig. 2, with a resistor to limit the current flow and safeguard the cell, it can be shown that a certain amount of current will pass through the cell, even with all light excluded, and this is known as dark current.

DARK RESISTANCE. Resistance of a cell measured under dark conditions, that is to say, with only dark current flowing. See DARK CURRENT.

DASH-POT. Device for preventing the sudden, rapid, or oscillatory motion of any moving part of a piece of apparatus. It has the form of a piston in a closed cylinder filled with air or oil. One part is fixed and the other attached to the moving part of the apparatus. The dash-pot operates by virtue of the slow rate that fluid can be transferred through a small aperture from one side of the piston to the other.

D.A.V.C. Abbreviation for delayed automatic volume-control. See DELAYED A.G.C.

db. Abbreviation for DECIBEL.

D.C. Abbreviation for DIRECT CURRENT.

D.C. AMPLIFIER. Amplifying apparatus capable of following the slowest of amplitude changes, sometimes called zero frequency. In practice, such an amplifier might be used to handle slowly changing direct currents, and would be generally similar to the conventional resistance-capacitance type, but with the grid blocking capacitors omitted. Separate power supplies to successive valves then become necessary, as in Fig. 3.

D.C.C. Abbreviation, in reference to conductors, meaning double-cotton covered.

D.C. COMPONENT. That part of a current wave form which is a direct current. Current with certain types of wave form can be simulated by sinusoidal currents to which is added a direct current (see FOURIER ANALYSIS). This direct current is called the D.C. component of a rectified wave. The sinusoids represent the A.C. components. See RECTIFICATION, RIPPLE, SMOOTHING CIRCUIT.

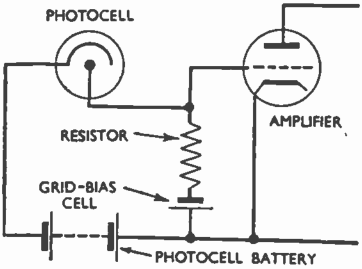


Fig. 2. Simplified circuit which can be used to indicate that dark current is flowing through a photocell.

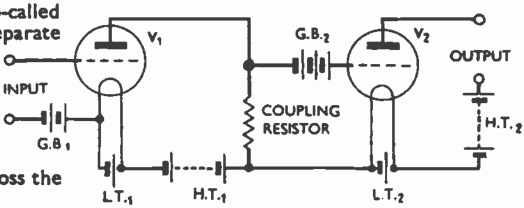


Fig. 3. Simplest form of so-called D.C. amplifier is with separate battery (or mains circuit) to each valve. *G.B.*2 is connected so as to "back off" the otherwise excessive negative bias on the grid of *V*2 from the voltage drop across the coupling resistor.

D.C. GENERATOR. Machine for the production of direct current. It is identical with a D.C. motor; in fact, any D.C. motor may be used as a D.C. generator and any D.C. generator as a motor. For constructional details, see MOTOR.

The series machine is unsuitable for ordinary purposes as, owing to the field windings carrying the armature current, the generated voltage increases as the load is increased. It is often used, however, as a booster to compensate for the drop of volts in a long cable.

The shunt-connected D.C. generator gives a voltage characteristic which falls somewhat as the load is increased, but, so long as the load changes gradually and the generator is under constant supervision, the drop in voltage can be compensated for by adjustment of the field rheostat. When the load is fluctuating, some automatic method of maintaining the voltage is required and the compound machine is used. It is so arranged that the effect of the series winding at full load is just sufficient to compensate for the fall of voltage that would occur if the shunt winding was used alone.

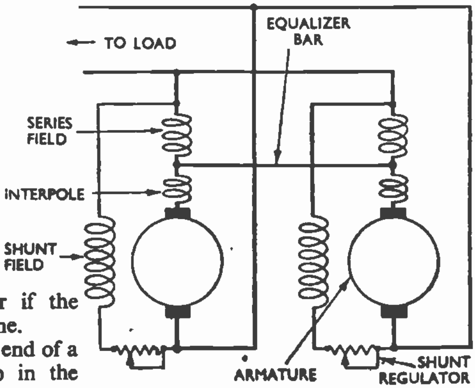


Fig. 4. When compound-wound D.C. generators operate in parallel, it is necessary to connect the series windings together on the armature side by means of an equalizer bar of low resistance.

If the load is situated at the end of a long cable, the voltage drop in the cable may be allowed for by "over-compounding" the generator so as to give a higher voltage at full load than at no load.

When compound generators are operated in parallel, it is necessary to connect the series windings of the two machines together on the armature side as well as on the busbar side by means of a low-resistance equalizer bar as shown in Fig. 4. Otherwise a state of instability develops, and one machine takes all the load whilst the other runs as a motor.

D.C. SIGNALLING. Method of communication by line in which the equipment at the receiving end is operated by pulses of direct current sent along the line.

D.C. TRANSMISSION. In electrical engineering, the passage of direct current along lines to operate equipment situated at some distance from the generator (for example, London Transport Underground can be said to employ D.C. transmission); in radio engineering, the radiation of a modulated carrier wave, the modulation wave form of which includes a D.C. component.

A system covered by the latter definition is used in the B.B.C. television service; the modulation range of 30–100 per cent modulation is arranged to be proportional to the D.C. output of the cameras which, in turn, is a measure of the average brightness of the scene that is being televised.

DEAD-BEAT. Tuned circuit or other potentially oscillatory device (such as the needle of a measuring instrument) so heavily damped that it cannot, in fact, oscillate. If a tuned circuit has what is called critical damping, it will, on being given momentary excitation, make a single unidirectional swing and come to rest. It will not "ring."

A dead-beat measuring instrument displays an immediate steady reading, without swinging or oscillation of its pointer. See DAMPING, RINGING.

DEAD END. Portion of a tapped inductor which is not in use at a given moment. A tapped inductor has one or more intermediate connexions to points on the winding.

DEAD-END EFFECT. Absorption of energy by unused portions of a tapped inductor. It is most marked when the inductance and self-capacitance of the unused portion chance to resonate at the frequency, or a harmonic thereof, to which the rest is tuned.

DEAD-END SWITCH. Device for minimizing dead-end effects by short-circuiting unused portions of a tapped inductor, either as a whole or (more effectively) in sections. It commonly takes the form of a rotary stud switch with a broad wiper blade instead of a narrow finger, as illustrated in Fig. 5. Instead of picking out single studs, the broad wiper or vane covers and connects together all the studs at the unused end of the inductor.

DEBUNCHING. Tendency, in a narrow electron beam, for the particles to spread out because of the mutual repulsion due to their negative charges. This tendency can be counteracted by suitably charged electrodes surrounding the beam, or, as in a gas-focused cathode-ray tube, by having some gas molecules in the tube. The positive ions from these molecules remain relatively static because of their relatively great mass, and those in the path of the electron beam attract the electrons and cause the beam to converge. By this method it is possible to focus the electron beam on the screen. See GAS FOCUSING.

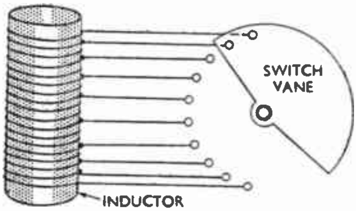


Fig. 5. Rotary type of dead-end switch; as the vane is rotated it connects up the contact studs, so short-circuiting the unused part of the winding.

DECADE INSTRUMENT. Instrument providing values of inductance, capacitance or resistance varying in multiples of ten, for example, 1 ohm, 10 ohms, 100 ohms; 1 henry, 0·1 henry, 0·001 henry. Such instruments are usually designed for precision work in laboratories and have calibrated controls.

DECAMETRIC WAVE. Radio-wave of 10–100 metres wavelength, that is to say, within a frequency range of 3–30 Mc/s. See HIGH-FREQUENCY WAVE.

DECAY COEFFICIENT. Synonym for DAMPING COEFFICIENT.

DECAY FACTOR. Synonym for DAMPING COEFFICIENT.

DECCA. See NAVIGATIONAL AID.

DECIBEL. Number obtained from the logarithm of the ratio of two values of electrical power. If P_1 and P_2 be two powers, then $10 \log_{10} \frac{P_1}{P_2}$ expresses the power ratio in decibels. (A bel is $\log_{10} \frac{P_1}{P_2}$.) Decibel is commonly abbreviated to db.

In the theory and practice of transmission, the decibel is, perhaps, the most used and most useful quantity, because the comparison of powers, rather than voltages, is so frequently necessary in line transmission.

It is more rewarding to compare powers than currents or voltages because, whether the system of transmission is telephony, telegraphy, facsimile or television, power is necessary to send signals through the line and to reproduce the signal in a form intelligible to the human senses. The line carries the messages, but, in so doing, power is lost. Obviously, before designing the equipments for sending and receiving the messages, the power loss in the line must first be calculated, so that it may be restored by amplifiers.

Transmission lines are usually terminated in a resistance equal to their characteristic impedance, so that the best matching is obtained and the only power lost in transmission is that due to attenuation. Because the rate at which power loss increases with the length of the line is an exponential law, the logarithm of the ratios of different amounts of power at different points along the line, which can also be expressed as the loss in decibels, is the same for the same length of line. This means that we can say of any given uniform line, suitably terminated, that its loss is so many decibels per mile, kilometre, or whatever unit of length is desired. Thus, if a line has a loss of 2·0 db. per mile, a line 10 miles long introduces a loss of 20 db.

To compensate for this loss, an amplifier with a gain of 20 db. is wanted. The above example shows how useful it is to have a logarithmic unit to express gain or loss; using this unit, it is unnecessary to work out power loss by calculations involving exponentials.

We can now go further and see that any power lost in transmitting any

DECIBEL TABLE

Greater than Unity

Power	*Decibel*	*Voltage or Current*	*Decibel Gain*
1	0	1	0
2	3·0*	2	6·0*
3	4·8*	3	9·6*
5	7·0*	5	14·0*
10	10·0	10	20·0
20	13·0*	20	26·0*
30	14·8*	30	29·6*
50	17·0*	50	34·0*
100	20·0	100	40
1,000	30·0	1,000	60
10,000	40·0	10,000	80

Fractions of Decibels

Voltage or Current Ratio	*Decibel*
1·01	0·1
1·02	0·2
1·03	0·3
1·04	0·4
1·06	0·5
1·07	0·6
1·08	0·7
1·10	0·8
1·11	0·9
1·12	1·0

Note. Figures marked * are not quite exact, but their error is usually negligible. Thus 3 db. is equivalent to a power ratio of 1·99, not of 2 as stated.

Less than Unity

Power	*Decibel*	*Voltage or Current*	*Decibel Gain*
1	0	1	0
0·5	3·0*	0·5	6·0*
0·2	7·0*	0·2	14·0*
0·1	10·0	0·1	20·0
0·05	13·0*	0·05	26*
0·02	17·0*	0·02	34*
0·01	20·0	0·01	40
0·001	30·0	0·001	60
0·0001	40·0	0·0001	80

wave through any network can be conveniently expressed in decibels. As a corollary, any power represented by so many decibels requires an amplifier of a certain gain in decibels to restore it. A filter may give a certain loss, even in the pass-band; its attenuation characteristic is conveniently expressed in decibels. If a transformer is inserted in a circuit, it inevitably introduces some loss, and this is expressed as an insertion loss in decibels (see INSERTION LOSS).

The power in an electrical circuit is given by the ratio of the square of a voltage acting across the circuit to the resistance of the circuit (see POWER, POWER FACTOR). Thus, if at some point in a circuit there is a voltage E_1 and a resistance R and at another a voltage E_2 and a resistance R, there are two powers E_1^2/R and E_2^2/R. The ratio of these two powers is $\frac{E_1^2}{E_2^2}$ and is independent of R. This makes it possible to express the power ratio in decibels by taking $10 \log_{10} \frac{E_1^2}{E_2^2}$, or $20 \log_{10} \frac{E_1}{E_2}$. Similarly, since power is expressed as RI^2, where I is a current, the power comparison in decibels in terms of two currents flowing in equal-value resistors is $20 \log_{10} I_1/I_2$.

A summary of the arguments set out in the foregoing is contained in the accompanying table. Note that decibels express gain or loss of power. A loss is sometimes given a minus sign and a gain a plus sign (see ACTUAL LEVEL).

Consider now an amplifier, whose input voltage is 0·1 and whose output voltage is 10. The resistance value of the input terminals is 50,000 ohms and the output load is 1,000 ohms. It is a common error to assume that the amplifier has a gain of 40 db. obtained by the ratio of $\frac{\text{output volts}}{\text{input volts}} = \frac{10}{0{\cdot}1} =$ 100. $20 \log_{10} 100 = 40$ db.

In fact, because the input voltage acts across a resistance quite different from that at the output, the power ratio must be calculated to get the true gain. Thus, the input power is $\frac{0{\cdot}01}{50{,}000}$ watts or $\frac{0{\cdot}01}{50}$ mW, and the output power is $\frac{100}{1{,}000} =$ 100 mW; so the gain in power is $\frac{50 \times 100}{0{\cdot}01} = 50 \times 10{,}000 = 50 \times 10^4$, or 40 db. (given by 10^4) + 17 (given by 50), or 57 db.

There is, in fact, a unit which compares the ratio of currents, regardless of the resistance value of circuits. This is called the NEPER (q.v.).

The vital point is that a decibel is a power ratio, and cannot be worked out in terms of voltage or current ratios unless the resistance value of the two circuits is the same. Thus, if a line terminated in its characteristic impedance shows an input voltage of 1 V and an output voltage of 0·1 V, we could compare these voltages to find a loss of 10:1 in volts, representing a loss of 20 db. Similarly, attenuation between the input and output of a symmetrical T- or π-filter can be evaluated simply from a comparison of the voltages at these points.

Attenuators calibrated in decibels are often used in transmission measurements. These are resistance networks (often of 600 ohms characteristic impedance) and switches are used to include, or take out, different sections of the network.

The radio engineer is perhaps not quite so likely to use the decibel, because he is so frequently concerned with voltage amplification and voltage frequency response; if not related to resistive impedance, the decibel becomes meaningless. Moreover, the attenuation of waves when transmitted over distances along the earth's surface does not, as in line transmission, follow an exponential law, and again it is more common and more useful to consider field strengths in absolute, or perhaps in relative, terms. Nevertheless, in the design of networks, equalizers, filters and power amplifiers, the decibel is of paramount importance and convenience. See ATTENUATION, BEL, INSERTION LOSS, NEPER, POWER, POWER FACTOR.

DECIBELMETER. A.C. voltmeter calibrated in decibels, zero voltage on the meter normally being equivalent to 0·775 volt. This voltage gives a power dissipation of one milliwatt across a resistance of 600 ohms.

DECIMETRIC WAVE. Radio-wave of 10–100 cm. wavelength, that is, within a frequency range of 300–3,000 Mc/s. The propagation characteristics of this type of wave are similar to those of centimetric waves. See CENTIMETRIC WAVE.

DECINEPER. One tenth of a neper. See NEPER.

DECOHERER. Mechanism for ensuring that a coherer ceases to conduct when no longer actuated by the applied signal. An electromechanical device is generally used to apply a gentle vibration to the coherer tube.

DECOUPLER. Network inserted between two circuits with the object of reducing the coupling between the circuits caused by physical connexions such as H.T. and G.B. leads. The term is not used to describe shielding which tends to prevent coupling due to stray electrostatic or magnetic fields. See PADDING.

DECOUPLING. Use of a decoupler circuit or network.

DECREMENT. Rate of dying-away of current in an oscillatory circuit when ringing. More precisely, it is the ratio between the peak value of one oscillation and the peak value of the preceding one, as indicated in Fig. 6. In its usual (logarithmic) form, decrement is given by the expression $\pi R \sqrt{C/L}$, where R is the circuit resistance, L and C being the inductance and capacitance.

DECREMETER. Instrument for measuring decrement by an indirect method involving known changes of reactance in a circuit. The method employs a capacitor with plates so shaped that a given change of dial reading produces a constant percentage change of capacitance in the circuit. See DECREMENT.

DE-EMPHASIS. Reduction in the relative amplitude of the higher modulation frequencies, effected at the receiver, to compensate for pre-emphasis at the sender. See PRE-EMPHASIS.

DEFINITION. In general, the capability of a television system to reproduce detail in the original scene. It is specified numerically by the number of lines of scanning. See HIGH-DEFINITION TELEVISION, LOW-DEFINITION TELEVISION.

DEFLECTION DEFOCUSING. In a cathode-ray tube, defocusing which becomes progressively greater as the deflection is increased. Asymmetrical deflection is particularly likely to cause it, because of the effect of unbalanced deflecting potential on the electron lens, and symmetrical deflection is thus preferable. Magnetically deflected tubes are also liable to deflection defocusing unless the deflector coils are very carefully designed to obviate axial components of the field. See ASYMMETRICAL DEFLECTION, ELECTRON LENS, FOCUSING, SYMMETRICAL DEFLECTION.

DEFLECTION SENSITIVITY. Degree of spot displacement, in a cathode-ray tube, resulting from the

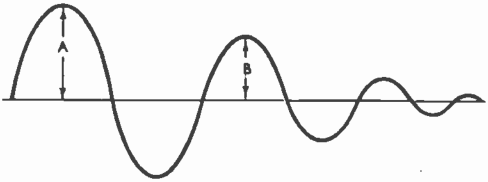


Fig. 6. Damping of an oscillatory current is governed by the decrement of the circuit; the ratio of *B* to *A* (as shown here) is a measure of the decrement.

application of a potential difference of one volt between a pair of deflector plates or a current of one ampere in the deflector coils. Deflection sensitivity equals $\frac{X}{V}$ mm. per deflection volt, where X is a factor characteristic of the tube geometry and V is the voltage of the final accelerator. See CATHODE-RAY TUBE.

DEFLECTION VALVE. Valve used in the cathode-ray tube time base to provide a source of potential or current, the rise and fall of which takes the form of a saw-tooth. This valve may be a thyratron, or a number of valves may be used to form a multivibrator or other form of oscillator circuit. (See TIME BASE).

A cathode-ray tube is sometimes employed for the production of varying currents by deflection of the beam from different "targets" on the screen, and thus might be called a deflection valve. The scheme is used in phase modulators. See ORBITAL-BEAM VALVE.

DEFLECTOR COILS. Coils associated with a cathode-ray tube and used for deflecting the electron beam over the surface of the screen by virtue of the magnetic field produced by the current flowing through them. Those coils which produce horizontal deflection are usually designated X, and those which produce vertical deflection Y. See MAGNETIC DEFLECTION.

DEFLECTOR PLATES. Electrodes in a cathode-ray tube which deflect the beam over the surface of the screen by virtue of the potentials existing between them. Those electrodes which produce horizontal deflection are normally designated X, and those which produce vertical deflection Y. See ELECTROSTATIC DEFLECTION.

DEGASSING. Removal of gas from inside the bulb of a valve. Ideally, the hard-vacuum valve should contain no gas at all; but in practice it is impossible to get a perfect vacuum. Nevertheless, the amount of residual gas left after degassing is very small indeed. The pumps used for degassing are elaborate; usually a motor-driven, oil-immersed pump is used. To get rid of occluded gas, which persists in the pores of the metal constituting the electrodes, these are raised to a high temperature while pumping goes on. The heating is produced by eddy currents induced in the metal by radio-frequency currents passed through coils surrounding the valve. See GAS-FILLED VALVE, GETTER, HARD-VACUUM VALVE, KEEPER.

DEGENERATION. Synonym for NEGATIVE FEEDBACK.

DEGENERATIVE AMPLIFIER. Synonym for NEGATIVE-FEEDBACK AMPLIFIER.

DE-IONIZATION TIME. Time taken for the ions and electrons in an ionized gas to recombine. To ionize a gas, the voltage acting across it must exceed a certain value (see IONIZATION POTENTIAL). For some time after the voltage is switched off, the gas is still conductive; this means that the current flowing in the gas cannot be intermittent if the voltage is switched on and off again sufficiently rapidly. Thus a gas-filled valve will not give intermittent currents following alternating potentials if the frequency is much greater than 50 kc/s, as the gas becomes non-conductive only after a lapse of time sufficient to allow the ions and electrons to combine and become neutral molecules and atoms. See GAS-FILLED VALVE, GLOW-TUBE.

DELAY DISTORTION. Distortion due to variation of the propagation time of the system with frequency. Numerically it is the difference in milliseconds between the time of propagation of the envelope of a wave at any frequency and that of a wave at a specified frequency, usually 800 c/s in telephony. Delay distortion takes place in telephone lines, cables, waveguides (especially near the critical frequency) and, due to ionospheric effects, in electromagnetic propagation. See GROUP DELAY, GROUP VELOCITY, TRANSIENT DISTORTION.

DELAYED A.G.C. Automatic gain-control which does not come into action unless the incoming signal exceeds a certain predetermined amplitude. This is accomplished by the method explained in Fig. 7. Weak signals are thus subjected to the full gain of the R.F. or I.F. amplifier, and strong ones to lower gain so that output remains substantially constant. See AUTOMATIC GAIN-CONTROL.

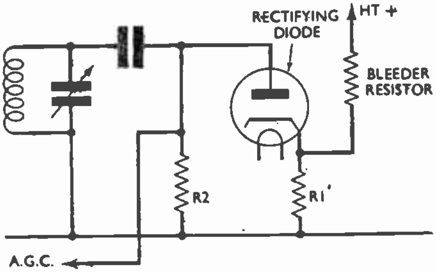


Fig. 7. To prevent A.G.C. from coming into action until the signal exceeds a certain minimum strength, a small negative bias may be applied to the anode of the rectifying diode. In this circuit the bias is obtained from the voltage drop across R_1, which is fed from the bleeder resistor; the A.G.C. voltage is developed across R_2.

DELAYED AUTOMATIC GAIN-CONTROL. See DELAYED A.G.C.

DELAYED AUTOMATIC VOLUME-CONTROL. See DELAYED A.G.C.

DELAYED A.V.C. Synonym for DELAYED A.G.C.

DELAY EQUALIZER. Equalizer which corrects delay distortion. See DELAY DISTORTION.

DELAY NETWORK. Electrical network designed to provide a specified delay in the transmission of currents with frequencies lying within a certain band. Such networks are used in telephone systems to allow time for switches or relays to be operated by speech currents. See DELAY DISTORTION, DELAY EQUALIZER.

DELLINGER FADE-OUT. Complete fade-out of short-wave radio signals. This phenomenon is the result of a burst of ionizing radiation from an eruption on the surface of the sun. It causes an abnormal increase in the ionization of that portion of the ionosphere below the E-layer. Radio-waves travelling through this region are almost completely absorbed.

The effect is usually complete within a few minutes of the eruption and may last for several hours. All parts of the earth illuminated by the sun suffer, but the effect is not apparent at night. The lower the frequency in use, the longer is the duration of the fade-out. See ABSORPTION, FADING, IONOSPHERIC RAY, MAGNETIC STORM.

DEMODULATION. Process which extracts the modulating wave from an amplitude-modulated wave by use of a local oscillator. Although detection and demodulation produce the same result, the processes are different. In demodulation of a modulated wave containing carrier and two sidebands, the modulated wave is remodulated by a wave having the same phase and frequency as the carrier wave.

Sideband frequencies in an amplitude-modulated wave are obtained by adding and subtracting the frequency of the modulating wave, to or from that of the carrier wave (see AMPLITUDE MODULATION, SIDEBAND). Thus a modulated wave contains waves having frequencies of $f_c + f_m$ and $f_c - f_m$, where f_m is the frequency of one sinusoidal modulating wave. If this wave is remodulated by a wave of frequency f_c, then differences of $f_c + f_m - f_c = f_m$ and $f_c - (f_c - f_m) = f_m$ are obtained. The addition of the waves produces waves of frequency $2f_c \pm f_m$. These spurious waves are eliminated by filters. Thus the remodulating of the modulated wave extracts the modulating wave. This remodulating is called demodulation.

The demodulating wave, supplied from a local oscillator, must be synchronized with the carrier wave in the modulated wave; thus it must have the same frequency and the same phase, otherwise the extracted modulating wave is distorted. In the demodulation of a single-sideband modulated wave, it is not necessary to set up synchronism with the carrier wave; but the frequency of the demodulating wave must be very close to that of the carrier wave. See DEMODULATOR, SINGLE-SIDEBAND MODULATION, SUPPRESSED-CARRIER MODULATION.

DEMODULATOR. Device using an oscillator which extracts the carrier wave from a modulated wave. It is essential, first, that the oscillator synchronizes with the carrier wave and, secondly, that the filter eliminates waves of twice the frequency of the carrier wave. Note that no detector is necessary. The difficulty lies in synchronizing the local oscillator without producing beat frequencies in the loudspeaker when tuning-in. Demodulators are chiefly used for the reception of commercial speech transmission in which the modulated wave contains only a single sideband. Precise synchronization is not then necessary. See DEMODULATION, DETECTOR, MODULATION.

DE-POLARIZATION. Action which takes place in a primary cell and tends to reduce the effects of polarization. See POLARIZATION.

DE-POLARIZER. Any chemical producing de-polarization.

DEPTH OF MODULATION. See MODULATION DEPTH.

DEPTH OF PENETRATION. Extent to which a current spreads into the substance of a conductor. Alternating currents of high frequency tend to flow on the surface of conductors, penetrating only to shallow depths; a direct current, on the contrary, distributes itself uniformly through the whole cross-section of the conductor (Fig. 8).

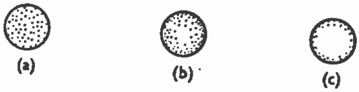


Fig. 8. Direct current spreads uniformly through the substance of a conductor (*a*). The depth of penetration is less for alternating currents (*b*), and, if of sufficiently high frequency, they are confined to the surface layer (*c*).

DEPTH-SOUNDING. Determining the depth of water beneath a ship. A modern method utilizes beamed trains of supersonic waves sent out by a projector fitted on the bottom of the hull. These waves travel down through the water, are reflected by the sea bed and return to the ship. The velocity of the waves being known, the time that elapses between the transmission of a train of waves and the reception of the echo from the sea bed is a measure of the depth of water.

Direct indication of the depth of water is provided by an indicator with a linear time scale. Suppose there are 5 fathoms of sea water beneath the ship. The average velocity of the supersonic waves in sea water being 820 fathoms per second, a total time of 12·2 milliseconds is taken for the waves to travel the total distance of 10 fathoms from ship to sea bed and back to the ship. The indicator is so arranged that at the moment of transmission it reads 0 fathoms and, 12·2 milliseconds later, 5 fathoms.

The principal parts of a depth-sounding installation are:

(1) A transmitter which takes electrical energy from the mains or a battery, transforms it and excites the transmitting projector at appropriate intervals.

(2) A transmitting projector which converts the electrical energy into supersonic waves in the water. In some installations the same projector is used for the reception of the echo.

(3) A receiving projector, if a single projector does not perform the dual function of transmission and reception, to convert the supersonic waves of the echo into electrical energy.

(4) An amplifier to amplify the echo

signal sufficiently to operate the indicating apparatus. In some installations, the transmitter and amplifier circuits are contained in a single transmitter-receiver unit.

(5) A recorder and/or visual indicator, together with a timing device to trigger the transmitter when the scale indication is at zero.

Of the projectors used in marine installations, there are two main types, operating on magneto-striction and piezo-electric principles respectively.

In the Marconi equipment known as the "Seagraph" Echo-sounder, the projector is of the high-power magneto-striction type. It may be installed either in a hull casting, and thus in direct contact with the sea, or internally so that transmission and reception take place through the ship's shell plating. The former method, known as the pierced-hull method, gives an improved performance in deep water or under bad weather conditions when the echo may be considerably weakened by aeration below the ship.

With pierced-hull installation, only one projector is required, acting as

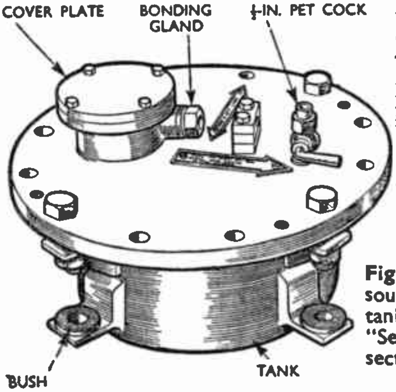
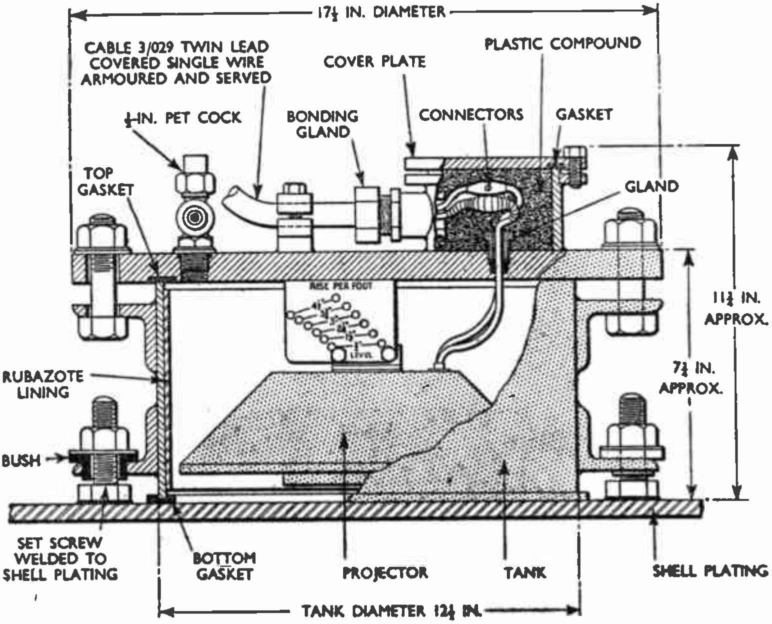


Fig. 9. An example of modern depth-sounding equipment; (*left*) the projector tank of the internally installed Marconi "Seagraph" Echo-sounder, and (*below*) a section of the assembly, showing the projector in the tank.



both transmitting and receiving projector, but two are normally installed, one acting as a stand-by. With internal fitting, two projectors must be used, one for sending and the other for reception.

The projector consists of a flat circular magneto-strictive element built up in the form of a deep annular ring which has a natural frequency of vibration of 14 kc/s, approximately. A conical reflector is used to redirect the vibrations from the circumference of the element from a horizontal to a vertical direction.

When the projector is fitted internally, the element is mounted inside a tank, secured to the bottom plate of the ship (Fig. 9), and filled with fresh water. When the ship's hull is pierced, the projector is secured inside a steel casting which surrounds the inner side of a hole in the shell. The upper end of the casting is sealed off with a heavy steel plate and the projector is sealed from the sea by a thin stainless steel cover, filled with fresh water, and so arranged that it fills completely the cavity made in the shell plating.

The transmitter and the amplifier circuits are contained in a single "Transceiver" unit (Fig. 10). This unit also contains a power-supply unit for the whole equipment. The power-supply unit is suitable for operation either from a 24-volt battery or from the ship's D.C. mains (110 volts or 220 volts). H.T. voltages are obtained by means of a vibrator and a system of transformers and rectifiers.

The transmitter (Fig. 11) consists of a 2-μF capacitor and a mercury-vapour discharge tube, connected in series with each other and with the projector winding. Its action is as follows: The capacitor is charged up to 1,200 volts through a high resistance from the power-supply unit. This voltage is also impressed on the anode of the mercury vapour tube, but the latter cannot operate until it is "struck" by a considerably higher voltage.

The keying switch in the recorder is connected in series with the primary of a high-ratio step-up transformer. When

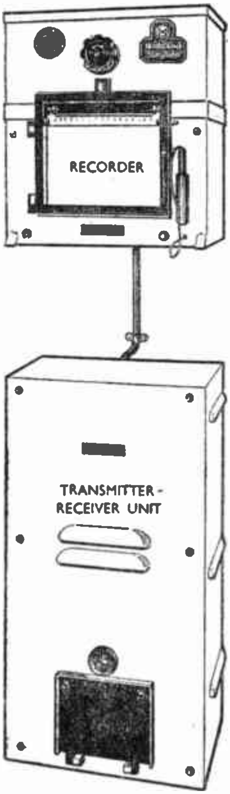


Fig. 10. Above the "Transceiver" unit of the Marconi "Seagraph" Echo-sounder is a depth recorder unit which provides a graph of the kind shown in Fig. 12.

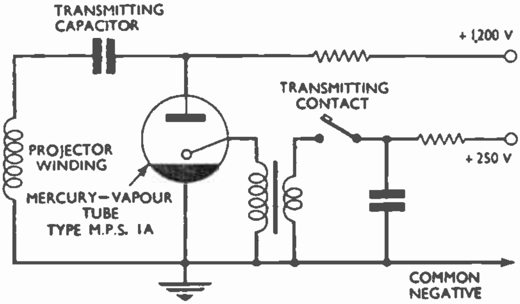


Fig. 11. Basic transmitting circuit of the "Seagraph" depth-sounding equipment described in the text.

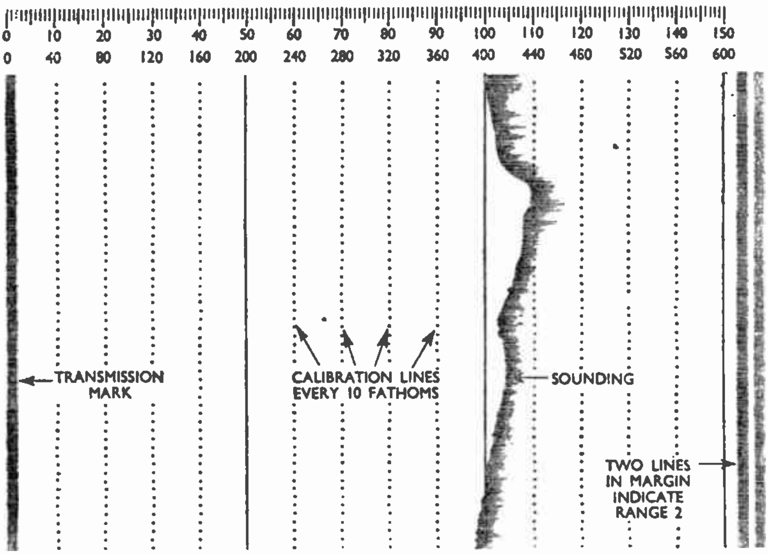


Fig. 12. Portion of a typical depth-sounding record produced by the Marconi "Seagraph" equipment operating, in this case, on range 2 (0-150 fathoms). The marks made by the stylus form a contour of the sea bed.

the switch closes, a high-voltage pulse, of the order of 12,000 volts, is produced in the secondary of this transformer and applied to the ignition electrode of the mercury-vapour tube.

The tube is triggered off and the transmitting capacitor discharges through the projector winding. The mercury-vapour tube extinguishes at the end of the first half-cycle. The sudden release of the energy in the capacitor into the transmitting projector shock excites the latter, causing the magneto-strictive element to vibrate at its own natural frequency.

The amplifier contains four valves, resistance-capacitance coupled. The input is tuned to 14 kc/s. The output circuit of the final stage is tuned and connected to a full-wave rectifier system, the output of which is taken to the recorder stylus.

During transmission, the input of the amplifier is short-circuited. This is achieved by the use of an auxiliary anode in the mercury-vapour discharge tube. Use is made of an automatic time-controlled gain system that depresses the gain considerably at the recorder-scale zero and progressively less as the indicator advances over the scale, the condition for maximum gain being reached at the 200 fathoms mark, approximately.

The recorder (Fig. 10) provides a paper record of the depths of water beneath the ship. A typical sounding record is shown in Fig. 12. The recorder stylus, which runs in a straight line across sensitized paper, is attached to an endless belt and is driven at a uniform speed, corresponding to the range scale in use.

The paper is used in a damp condition and when an echo pulse of current from the amplifier passes from the stylus through the paper, iodine is liberated and leaves a brown mark. The paper is pulled slowly past the moving stylus and, since there are many transmissions per minute, the marks join together into a continuous line that forms a contour of the sea bed.

The contact that closes the trigger circuit of the transmitter when the stylus is at the scale zero is operated by a keying button on the stylus belt.

Graduation lines are electrolytically printed on the record, showing 10-ft., 10-fathom or 40-fathom intervals, depending upon the range in use. An indication of the range is also automatically printed on the record in the form of vertical lines at the right-hand side: one line for Range 1, two lines for Range 2 and three lines for Range 3.

The three ranges are:
Range 1, 0–150 ft. (0–25 fathoms);
Range 2, 0–150 fathoms;
Range 3, 0–600 fathoms.

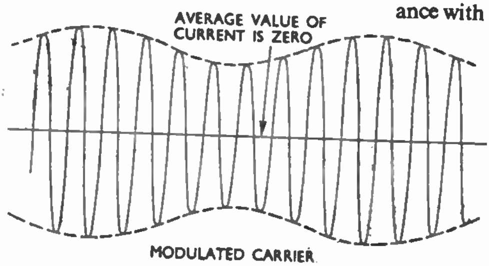
The rates of sounding are:
Range 1, 209 soundings per minute;
Range 2, 48·5 soundings per minute;
Range 3, 12·0 soundings per minute.

DERIVED UNITS. Any system of units derived directly from the basic units of length, time and mass. See PRACTICAL SYSTEM OF UNITS.

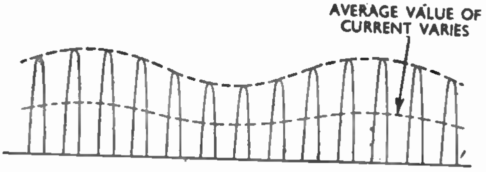
DETECTION. Process of making audible (or otherwise reproducible) the variations of amplitude (or frequency) of a modulated carrier wave. The frequencies of the currents used in the generation of wireless waves are well above the limits of audibility and consequently the currents picked up on a receiving aerial cannot be heard directly.

It is necessary to modulate the currents in the transmitting aerial in some way, the most common method being to vary the strength, or amplitude, in accordance with the intelligence to be conveyed (see MODULATION). Similar variations in amplitude then occur in the received signal, but, as these variations are still only changes in the strength of a carrier wave which is oscillating many hundreds of thousands of times per second, the mean value is still zero. It is necessary, therefore, to introduce some device which will respond to the modulation, that is to say, one that will provide a current proportional to the changes in amplitude, which is what we are primarily interested in.

The most usual way of doing this is to introduce into the circuit some device which conducts current more easily in one direction than in the other. The mean value of the current is then no longer zero, but varies in accordance with the changes in strength of the carrier. This will be clear from Fig. 13, where the first line shows a modulated carrier, that is to say, a high-frequency oscillation of which the strength is varying at a lower frequency. For simplicity, the



MODULATED CARRIER



RECTIFIED CARRIER

Fig. 13. Effect of detection on a high-frequency oscillation; the average value of current is zero in the modulated carrier, but varies in accordance with the modulation when the carrier-wave is rectified.

carrier frequency has been chosen at only about ten times the modulation frequency so that the individual waves can be shown clearly; but in practice, the carrier frequency is many hundreds, or even thousands, of times greater than the modulation frequency.

The second line shows the effect of passing this current through a non-linear device which cuts off the current completely in one direction. It will be seen that the mean value of the current is now changing with the modulation. If such a current were passed through a telephone receiver, for example, the receiver, while unable to take any account of the high-frequency carrier current pulses, would respond to the variations in mean current.

An ideal detector would pass no current at all in one direction, but permit current in the forward direction to an extent which was strictly proportional to the voltage applied across the circuit. Such detectors, however, are not found in practice. Crystal rectifiers (see CARBORUNDUM DETECTOR and CRYSTAL DETECTOR) pass an appreciable reverse current, though this is considerably less than the forward current, and does not seriously affect the performance. In the case of a diode rectifier, the reverse current is so small as to be negligible.

A more serious source of difficulty is that the changeover from the non-conducting to the conducting condition is not sudden but gradual, so that the "knee" of the curve is not sharp. It will be clear, therefore, that the current which will flow is not directly proportional to the applied voltage, being smaller with small voltages than with large.

Most detector characteristics are fairly linear beyond the knee. In other words, beyond the transition portion, the characteristic is approximately a straight line, so that the current output is proportional to the voltage applied. For this reason, arrangements are made, in all except the simplest receivers, to amplify the radio-frequency signals before applying them to the detector, so that the signals are of such a strength as to swing well beyond the initial curved portion of the characteristic. See DETECTOR, LINEAR DETECTION.

DETECTION COEFFICIENT. Ratio of the actual audio-frequency output from a detector to the theoretical output obtainable with perfect rectification. In a practical detector circuit, we apply the signal to a detector in series with a load. This may be a pair of telephones in a simple crystal receiver, but is more usually a resistance-capacitance combination (see DIODE DETECTOR).

The audio-frequency voltage is developed across the total circuit impedance consisting of the load and the detector in series. Hence only part of the total audio-frequency voltage is actually available across the load. Thus, if we had a carrier input of 1 volt modulated to a depth of 30 per cent, we should expect 0·3 volt audio-frequency output; whereas, in practice, we should obtain only about 0·25 volt, corresponding to a detector efficiency of 83 per cent.

To maintain a high efficiency, the load impedance should be made large compared with the internal resistance of the detector. With practical circuits, this requires a load of 0·1 to 0·5 megohm.

The internal resistance of a practical detector decreases appreciably as the signal strength increases. Hence the detection coefficient improves with increasing signal strength. With very weak signals it is likely to fall well below the figure quoted above, which is a further reason for the use of radio-frequency amplification prior to the detector stage.

DETECTOR. Device with a non-linear current/voltage characteristic used to separate the modulating wave from a modulated carrier wave. The term is generally used in connection with amplitude modulation; a detector for frequency-modulated or phase-modulated waves is usually known as a DISCRIMINATOR (q.v.).

Though some types of detector circuit are very similar to rectifier circuits, the essential difference between them is that, in general, the input to a detector is a modulated wave and its output is at modulating-wave frequency, whereas the input to a rectifier is an unmodulated wave and its output is D.C.

The simplest type of detector consists of a contact between two dissimilar conductors or semi-conductors which are chosen to have the essential property of conducting more readily in one direction than in the other. Possibly the first type of detector to be used was a copper wire in contact with a crystal of galena; more modern counterparts of this are the copper-oxide detector and the germanium or silicon crystals extensively used for detecting centimetric waves during the Second World War.

The majority of detectors are, however, electronic valves; the most popular type is probably the diode detector, which is used almost universally in modern radio receivers. Other types of valve detector include the leaky-grid, the anode-bend and the infinite-impedance detectors.

In the early days of the superheterodyne receiver, the frequency-changer was known as the *first* detector, while the real detector was called the *second* detector. The frequency-changer has the function of transferring the modulation from a carrier wave of one frequency to a carrier wave of a different, and usually lower, frequency; but this does not agree with the definition of a detector and the term "first detector" was thus a misnomer. Nevertheless, there was some justification for use of the term because the early frequency-changers did embody some form of detector, usually of the anode-bend type. Frequency-changing was achieved in those days by adding (connecting in series) the output of the local oscillator with the output of the R.F. amplifier. The result of such an addition is a complex wave from which the wanted output at the difference frequency can be obtained only by the process of detection. Thus the additive type of frequency-changer necessarily embodies some form of detector.

Modern frequency-changers operate on an entirely different principle: the output of the oscillator and that of the R.F. amplifier are, in effect, multiplied together and the wanted output at the difference frequency is obtained directly and without the necessity for any form of detector. Multiplicative frequency-changers cannot, therefore, be classed as detectors, nor do they contain detectors. See ANODE-BEND DETECTION, GRID DETECTION, INFINITE-IMPEDANCE DETECTION.

DETUNING. Act or process of adjusting the tuning of a circuit or apparatus away from a particular frequency. It is sometimes done, for example, in the intermediate-frequency circuits of a superheterodyne receiver, in a particular manner to obtain some desired shape of resonance curve.

DEVIATION RATIO. Ratio of the frequency deviation of a frequency-modulated wave to the maximum frequency of the modulating wave. See FREQUENCY MODULATION.

DIAGONALIZING. System of allocation of carrier-wave frequencies to broadcasting senders in a continental area in which senders geographically close together use carrier-wave frequencies which are widely different. Diagonalizing is intended to minimize interference between broadcasting senders caused by the overlapping of sidebands in the service areas of senders which are close to one another. There is little virtue in the system because, at night, the reflected ray from even far-distant senders is strong enough to cause interference in a B-service area. See IONOSPHERE, SERVICE AREA.

DIAGRAM SYMBOLS. See SYMBOLS.

DIAL. Plate, usually circular and bearing radial graduations, which is used in conjunction with a pointer to indicate units of measurement in a variable component. The dial may be fixed and the pointer rotated over it, or the pointer or index mark may be fixed and the dial rotated past it. In a broadcast receiver, the wavelength or frequency dial may be marked also with the names of broadcasting stations at appropriate points on the scale.

The term has a special meaning in telephony; it is used to describe the rotatable plate with finger holes with which a subscriber sends trains of impulses to an automatic telephone exchange when making a call.

DIAMAGNETIC. Property of having a lower magnetic permeability than unity; lower, that is, than the permeability of a vacuum.

DIAMOND AERIAL. Aerial designed to cover a considerable band of frequencies, consisting of a half-wave dipole in which each half resembles a CONICAL AERIAL (q.v.); the broad ends of the two cones are placed adjacent to each other, however.

DIAPHRAGM. Thin plate or cone supported at its periphery. When subjected to air pressures produced by sound waves, the diaphragm vibrates at the frequency of the sound. The vibrations thus produced may be converted into electrical energy, as in the microphone. Conversely, if an iron diaphragm is placed in the field of an electromagnet, it can be made to vibrate at audio frequency by applying speech currents to the electromagnet; this principle is applied to the loudspeaker and the headphone. See HEADPHONE, LOUDSPEAKER, MICROPHONE.

DIELECTRIC. Insulating material, especially that separating the plates of a capacitor.

DIELECTRIC CONSTANT. Synonym for RELATIVE PERMITTIVITY.

DIELECTRIC HYSTERESIS. Timelag effect shown by a dielectric material in recovering from subjection to an electric strain.

DIELECTRIC LOSS. Energy dissipation in the dielectric of a capacitor when carrying an alternating current. The theoretically perfect capacitor has zero loss, but, in practice, energy loss is caused in various ways; for instance, by the imperfections of the insulating material between the plates; when carrying a heavy current the dielectric heats up—a sure sign of energy loss. Dielectric losses can, of course, occur wherever there is capacitance between parts of a circuit at different potentials. The extent of the loss depends on the "quality" of the dielectric material. See CAPACITANCE.

DIELECTRIC STRENGTH. Synonym for ELECTRIC STRENGTH.

DIELECTRIC STRESS. Synonym for ELECTRIC STRENGTH.

DIFFERENTIAL ANODE CONDUCTANCE. Synonym for ANODE SLOPE-CONDUCTANCE.

DIFFERENTIAL ANODE IMPEDANCE. See ANODE IMPEDANCE.

DIFFERENTIAL ANODE RESISTANCE. Synonym for ANODE SLOPE-RESISTANCE.

DIFFERENTIAL ELECTRODE CONDUCTANCE. Synonym for ELECTRODE SLOPE-CONDUCTANCE.

DIFFERENTIAL ELECTRODE IMPEDANCE. See ELECTRODE IMPEDANCE.

DIFFERENTIAL ELECTRODE RESISTANCE. Synonym for ELECTRODE SLOPE-RESISTANCE.

DIFFRACTION. Effect occurring in the lower air-layers above the earth which enables the ground wave of a sending station to follow the curvature of the earth and travel beyond the optical range. When a wave is travelling over an imperfectly conducting body, such as the earth, the electric field of the wave must have a component horizontal to the earth, because the currents induced in the earth require potential differences over the surface to produce them.

The electric field of a vertically polarized wave is, therefore, no longer vertical, but tilted, the foot dragging behind. The exact angle of tilt depends upon the conductivity and the relative permittivity of the area over which the

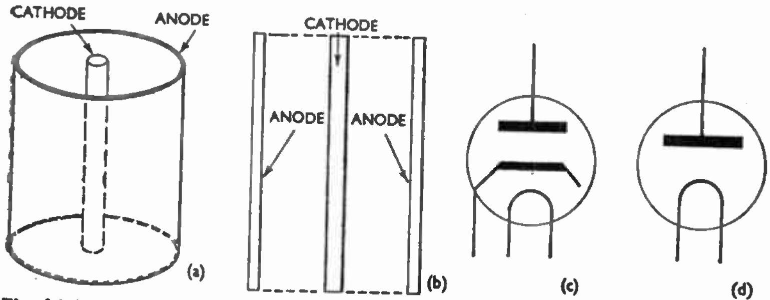


Fig. 14. Basic features of the diode (*a*); vertical section of electrodes (*b*); representation of the diode with (c) an indirectly heated and (*d*) a filament cathode.

wave is travelling. The effect of diffraction is well known in connexion with light rays, where the rays "leak" around an opaque body and illuminate an area which one would expect to be in shadow if the rays followed straight lines.

The effect of diffraction becomes greater as the wavelength increases, and this partly accounts for the fact that the ground wave travels longer distances as the wavelength is increased. As the wavelength is reduced, however, the ground-wave range becomes very small, and, on ultra-short wavelengths, it may not be much more than the optical range. See ABSORPTION, CONDUCTIVITY, PERMITTIVITY, POLARIZATION.

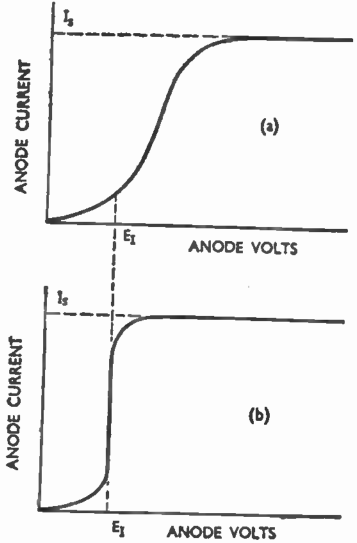


Fig. 15. Anode-volts/anode-current characteristics of (*a*) a hard-vacuum diode and (*b*) a gas-filled diode. Below the ionization potential E_I both graphs are the same, and the maximum current I_s is the same in each.

DIODE. Valve having two electrodes, namely, anode and cathode. A diode and its diagrammatic representation are shown in Fig. 14. A diode used in a mains unit is known as a rectifier valve; it is known as a detector when used to rectify radio-frequency waves.

The diode may be either a hard-vacuum or gas-filled type. When gas-filled, it is used to rectify mains A.C. The hard-vacuum diode is used for mains rectification and the detection of radio-waves.

The anode-volts/anode-current characteristics of a hard-vacuum and a gas-filled diode are shown in Fig. 15; both valves exhibit the same characteristics at low anode voltages while the current is limited by SPACE CHARGE (q.v.). Once space-charge limitation no longer applies, a hard-vacuum diode exhibits a uniform anode slope-resistance. When the anode current reaches the total emission of the cathode the graph becomes horizontal, as the cathode cannot supply any more electrons to provide the increased current which would flow, in a conductor obeying Ohm's law, with increased voltage.

The state of affairs in a gas-filled diode is different: once the gas is ionized, positive ions attracted to the space charge neutralize it and the current increases, causing more ions to form. Anode current is thus increased until this quantity reaches saturation. See EMISSION LIMITATION, GAS-FILLED DIODE, IONIZATION, MERCURY-ARC RECTIFIER, SPACE CHARGE, SLOPE RESISTANCE.

DIODE DETECTOR. Two-electrode valve used for detection. Detector diodes are made of small dimensions to reduce self-capacitance, and are designed to have a low internal A.C. resistance so that the detection coefficient shall be as high as possible.

The application of one form of diode detector is shown in Fig. 16. The diode is in series with a load resistor and a parallel capacitor. On the arrival of a signal, the diode conducts when its anode is positive. The resulting current charges the capacitor to a voltage nearly equal to the peak value of the applied signal. Some of the charge leaks away through the resistor during the remainder of the cycle. On the next positive peak the diode conducts again when the applied signal exceeds the voltage to which the capacitor has charged, and makes good the loss which has taken place through leakage. The action is illustrated in Fig. 17.

If the signal is varying in amplitude, as in the case of a speech-modulated carrier, then, provided the modulation changes are slow in comparison with the carrier frequency (which is always the case in a practical system), the voltage on the capacitor will adapt itself all the time to the changing amplitude, so that the voltage across it varies in accordance with the modulation voltage.

For this process to be reasonably faithful, the time constant of the resistance-capacitance circuit must not be too long (see TIME CONSTANT). In other words, the value of the resistance relative to the capacitance must be low enough to permit the charge to leak away at least as fast as the most rapid change of carrier amplitude corresponding to the highest modulation frequency.

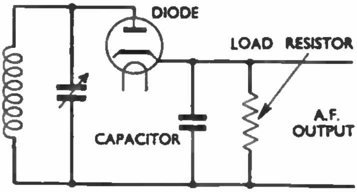


Fig. 16. Circuit showing application of one form of diode detector. Resulting action is illustrated in Fig. 17.

If the capacitance is too large and/or the resistance is too high, the charge cannot leak away sufficiently rapidly, and distortion will result. This shows itself as a loss of upper frequency in the response while, if the time constant is very much too large, the circuit fails to follow the modulation, and the reproduction sounds choked.

A second form of circuit is shown in Fig. 18. Here the resistor is connected

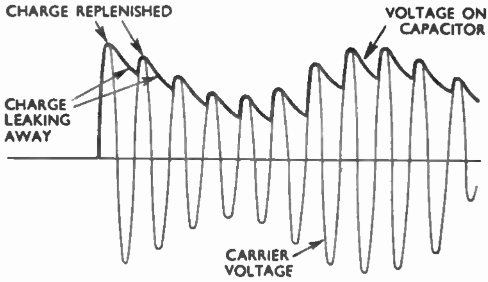
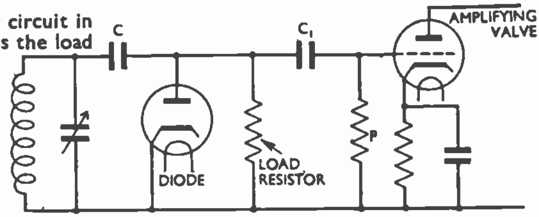


Fig. 17. Diagram showing the wave form produced by the alternate leaking-away and replenishment of the charge on the capacitor in the diode-detector circuit of Fig. 16.

across the diode. The action is the same as for Fig. 16. The capacitor *C* charges on the peaks of the carrier, the charge then leaking away through the resistor during the period that the diode is non-conducting. In the circuit of Fig. 18 the voltage across the load resistor has been transferred to an amplifying valve through a coupling capacitor C_1 and leak. This second network modifies the effective diode load at modulation frequencies. To avoid distortion, the resistance of *P* should be at least four times the diode load resistance.

Fig. 18. Diode-detector circuit in which the voltage across the load resistor is applied to the grid of an amplifying triode. To avoid distortion the value of *P* should be at least four times the load resistance.



DIPLEX OPERATION. In telecommunication, the transmission or reception of two separate messages on a single set of equipment.

DIPLEX RECEPTION. Reception of two transmissions of different frequencies by means of two receivers working on a common aerial.

DIPOLE. Synonym for HALF-WAVE DIPOLE.

DIPOLE AERIAL. See HALF-WAVE DIPOLE.

DIRECT ADMITTANCE. The reciprocal of direct impedance. See DIRECT CIRCUIT, DIRECT IMPEDANCE.

DIRECT BEARING. Direction of a distant point measured along the shorter of the two possible Great Circle directions. See BEARING, RECIPROCAL BEARING.

DIRECT CAPACITANCE. See DIRECT IMPEDANCE.

DIRECT CIRCUIT. In telegraphy, a circuit in which currents are transmitted from one station to operate the distant signalling instrument without the use of relays at intermediate points along the route.

DIRECT COUPLING. Coupling of circuits by physical connexion between them, as distinct from INDUCTIVE COUPLING (q.v.). Direct coupling is otherwise called common-impedance coupling, and the current path may be either capacitive or resistive.

DIRECT CURRENT. Current which flows steadily in one direction, and without regular variations in strength. Direct current (D.C.) is that given by the simplest sources, such as the primary battery or accumulator, and is the simplest form of electrical energy. Its effective value in a circuit, for instance, is fixed merely by the strength of the electromotive force or voltage and by the natural opposition of the circuit (more technically known as its resistance). There are no complications such as arise with alternating currents (A.C.).

The magnitude of D.C. varies directly with the voltage—twice the voltage means twice the current—and inversely with the resistance: twice the resistance means half the current, and so on. Again, the power which it delivers is found simply by multiplying the voltage by the current; a current of 5 amp. at a pressure of 10 volts gives a power of 50 watts. Another form of the same relationship states that, in a circuit of given resistance, the power is proportional to the square of the current. This follows because to double the current it is necessary to double the voltage also, and that is equivalent to multiplying the product of these quantities by four.

Although D.C. is not so universally useful as A.C., it has many special applications. D.C. is valuable, for example, in electric traction; the D.C. motor is more flexible than most A.C. types, and lends itself to fine adjustment of power and speed, as well as being capable of starting under heavy loads.

Various electrolytic processes demand the use of D.C.; electro-plating is possible only with a non-reversing flow of current, and accumulators can be charged only by means of such a current. Arc lights, too, are best run from D.C. and cinema projectors are therefore provided with a direct-current supply.

Direct currents of small power are customarily obtained from primary batteries or from accumulators; the bigger currents needed for electroplating and arc lamps may be obtained from big rectifiers of, for instance, the mercury-arc type, or from the kind of rotating generator called a dynamo. This machine is essentially similar to the alternator, in that it consists of an armature which carries a winding, or series of windings, and is revolved in an intense magnetic field. The dynamo, or D.C. generator, differs from the alternator in having a form of rotating switch fitted to the armature shaft to alter the connexions of the armature windings as they turn so as to keep the current flowing out of the machine always in the same direction.

The principle of the dynamo is simply that of ELECTROMAGNETIC INDUCTION (q.v.), seen also in the transformer, the alternator and many other devices used in electrical engineering and radio communication. The powerful magnetic field, in which the armature is spun, is produced by an electromagnet fed with current generated by the machine itself; the electromagnet windings may be in series with the armature, so that they carry the whole output current of the dynamo, or they may be in parallel, carrying only a fraction of the output. These two types of D.C. generator are known respectively as series and shunt machines.

Direct currents are used in radio for the anode supply of valves, and also for developing the grid-bias voltages. In the common type of mains receiver, D.C. is obtained by rectifying and smoothing an alternating voltage provided by a transformer (see RECTIFICATION, SMOOTHING CIRCUIT). D.C. is little used for general power distribution, mainly because it cannot be transformed up and down in voltage without the use of rotating machinery See ALTERNATING CURRENT.

DIRECT-DISC RECORDING. System of gramophone recording in which the recorded disc may be reproduced without resorting to processing. See ELECTRICAL RECORDING.

DIRECT DRIVE. Sending system in which there is direct coupling between aerial and oscillator circuit.

DIRECT IMPEDANCE. Impedance (or capacitance, inductance, resistance, etc.) existing between two terminals of a network having several terminals. The term is more likely to be used in connexion with the analysis of the theory of transmission, than with day-to-day practice and design.

Direct impedance may be more fully defined as a term indicating that the quantity specified is that pertaining to the current path or paths directly connected to the two terminals specified, any current reaching these terminals by way of any other terminals being left out of account in measuring or reckoning the quantity concerned. See CIRCUIT, NETWORK.

DIRECT INDUCTANCE. See DIRECT IMPEDANCE.

DIRECTIONAL AERIAL. Synonym for DIRECTIVE AERIAL.

DIRECTIONAL RECEIVER. Complete receiver and aerial-system so designed that reception efficiency is at a maximum on signals from a particular direction.

DIRECTIONAL SENDER. Complete sender and aerial-system so designed that radiation is at a maximum in a particular direction. The direction may be fixed as for a station designed to communicate with another of known position, or it may be variable, as in a directive-signalling beacon.

DIRECTION-FINDER. Complete apparatus, including aerials and receiver, for determining the direction of arrival of radio-waves. The simplest direction-finder is a receiver working from a loop-aerial (Fig. 19). The strong directional properties of this combination must be familiar to users of portable receivers, which must be turned to either of two diametrically opposed directions to receive maximum signals from a station (see RECIPROCAL BEARING). Midway between these two settings there is another orientation in which signal strength is nil or is greatly reduced. This minimum position is normally more sharply defined than the maximum and is therefore used in determining bearings with this and most other direction-finders.

In its simplest form, the plain loop direction-finder will not indicate which of the two possible orientations denotes the true direction of the sender; the minimum-signal position merely shows that the loop is broadside on to the wave front but does not indicate from which side the waves are approaching. A comparatively minor modification, however, enables the direction to be determined (see SENSE-FINDING).

The loop direction-finder is subject to errors, which are minimized in more highly developed types; but its simplicity and compactness make it attractive wherever great precision is not essential. In a practical installation, such as on a ship or aircraft, the loop is usually constructed in a convenient weather-proof form and mounted externally; for example, on the roof of the ship's radio cabin or under the fuselage of an aircraft. The loop is then provided with a remote control, usually of a simple mechanical kind, but sometimes employing a pair of self-synchronizing motors, enabling it to be turned by the operator sitting at his receiver.

The loop must be small so that it can be rotated easily; it is therefore a somewhat inefficient pick-up device for medium and low frequencies. This in turn indicates the need for a high-gain receiver, which was not available in the early days of direction-finding work. For permanent ground installations, therefore, other types were developed in which the aerial or aerials need not turn. In the Bellini-Tosi system, for instance, fixed loops are used; these are connected to the field coils of a goniometer, the search coil of which is used to determine the equivalent direction of wave travel (see BELLINI-TOSI DIRECTION-FINDER).

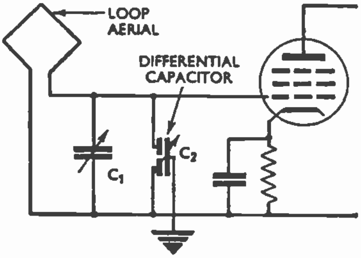


Fig. 19. First stage of a simple loop direction-finder. The rotatable loop is tuned by C_1, while the differential capacitor C_2 equalizes the stray capacitance to earth from the two sides of the circuit to eliminate antenna effect.

As the loops need not rotate, they can be made large and capable of effective pick-up, especially on medium frequencies; and receiver gain need not be high, a strong point in favour of the system when it was first developed. Now that highly sensitive receivers of stable and robust types are available, the loops need not be so large, and Bellini-Tosi direction-finders are often used on shipboard.

In closed-loop direction-finders, certain residual errors are troublesome, and the spaced open-aerial type is consequently often preferred when space permits, as, for instance, on ground stations (see POLARIZATION ERROR, RADIOGONIOMETER, SPACED-AERIAL DIRECTION-FINDER).

In a typical form, there are four open aerials symmetrically spaced and connected in opposite pairs to a goniometer in the receiver building, which is situated at the centre of the aerial-system. Direction-finders of this sort can be arranged to minimize errors produced by such phenomena as the presence in the radiation of components which are polarized in other than vertical directions.

At night it is common for waves which have travelled some distance to contain a substantial proportion of erratically polarized radiation; the simple loop or Bellini-Tosi direction-finder is therefore sometimes incapable of giving correct bearings after dark, whereas the Adcock in its most effective form will continue to do so.

A typical spaced-aerial direction-finder of the Adcock type for operation on medium and long wavelengths consists of four mast aerials, each about 120 ft. high, set at the corners of a square having 200-ft. sides, with the receiver building situated in the centre.

From the base of each mast, a buried and screened concentric feeder runs to the receiver hut, and to the goniometers of the receiver. One goniometer is provided for each frequency range to be covered. Suitable switching arrangements connect the relevant goniometer to the receiver, which is a highly sensitive superheterodyne with separate oscillator for beat reception of unmodulated signals, and possibly a note filter and other refinements for dealing with jamming.

For sense-determination, a fifth, vertical aerial is usually provided which can be combined with the direction-finding aerials to produce an asymmetric polar diagram. This sense aerial is commonly hung immediately above the receiver hut, with its upper end supported by triatic stays running between the tops of the aerial masts. See CARDIOID DIAGRAM, SPACED-AERIAL DIRECTION-FINDER.

DIRECTION-FINDING. Determination of the bearing of a distant sender by means of observations on the signals received from it. The basic principles of direction-finding are of the utmost simplicity, and to the first experimenters it must have seemed to offer a navigator's aid of truly revolutionary importance. To all appearances it is necessary only to set up a sharply directive, rotatable-aerial system such as a loop of suitable design, orientate it by seeking the setting for minimum signal, which is usually more sharply defined than the maximum, and read off the bearing which it indicates. In favourable conditions it may indeed be as simple as that, and the bearing of the distant sender can be decided to an accuracy of two degrees or better.

Given bearings of similar accuracy on two or more distant senders suitably situated, the observer can fix his own position with some precision on a map showing the positions of the two senders; from these he draws lines corresponding to bearings which are the reciprocals of those he has measured with his direction-finder (see RECIPROCAL BEARING). The intersection of the lines indicates the observer's position. Alternatively, the navigator of a ship or aircraft who wishes to fix his position may enlist the help of ground direction-finding stations, asking them to take bearings on him while he sends a test signal.

The ground direction-finders are generally arranged in chains of two or three widely spaced stations connected by land-line telephone. One of the stations, acting as "control," receives telephoned bearings from the other stations in the chain, combines them with its own, plots all bearings on a map and then signals a position or fix to the inquirer. Despite the apparently lengthy procedure involved, this system has been so highly developed that the navigator is given the required information in under a minute.

The latter method has an advantage in that the somewhat elaborate and specially calibrated apparatus needed for accurate direction-finding can be carefully located on a well-chosen permanent site, thus obviating the limitations and error-prone complications of shipboard or aircraft use. On the other hand, the method is relatively cumbersome and is expensive. Ships and aircraft therefore often carry their own direction-finding gear, for use when a quick position check is required, or when out of range of suitable D.F. stations.

Direction-finding is not, in fact, the simple and accurate process that it seems. Study of the behaviour of radio-waves, and of directive aerial-systems, reveals many complications. It is found, for instance, that radio-waves do not necessarily follow shortest-distance-between-two-points paths; often they are deflected, and arrive at the direction-finder from a false direction after reflection from a ground feature or an irregularity in the E-layer or F-layer.

Or the direction-finder may find itself receiving a mixture of direct and reflected ray, which is likely with some equipments to result not only in actual errors but in bearings so indefinite as to be almost useless. The aerials and aerial-circuits themselves are also potential sources of error (see ANTENNA EFFECT, POLARIZATION ERROR).

Indeed, it is remarkable that direction-finder bearings are so accurate. An experienced operator can generally recognize the conditions likely to produce major errors, and can warn his navigator against undue reliance on D.F. position at such times.

As an alternative to the methods just described, direction-finding may be done with the aid of directive transmissions from senders at known positions (see BEACON DIRECTION-FINDER). Such methods are often of only moderate accuracy, but they have the advantage of being simple to use; the user is not required to measure the bearing, but to observe certain indications which show when the sender is directing its radiation straight towards him. At that moment, the signals themselves carry a coding enabling the observer to deduce the bearing; in most cases all this can be done with an ordinary communications receiver and aerial-system. See DIRECTION-FINDER.

DIRECTIVE AERIAL. Aerial which radiates or receives most strongly in some particular direction or directions. A directive aerial may take many forms, the classic example being the inverted-L, which functions most effectively in the direction of the down-lead end. In general, those aerials used for work at the higher frequencies for which the aerial length bears some special relation to the wavelength are directive to a limited extent. Thus the simple half-wave dipole radiates or receives most strongly in directions at right-angles to its length and most feebly from its ends, giving a figure-of-eight polar diagram.

An array of such dipoles, placed end to end and suitably spaced in the same plane, produces a progressively more elongated figure as the number of elements is increased. Still further elongation, which means increased directive effect, can be obtained by placing reflectors behind each active element in order to weaken backward radiation and increase forward direction.

In another form, the aerial consists of a single element, normally a half-wave dipole, placed at the focal point of a reflector-system which may be a metallic surface, usually of parabolic form, or an assembly of passive elements so spaced and positioned as to produce a similar focusing effect; or a wire mesh surface can be used. Such an aerial-system radiates a more or less sharply focused narrow beam, such as is used for radar purposes, or for point-to-point communication on the higher frequencies. See AERIAL, AERIAL-ARRAY, HALF-WAVE DIPOLE, PASSIVE AERIAL, RHOMBIC AERIAL, YAGI AERIAL.

DIRECTIVE SENDING. Radiation which is at a maximum in some particular direction or directions. See DIRECTIONAL SENDER.

DIRECTIVE-SIGNALLING BEACON. Automatic radio sender which, by means of a directive-aerial system, radiates characteristic signals in a succession of known directions, so that ships or aircraft may obtain a bearing without the use of direction-finding apparatus. In a simple form, for instance, the beacon may radiate a revolving beam, carrying signals coded to indicate the bearing of the radiation at any given moment.

A distant observer has then only to listen to the beam as it sweeps by, and note the coding at the moment of maximum loudness. This is the instant when the beam is aimed directly towards him, and by referring to printed data on the particular beacon he can find out from what direction it radiates the particular code signal he has just noted, and thus find his bearing from the beacon. By repeating the process on a second beacon suitably placed, the observer can of course get an actual fix of his position.

DIRECTIVITY. Property of an aerial whereby radiation is concentrated into a particular direction or zone of directions, usually expressed as a solid angle. The directivity of an aerial is defined as the ratio of the power radiated into a specified solid angle to the power that would be radiated into that angle by some other reference aerial energized with the same power. See DIRECTIVE AERIAL.

DIRECTLY-HEATED CATHODE. Synonym for FILAMENT.

DIRECTLY-HEATED VALVE. Valve with a filament-type cathode.

DIRECTOR AERIAL. See PASSIVE AERIAL, YAGI AERIAL.

DIRECT PICK-UP. Reception in which the wiring and components of a radio receiver act as an aerial, picking up strong signals directly. Good screening is the best preventive of this possible source of interference by nearby senders.

DIRECT RAY. Ray which has travelled over the earth's surface and not via the ionosphere. See GROUND RAY.

DIRECT RECEPTION. Synonym for DIRECT PICK-UP.

DIRECT RESISTANCE. See DIRECT IMPEDANCE.

DIRECT VIEWING. Term given to the system of cathode-ray television reception in which the viewer looks directly at the screen of the cathode-ray tube. In some receivers the cathode-ray screen is arranged to be scanned backwards, and the television image is viewed by means of a mirror set at an angle to the tube. In most receivers, however, direct viewing is employed. There is no technical preference between the two, and the choice depends on the style of cabinet, and its dimensions, and not on any technical advantage of one method over the other.

DIRECT WAVE. Synonym for GROUND WAVE.

DISC ANODE. Anode in the form of a disc. Certain forms of glow-tube have anodes in this form. The anode of a cathode-ray tube is also in the form of a disc. See ANODE.

DISC DISCHARGER. Synonym for ROTARY SPARK-GAP.

DISCHARGE LAMP. See ELECTRIC DISCHARGE LAMP.

DISCHARGER OSCILLATOR. Oscillator working on the principles of arc discharge. See DUDDELL ARC, POULSEN ARC.

DISCHARGE TUBE. See CATHODE-RAY TUBE, GAS-FILLED TRIODE.

DISC PRISM. System of mechanical scanning, invented by Jenkins of America, in which, instead of there being a spiral of holes or lenses in a metal plate to provide scanning, there are two prismatic discs. The discs are made of glass, and each is ground round its edge to act as a prism. The angle of the grinding varies continuously round the whole disc until it reaches the point at which the grinding started, so that there is a sudden change between the maximum and minimum angle, as shown in Fig. 20.

When passed through a prism, light is refracted, or bent. The amount of refraction depends on the angle of the prism. Thus, when a beam of light passes through one of the Jenkins's discs, it is refracted to an extent which depends on the angle of the prism at that point. Since the angle increases as the disc rotates, it is clear that if the beam is kept stationary, the light will be deflected an increasing amount as the disc revolves. In other words, the beam is made to scan in a straight line.

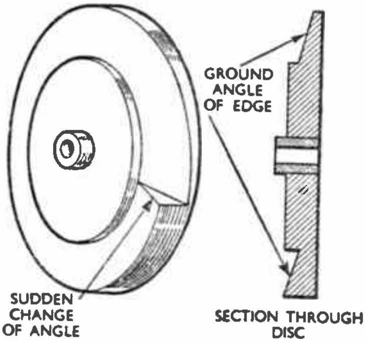


Fig. 20. Disc prism ground at the edge to give a continuously changing angle so that a beam of light is refracted progressively as the disc revolves.

At the point where the angle changes suddenly the beam is made to come back to the starting point, so that the disc causes a scan of the beam at a constant speed in one direction, with a sudden fly-back. Thus, one disc can be used for, say, a horizontal scan of the beam of light.

The other disc is arranged to rotate behind the first disc so as similarly to scan the beam, but in a vertical direction.

One disc obviously runs at a speed corresponding to the number of lines per second, and the other disc revolves more slowly at a speed corresponding with the number of picture frames per second. The second disc is sometimes referred to as an analyser.

DISCRIMINATOR. Circuit which produces an output voltage or current that is directly proportional to the frequency or phase of the signal applied to its input terminals, and has a sense depending on whether the frequency of the applied voltage is above or below a certain value. See AUTOMATIC TUNING-CONTROL, FREQUENCY DISCRIMINATOR, FREQUENCY MODULATOR.

DISC SCANNER. Device for mechanical scanning in television, comprising a metal disc with a number of perforations in it. Light is directed on to the subject to be televised, and from this it is reflected on to a light-sensitive cell through the holes in the disc.

In the original 30-line system, devised by J. L. Baird, a large metal disc, with 30 holes arranged in a spiral in it, was made to rotate in front of the subject. As each hole came round, it moved across the subject, scanning a single line across it. Succeeding holes scanned lines successively below each other until the last hole, on the inside of the spiral, completed the frame, as shown in Fig. 21. Scanning was usually carried out in a vertical direction.

A similar disc was used at the receiver, a neon lamp, modulated by the transmitted signal, being employed as a source of light. This light was projected through the holes in the disc on to a viewing lens and the picture was viewed direct. Synchronization was carried out by a phonic wheel on the spindle of the disc, the wheel being used to retard or speed-up rotation in accordance with the synchronizing signal transmitted.

The original mechanical disc scanner employed a disc of about 16 in. diameter; the spiral of holes was arranged to give a picture of about $1\frac{1}{2}$ in. by $\frac{5}{8}$ in., the picture being magnified by a lens. The holes were square and only about $\frac{1}{48}$ in. across.

DISC SCANNING. System of scanning in television by means of a revolving disc with holes in spiral form near its edge (see DISC SCANNER).

As each hole passes across the scene, successive portions of it can be seen. If, as in the Baird system of television, a disc containing 30 holes is used, each hole provides a succession of strips of the picture in such a way as to break it up into 30 successive strips or lines, a complete scan being accomplished once every revolution.

If a lens is situated between a person looking at the disc and the scene so as to focus the light reflected from the scene through each hole on to his eye, and the disc is slowly turned, the observer will see the picture in successive strips until the whole picture has been covered. If the disc is speeded-up, the impression is not one of a succession of strips of picture, but that of a complete picture because of persistence of vision.

If the light falls on, instead of an observer's eye, a photocell while the disc scans the scene, as shown in Fig. 22, variations of electric current will be produced which can be transmitted through a wire or sent by radio.

At the receiver the process is reversed. The radio signal is made to modulate the light from some form of lamp. This light is passed through a disc similar to that used at the sender, and the result, if the receiver disc scanner is synchronized with that at the sender, is that the picture is built up again in strips which, owing to persistence of vision, give the impression that the eye is looking at a complete picture.

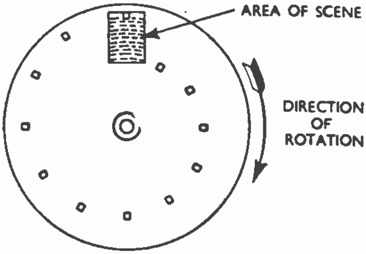


Fig. 21. Principle of the disc scanner invented by Nipkow; the holes, which scan the scene to be televised, are arranged in a spiral.

Since the photocell reacts only to different intensities of light, and does not itself analyse the picture detail, it is obvious that, the more numerous the individual strips, or lines, into which the picture can be divided, the better the resultant definition. In other words, the greater the number and the smaller the size of holes, the clearer will be the detail in the received picture.

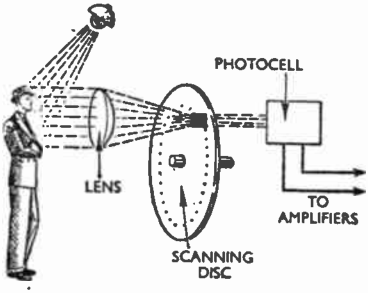


Fig. 22. Simplified diagram of disc scanning in which head and shoulders of the subject are illuminated and scanned by a 30-hole disc to give 30-line (low-definition) television.

The present method of television used in Great Britain provides for a division of the scene into 405 lines. This would mean 405 holes on the scanning disc, if discs were used. Each hole would have to be accurately placed, and the disc would have to be relatively large. In fact, this system would be so clumsy that it would be next to impossible to achieve real success.

DISPLACEMENT CURRENT. Hypothetical current used to explain the transferring of voltages across the dielectric of a capacitor. A practical instance occurs in the apparent passage of an alternating current through a capacitor (see CAPACITANCE). There is, in fact, no actual conduction current through the dielectric of the capacitor, but current does continue to flow round the circuit; where it encounters the conductive interruption in the capacitor, it is regarded as a displacement current in the dielectric material.

DISSECTOR MULTIPLIER. See IMAGE-DISSECTOR MULTIPLIER.

DISSECTOR TUBE. See IMAGE DISSECTOR.

DISSIPATION. Loss of power in any loss-producing circuit or component part thereof, such as a resistor or a capacitor with dielectric loss.

DISTANT RECEPTION. Reception of broadcasts at locations well outside the service area of the sender. Such reception is generally disappointing because of fading and noise. See LOCAL RECEPTION, SERVICE AREA.

DISTORTION. In a communication system, any difference, especially of waveform, that exists between the original and the reproduced signals. Although the various kinds of distortion are defined elsewhere under their respective names, they are, for convenience, classified here.

The first main type of distortion is that in which the gain (positive or negative) of the system varies with frequency; it is known as attenuation distortion. A particular case of it is aperture distortion. Effects similar to attenuation distortion, known as scale distortion, are produced in the process of hearing reproduced sound. Pre-emphasis, corrected elsewhere by de-emphasis, is deliberate attenuation distortion.

The second type, that in which the gain of the system varies with amplitude (usually instantaneous amplitude), is non-linear distortion. The various effects so produced are harmonic distortion, intermodulation distortion and amplitude distortion. Tracing distortion in gramophone reproduction is a particular example.

Amplitude distortion is sometimes deliberately introduced by a compressor and corrected elsewhere in contrast amplification by an expander.

The third category includes those forms of distortion that are not evident in the steady state, and so are called transient distortion. Particular forms are delay distortion, phase distortion and overshoot, or ringing. See also BUILDING-UP TIME.

In addition to the uses of deliberate distortion mentioned above, it is applied in order to obtain special waveforms, additional frequencies, etc.

Various kinds of visual distortion in television and oscillography include barrel distortion, keystone effect, origin distortion, pincushion distortion and trapezium distortion.

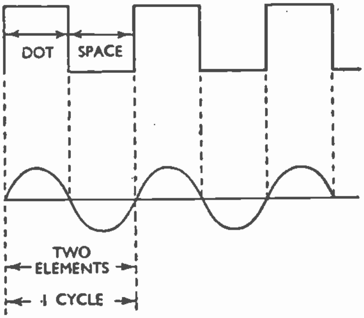


Fig. 23. Dot frequency of a code signalling system; a dot and a space together comprise one cycle.

DISTORTION FACTOR. Measure of total harmonic distortion, expressed as a percentage and given by:

$$100\sqrt{\frac{\text{sum of squares of amplitudes of harmonics}}{\text{square of amplitude of fundamental}}}$$

See HARMONIC DISTORTION.

DISTRIBUTED CAPACITANCE. Capacitance not concentrated in a capacitor but spread along, say, an aerial wire, between adjacent turns of an inductor winding, or between the wires of a feeder.

DISTRIBUTED CAPACITY. See DISTRIBUTED CAPACITANCE.

DISTRIBUTED INDUCTANCE. Inductance not concentrated in an inductor, but spread along, say, an aerial wire or feeder.

DISTRIBUTOR. In a telegraph system, a rotating device which automatically switches the intelligence to be conveyed to the different channels of a multiplex system.

DISTURBANCE. Synonym for INTERFERENCE.

DIVERSITY CHANNEL. Single channel in a diversity system.

DIVERSITY RECEPTION. Reception of a signal by means of a diversity system.

DIVERSITY SYSTEM. In telecommunication, any system by which a single signal is received either by the combination of, or selection from, a number of signals radiated by a group of individual senders. See CHANNEL DIVERSITY, DIVERSITY CHANNEL, DIVERSITY RECEPTION, RAY DIVERSITY.

DIVIDED CIRCUIT. In telegraphy, a circuit on which one or more message-channels are terminated at some point other than the terminal station of the circuit.

D-LAYER. Ionized layer in the atmosphere, believed to result from the impact of particle radiation emitted from the sun. This layer, considerably lower than either the E- or F-layer, often blocks short-wave communication, but appears sometimes to improve conditions on long waves.

dn. Abbreviation for DECINEPER.

DOT FREQUENCY. Half the number of elements in a code signalling system. This definition will be better appreciated by reference to Fig. 23 and by remembering that a space in a code is considered as an element of the code. See MORSE CODE.

DOUBLE AMPLITUDE. Peak-to-peak value of an alternating current or voltage. In practice, double amplitude is simply twice the peak value, that is the sum of the positive and negative voltage swings. Double amplitude is illustrated in Fig. 24.

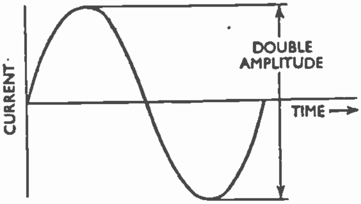


Fig. 24. The double amplitude of an alternating current or voltage is the peak-to-peak value, as shown.

DOUBLE-BEAM CATHODE-RAY TUBE. Cathode-ray tube in which the electrodes are so arranged that the electron beam from a single cathode is divided into two separate paths. It permits the simultaneous investigation of two variable quantities. See CATHODE-RAY TUBE, OSCILLOGRAPH.

DOUBLE-CURRENT SYSTEM. Telegraph system in which signals are transmitted by reversing a current that is normally on the line during transmission.

DOUBLE-DETECTOR RECEPTION. See SUPERHETERODYNE RECEPTION.

DOUBLE-DIAMOND AERIAL. See RHOMBIC AERIAL.

DOUBLE DIODE. Diode with two anodes insulated, and sometimes shielded, from one another; and usually, but not invariably, with a

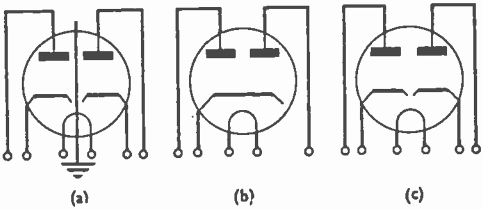


Fig. 25. Symbolic representation of three forms of double diode: (*a*) with separate indirectly heated cathodes and a shield between the diodes; (*b*) with a common cathode, and (*c*) as (*a*) but without shield.

common cathode. Fig. 25 shows a double diode. Exactly the same illustration applies to a full-wave rectifier circuit. The double diode is also used for full-wave rectification in detection circuits and is then known as a full-wave detector. For detection, the anodes are very small and are sometimes in the form of small discs. See DIODE, DOUBLE-DIODE TRIODE, FULL-WAVE RECTIFICATION.

DOUBLE-DIODE HEPTODE. Multiple valve comprising two diode anodes and a heptode electrode assembly surrounding a common cathode. See DIODE, HEPTODE, MULTIPLE VALVE.

DOUBLE-DIODE HEXODE. Multiple valve comprising two diode anodes and a hexode electrode assembly surrounding a common cathode. See DIODE, HEXODE, MULTIPLE VALVE.

DOUBLE-DIODE PENTODE. Multiple valve comprising two diode anodes and a pentode electrode assembly surrounding a common cathode. See DIODE, MULTIPLE VALVE, PENTODE.

DOUBLE-DIODE TETRODE. Multiple valve comprising two diode anodes and a tetrode electrode assembly surrounding a common cathode. See DIODE, MULTIPLE VALVE, TETRODE.

DOUBLE-DIODE TRIODE (or tetrode, pentode, hexode or heptode). Valve having the three or other appropriate number of normal electrodes and two small auxiliary diode anodes, the cathode being common both to the normal electrodes and to the diode anodes. Fig. 26 is a way of showing the double-diode triode diagrammatically.

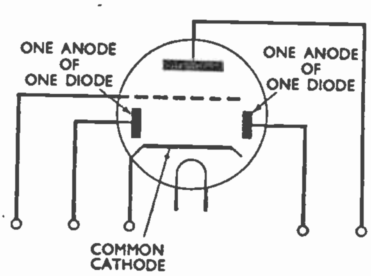


Fig. 26. Diagrammatic representation of a double-diode triode. The same (indirectly heated) cathode is used for the triode as for the two diodes.

The arrangement was designed to economize in cathode power and space generally. The one emitter suffices for the valve proper, as well as for the double diode. In many circuits the diode and other valve are used in cascade; thus detection and amplification, for example, can be carried out in the one valve. See DETECTOR, DIODE, DOUBLE DIODE, TRIPLE DIODE.

DOUBLE FEEDBACK. Circuit arrangement in which feedback occurs within a valve amplifier by way of two separate loops.

DOUBLE-FREQUENCY OSCILLATOR. Oscillating system in which two sets of oscillations are produced, each having a separate frequency.

DOUBLE-HUMP EFFECT. Double-peaked resonance effect (Fig. 27), normally resulting from tight coupling between two circuits. See BAND-PASS TUNING, COUPLING.

DOUBLE IMAGE. Effect produced on a cathode-ray tube screen where a second image, usually much weaker than the main image, is seen. The image is displaced by a slight amount from the main image, but is similar to it in every detail. The cause is reflection of the received radio signal from some object—usually near the receiving location.

Since the reflected signal has to travel a path longer than that of the direct signal, it arrives a fraction of a second later. It then passes through the receiver and modulates the cathode-ray tube, with the result that a "repeat" of the image just built-up is provided and a "ghost," or double image, results.

Large metal buildings, gasholders and passing aircraft frequently cause this effect. Sometimes little can be done about it, but often an aerial with a reflector carefully arranged to make it sharply directive can bring about a cure.

DOUBLE-POLE SWITCH. Switch for the simultaneous making or breaking of two separate paths of a circuit. See SWITCH.

DOUBLE-PURPOSE VALVE. Valve which may be connected up in two different ways to perform two distinct functions. Thus almost any valve may be so termed; for example, any triode may be connected up as an amplifier or as an oscillator, and any R.F. pentode can be used for radio-frequency or audio-frequency amplification.

The term "double-purpose" may also be applied to a valve containing two sets of electrodes with separate cathodes or a common cathode. Such a valve virtually consists of two valve structures in one envelope and the two electrode assemblies can be independently connected to external circuits. This is, however, more correctly termed a MULTIPLE VALVE (q.v.). See also DOUBLE DIODE, DOUBLE-DIODE TRIODE.

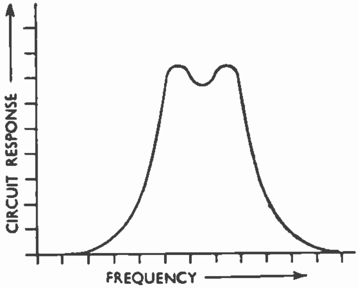


Fig. 27. Double-humped resonance curve which results from a tight coupling between two tuned circuits.

DOUBLER. Abbreviation of FREQUENCY-DOUBLER.

DOUBLE REACTION. Synonym for DOUBLE (positive) FEEDBACK.

DOUBLE RECEPTION. Synonym for DIPLEX RECEPTION.

DOUBLE RETROACTION. Synonym for DOUBLE (positive) FEEDBACK.

DOUBLE-SIDEBAND TRANSMISSION. Method of radio-telephony transmission in which both the bands of frequencies produced by modulation are radiated.

DOUBLET. Synonym for HALF-WAVE DIPOLE.

DOUBLE-WAVE RECTIFICATION. Synonym for FULL-WAVE RECTIFICATION.

DOUBLING. Abbreviation of FREQUENCY-DOUBLING.

DRAMATIC CONTROL PANEL. Equipment consisting of faders, switches and so on, used by a producer of radio drama to get a combined effect by the use of separate studios. The system is no longer used.

DRIVE. See MASTER OSCILLATOR.

DRIVEN SENDER. Sender the radiated frequency of which is determined by a master oscillator.

DRIVER. Stage of amplification providing the signal-frequency power for the following stage.

DRIVING-POINT IMPEDANCE. Ratio of the voltage at any two points on a network to the current flowing at these two points. See IMPEDANCE, NETWORK.

DRUM SCANNER. A mechanical system of television scanning which overcomes the drawback of the scanning disc, namely, the serious loss of light due to the light beam having to pass through small holes in the disc.

The mirror drum consists of a narrow drum, around the circumference of which are arranged small rectangular mirrors, the number corresponding with the number of lines required for the television system.

Each mirror is set at a different angle and scans one line of the picture. The change in angle between each mirror produces the successive lines across the picture required for scanning as indicated in Fig. 28.

The mirror drum has to be supplied with a source of light that is modulated by the received picture signal, this being reflected by the drum on to a screen. Synchronization of the drum with the sender is difficult and requires a powerful synchronizing signal, just

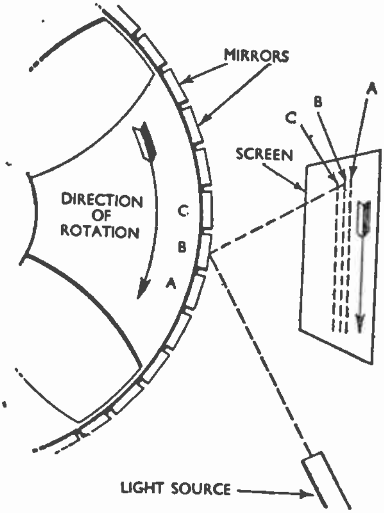


Fig. 28. Principle of the drum scanner; each mirror on the drum is tilted in relation to its neighbours and scans a light path slightly displaced from that scanned by the preceding mirror.

as the synchronizing of a disc scanner necessitates a powerful signal. This signal operates some form of phonic wheel which can pull the drum into step if it tends to revolve too fast or too slowly.

DRY BATTERY. Term frequently used to describe a battery of dry cells. See DRY CELL.

DRY CELL. Any primary cell in which the electrolyte is in the form of a paste rather than a liquid. The commonly used dry cell is a form of Leclanché cell. The construction of a dry cell of the type widely employed in high-tension batteries, portable torches, etc., is shown in Fig. 29. The container is made of zinc and forms the negative electrode, the positive electrode being a carbon rod capped with thin brass.

The manganese-dioxide de-polarizer is in contact with the carbon rod and held in a semi-permeable bag of linen or canvas. The paste electrolyte is formed from a sal-ammoniac solution and gelatine or flour. In some forms of cell, the de-polarizer is mixed with the paste electrolyte, the bag not being used.

DRY-CELL BATTERY. Number of dry Leclanché cells connected in series or in parallel. Such batteries are extensively used for H.T. and L.T. supplies for portable receivers. See LECLANCHÉ CELL.

DRY ELECTROLYTIC CAPACITOR. Form of electrolytic capacitor in which the electrolyte is of paste-like consistency and is "dry" in comparison with the aqueous, or "wet," type. See FIXED CAPACITOR.

DRY ELECTROLYTIC CONDENSER. Synonym for DRY ELECTROLYTIC CAPACITOR.

DRY-PLATE RECTIFIER. Synonym for METAL RECTIFIER.

D.S.C. Abbreviation, in reference to conductors, for double-silk covered.

D.S. & ENAM. Abbreviation, in reference to conductors, meaning double-silk covered and enamelled.

DUAL AMPLIFICATION CIRCUIT. Circuit in which the same valve ampli-

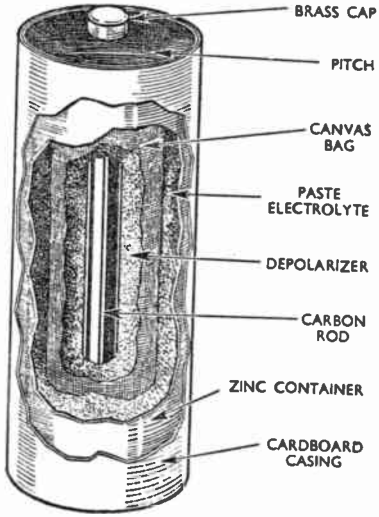
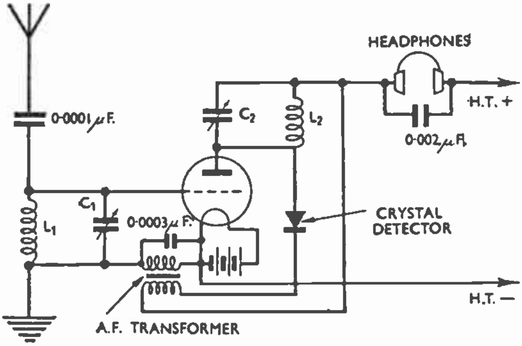


Fig. 29. Dry cell, partly cut away to show a typical form of construction.

Fig. 30. Simple dual-amplification, or reflex, circuit in which the valve amplifies the signal, first at radio frequency, and then again at audio frequency after rectification by a crystal detector.



fies the signal twice—once at radio and once at audio frequency. Such circuits had a considerable vogue in the early nineteen-twenties, for at that time the general-purpose triode was comparatively expensive, and needed half to three-quarters of an ampere of filament current at 6 volts. As large accumulators were used for filament supply—no mains valves being then available—there was an obvious advantage in making each valve do as much work as possible.

Fig. 30 illustrates one of the earliest and simplest dual or reflex circuits; points to be noted are the fixed capacitor in series with the aerial lead—a common device before the general adoption of the untuned, coupled aerial—the absence of grid bias, and the use of a simple tuned-anode circuit with the triode.

In this form of circuit an amplified version of the radio-frequency signal appears in the anode circuit, where it is first rectified by the crystal detector and then reflexed back to the grid circuit by the audio-frequency transformer. An audio signal is thus impressed on the anode current and causes an amplified version to be heard in the headphones. The fixed capacitors of 0·0003 and 0·002 μF are to by-pass radio-frequency signals.

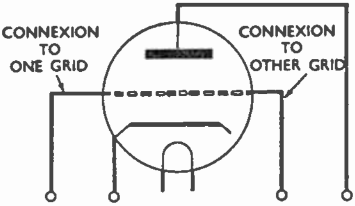


Fig. 31. Diagrammatic representation of a dual-grid valve (triode); the two grids are concentric.

DUAL-GRID VALVE. Valve with two concentric control grids. Either of the control grids (Fig. 31) may be connected to the anode, or both grids may be connected together. In the former case, the valve acts as a triode with a low amplification factor; in the latter case as one with a high amplification factor.

Two grids connected together shield the cathode from the anode more effectively for a given value of grid current, than does one closely wound grid. Thus two valves, one with a single and the other with a dual grid, may each give the same high amplification factor, but the dual-grid valve draws less grid current. This makes it particularly suitable for class-B valve operation. See WUNDERLICH VALVE.

DUDDELL ARC. System of producing alternating currents by connecting a D.C. supply across an arc discharger, and shunting the arc with an oscillatory circuit; it was discovered by Duddell in 1900. In Fig. 32 a constant D.C. supply is maintained across the arc by means of the battery, through the resistor R_0 and inductor L_0. The frequency f of the alter-

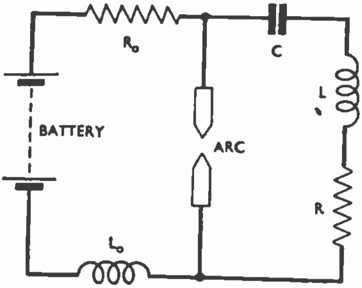


Fig. 32. Circuit for the Duddell-arc method of producing alternating current from a D.C. source. The frequency of A.C. thus derived is limited, however, to about 10,000 c/s.

nating currents in the oscillatory circuit *C*, *L*, *R* is obtained from $\omega = \frac{1}{\sqrt{LC}}$, where $\omega = 2\pi f$.

The Duddell arc produced low power and its frequency was limited to about 10,000 c/s. These limitations were imposed by the ionization-change rate in the arc. At higher frequencies, there was insufficient time for ionization changes to take place, and the negative resistance of the arc (upon the maintenance of which oscillation depended) became too small to maintain the circuit in oscillation. See POULSEN ARC.

DULL-EMITTER VALVE. Valve having a cathode which glows a dull red. Early in radio history, all valves had filament types of cathode made of tungsten wire which had to be heated to a high temperature to give the required emission; these filaments glowed brightly. With the introduction of the oxide-coated filament, and later of indirectly heated cathodes, less heat was required for adequate emission and the illuminating properties of valves were reduced. A distinction was then made between the old bright-emitter and the new dull-emitter valves. The term is now obsolete because nearly all valves are dull emitters and those that still use tungsten filaments often have water-cooled anodes which mask the light. See BRIGHT-EMITTER VALVE, EMISSION, INDIRECTLY HEATED CATHODE.

DUMB AERIAL. Synonym for ARTIFICIAL AERIAL.

DUMMY AERIAL. Any network simulating the electrical characteristics of an aerial. The simplest form of dummy aerial is a closed resonant circuit with capacitance, inductance and resistance equal to the effective values of the capacitance, inductance and resistance (including the radiation resistance) of the aerial it simulates. The exact equivalent is seldom realized in practice because the inductance and capacitance of an aerial are distributed whereas those of a closed circuit are "lumped." In testing senders it is convenient to use dummy aerials so that waves shall not be radiated. See CLOSED CIRCUIT.

DUODYNATRON. Valve oscillator in which two resonant circuits are connected to the inner grid and anode of a tetrode, the outer grid being maintained at a higher positive potential than the anode in order to provide a negative A.C. anode resistance which maintains oscillation in both the resonant circuits.

DUOLATERAL COIL. Synonym for DUOLATERAL-WOUND COIL.

DUOLATERAL WINDING. Method of winding coils for certain types of resistor, inductor and transformer in which two wires are wound on to a former simultaneously and side by side with the object of making two coil sections of identical inductance. The method is shown in the illustration (Fig. 33). It is sometimes known as "bifilar" winding. In making resistors, either the inner or the outer ends of each wire of the pair are joined together and the other pair are connected to the terminals so that, magnetically, the two sections are in series opposition; this forms a "non-inductive" resistor.

There is, however, considerable capacitance between the two wires, which appears as a shunt across the resistance, so that the method is limited to low values of resistance and to low frequencies. Some improvement may be achieved by connecting in series a number of sections wound in this way. If there are n sections, then the shunt capacitance is reduced in the ratio 1 : n^2. Other methods of winding, such as the Ayrton-Perry (see FIXED RESISTOR), have a wider field of use.

For making balanced inductors and balanced windings of transformers the method has advantages. In such cases, the outer end of one wire of the pair is joined to the inner end of the other wire of the pair, so that, magnetically, the two sections are in series aiding. The joint serves as an accurate centre-tap and the two halves are substantially equal in inductance. There are numerous applications where such a feature is desirable. For example, an inductor used as an inductive ratio arm in a measuring bridge; or a hybrid coil or other transformer where a high degree of balance is required between the two halves of one winding.

As a rule, it is impedance balance rather than inductance balance that is important; and for this reason the method is limited for the most part to audio frequencies. At very low frequencies, resistance inequalities between the two wires upset the balance; at higher frequencies it is almost impossible to ensure that the capacitance between the two wires is uniformly distributed along the length. In practice, the capacitance tends to be greater at one end than the other and therefore the effective capacitances across each half of the coil do not balance.

DUOLATERAL-WOUND COIL. Coil in which two wires are wound on to a former simultaneously and side by side with the object of obtaining identical inductance in two sections of the coil. See DUOLATERAL WINDING.

DUOLATERAL-WOUND INDUCTOR. Inductor having a duolateral-wound coil. See DUOLATERAL WINDING.

DUOLATERAL-WOUND RESISTOR. Wire-wound resistor having a duolateral-wound coil. See DUOLATERAL WINDING.

DUPLEX BALANCE. Network, used in connexion with line telegraphy, designed to simulate the impedance presented by a line. See BALANCING NETWORK.

DUPLEX OPERATION. In radio-communication, two-way

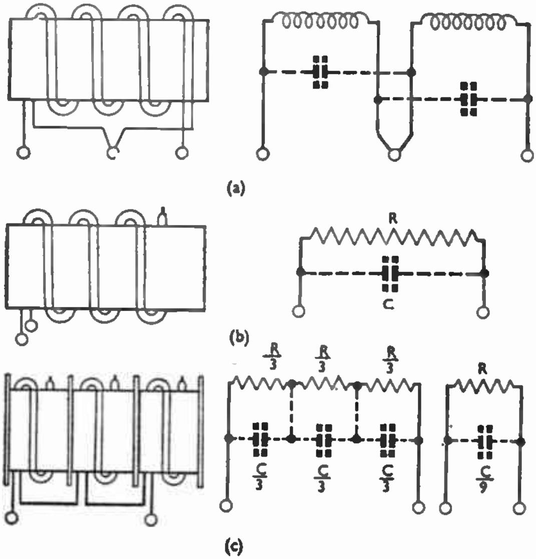


Fig. 33. Use of duolateral winding, showing the effect of capacitance between a pair of wires: (a) inductive connexion for balanced inductors and transformers; (b) non-inductive connexion for resistors, and (c) non-inductive series connexion for reducing self-capacitance.

transmission in which signals may be communicated simultaneously in both directions over the same circuit and using the same frequency band.

DUPLEX SYSTEM. System of communication employing DUPLEX OPERATION (q.v.).

DUPLEX VALVE. Two similar valve structures having a common cathode and housed in a single envelope. A diagrammatic representation of a duplex valve is given in Fig. 34. Such a valve is useful for BALANCED VALVE-OPERATION (q.v.).

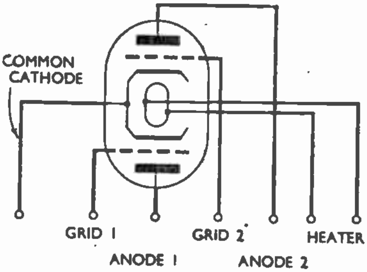


Fig. 34. Diagrammatic representation of a duplex valve. Anodes 1 and 2 and grids 1 and 2 are insulated from each other; the cathode, however, is common to both halves of the valve.

DUST CORE. Magnetic core, for an inductor or transformer, moulded from finely divided and insulated particles of a magnetic material, such as iron or nickel-iron alloy. The isolation of the particles greatly reduces the eddy-current loss, particularly at high frequencies, and their separation reduces the effective hysteresis loss, but, at the same time, also diminishes the effective permeability.

The powder is mixed with a suitable insulating binder, such as synthetic resin, and is formed at high pressure in a mould of the required shape. The

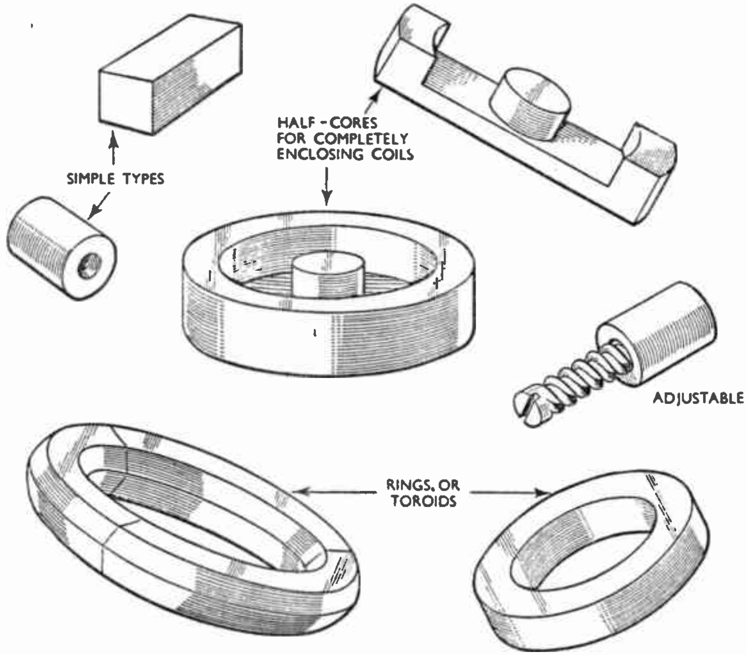


Fig. 35. Dust-cores, consisting of a powdered magnetic material and an insulating binder, are moulded in a variety of shapes, of which these are examples.

mixture is varied to suit the frequency of application as follows:

Frequency	*Material*	*Effective Permeability*
Audio	Nickel-iron	100
Carrier (on line)	,,	40
,,	Pure electrolytic iron	15
Radio	,,	4

Typical core shapes are illustrated in Fig. 35. See DUST-CORED INDUCTOR, FIXED INDUCTOR, IRON LOSS, VARIABLE INDUCTOR.

DUST-CORED COIL. Synonym for DUST-CORED INDUCTOR.

DUST-CORED INDUCTOR. Inductor having a core moulded from finely divided and insulated particles of a magnetic material such as powdered iron. The object of the magnetic core is to reduce the size of the inductor for a given inductance or to increase its Q-factor.

The purpose of finely dividing the material is to reduce the losses due to the core to a small value, even at radio frequencies. At these frequencies, the core usually consists of a rod of pressed iron-dust lying along the axis of the coil. The core may be moved along the axis of the coil to vary the inductance. This type of variable inductor is used in so-called permeability tuning. At lower frequencies, a toroidal-wound inductor on a ring-shaped core is often used. See DUST CORE, FIXED INDUCTOR, VARIABLE INDUCTOR.

DWARF WAVE. Term sometimes used to describe a radio-wave of 1–10 mm., that is, within a frequency range of 300,000–30,000 Mc/s. Work on such waves is at present mainly experimental, but, in general, the propagation characteristics are similar to those of centimetric waves. See CENTIMETRIC WAVE.

DYNAMIC CHARACTERISTIC. Valve characteristic relating variable quantities when the valve is arranged to function as an amplifier, frequency-changer, detector, oscillator or for any other purpose. The ordinary or static valve characteristic is a graph relating measured electrode voltages and electrode currents; thus no resistors may be used in external circuits, because these would affect electrode voltages and so make it impossible to compare valves one with another on a common basis.

The designer of valve circuits may be helped, nevertheless, by knowing how electrode currents vary with electrode voltage when resistors or impedors form part of an external circuit. Fig. 36 shows the typical change that might be noticed in a graph of grid volts plotted against anode current due to the existence of a resistor in series with the H.T. supply and the anode. Such a characteristic is known as a dynamic characteristic because it would show how the anode current varies with grid volts under operating conditions. See VALVE CHARACTERISTIC.

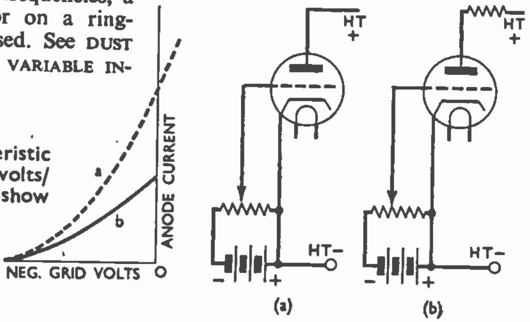


Fig. 36. Dynamic characteristic of a valve. The grid-volts/anode-current curves show respectively the general form that the characteristic takes when the valve is connected as at (*a*) and as at (*b*).

DYNAMIC CONDUCTANCE. Synonym for SLOPE CONDUCTANCE.

DYNAMIC IMPEDANCE. Synonym for REJECTOR IMPEDANCE.

DYNAMIC RESISTANCE. Synonym for SLOPE RESISTANCE.

DYNAMO. Term sometimes used for direct-current generator. See D.C. GENERATOR.

DYNAMOMETER. Instrument for measurement of power. Its operation depends upon the fact that, if current is passed in the same direction through two adjacent coils or wires, one of which is fixed and the other free to move, attraction will occur between the coils or wires and cause the movable member to rotate. The extent of its rotation is proportional to the degree of attraction between it and the fixed coil or wire and hence to the current flowing. The pointer is attached to the movable coil and, by causing this to move across a calibrated scale, measurements are obtainable.

DYNAMOTOR. Machine for changing the voltage of a D.C. supply; sometimes called a rotary transformer. It consists of an armature having two separate windings with independent commutators, but only one magnetic field which may be either shunt- or compound-wound. The machine thus combines the functions of motor and generator within a single casing.

DYNATRON. Triode or tetrode in which two adjacent electrodes are made positive with respect to the cathode, that nearer the cathode being more positive than the other. Over a certain range of potential, secondary emission from the outer electrode (usually the anode) causes the anode current to fall when its potential is increased, this indicating a negative anode A.C. resistance.

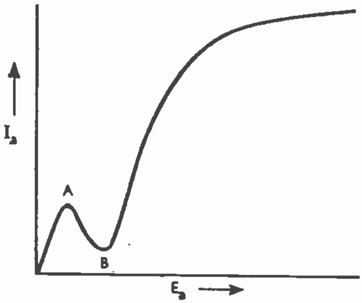


Fig. 37. Anode-current/anode-volts graph of a tetrode showing the kink AB, characteristic of the dynatron.

In the I_a–E_a curves of a tetrode valve (Fig. 37), the region *AB*, known as the "tetrode kink," illustrates this negative resistance.

DYNATRON OSCILLATOR. Valve oscillator in which the negative A.C. anode resistance of a dynatron is used to maintain oscillation in a resonant circuit included in the anode circuit. See OSCILLATOR.

DYNE. Unit of force in the system having the gramme, centimetre and second as its basic units. A dyne is that force which will apply an acceleration of one centimetre per second per second to a mass of one gramme.

DYNODE. Electrode in a valve which provides secondary electron emission.

E

EARPHONE. Single headphone used as a receiver on a telephone instrument. See HEADPHONE.

EARTH. Terminal or circuit point the potential of which cannot be changed. The potential of the terminal or point is called zero. The term may also describe a steady-potential point to which a number of circuits is joined so that all points so joined have the same potential. An earth is any means by which a conductive connexion is made to a point at zero or steady potential; for example, an earth may be formed by a water pipe in a house.

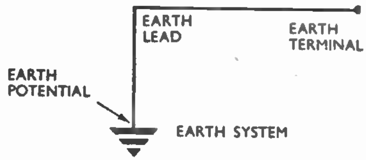


Fig. 1. As the earth lead connecting the earth terminal to the earth system has impedance, the earth terminal may have a potential difference to zero or true earth potential.

A typical phrase is "this point is connected to earth" or "is earthed"; what is meant is that the point is connected to a conductor which eventually finds its way to some earth system (see EARTH SYSTEM). In practice, an earth may be raised in potential owing to the fact that it is not directly connected to an earth system but is at some distance from it. This long connexion has impedance, and it is thus possible to raise the potential of that end of the earth conductor which is remote from the earth system.

Fig. 1 shows the meaning of earth when it is truly a terminal which is part of an earth system. In the great majority of cases, it is not essential to bring parts of circuits to zero potential so long as they are maintained at a steady potential. Thus, Fig. 2a shows how, in a valve amplifier, several connexions are taken to a

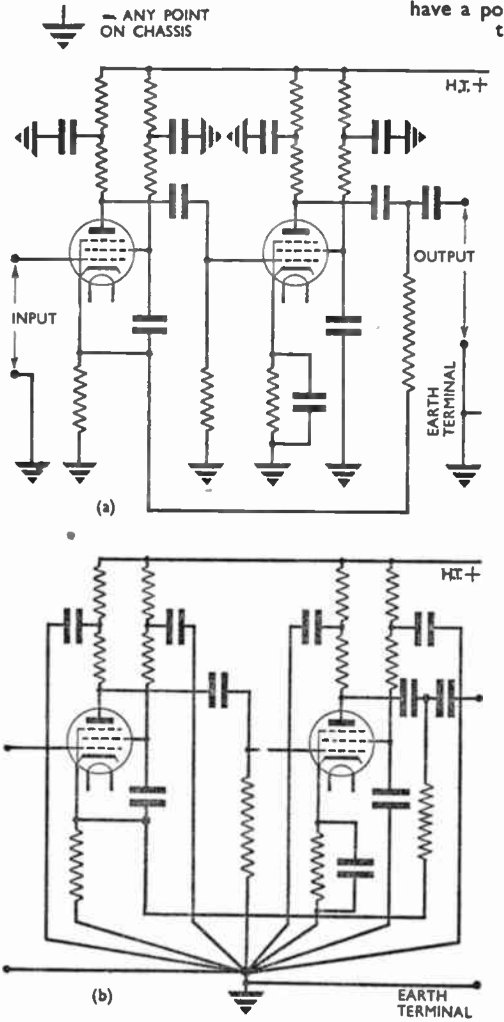


Fig. 2. Diagrams showing earth connexions. In (*a*) circuit points are joined to the chassis; this is not good practice in high-gain amplifiers operating at radio frequencies because differences of potential may be set up between parts of the chassis. In (*b*) all parts of the circuit are connected to a single point.

chassis, which is connected to the earth terminal. It is assumed, very often without justification, that no difference of potential can exist between different points on the same metal chassis. This is a dangerous assumption, particularly when the frequencies of the currents amplified are very high.

Thus Fig. 2b shows a good, and sometimes essential, practice, in which all the points that ought to be at the same potential are brought to a common terminal which is itself connected to one point on the chassis. Provided that this common earth point is connected to the earth lead or earth terminal, even though this may vary in potential, all the circuits in the amplifier will then rise or fall in potential together. This will not matter, because it will not result in any common-impedance coupling between the circuits themselves.

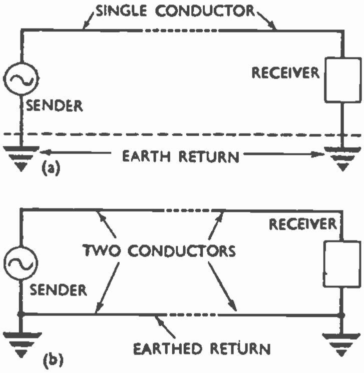


Fig. 3. Earth return (*a*) as distinct from the earthed-return circuit (*b*), in which a second conductor is used.

In many cases, a radio receiver will work perfectly satisfactorily without an earth connexion. This is because there is a point—usually the chassis—to which all common connexions are made. The aerial potential varies above and below the potential of the chassis, which is steadied to some extent either by its greater capacitance to earth or because of a connexion to the mains which approximates to an earth. See EARTH CIRCUIT, EARTHING, EARTH LEAD, EARTH POTENTIAL, EARTH TERMINAL.

EARTH CIRCUIT. Connexion or connexions leading from apparatus, or equipment, to the earth system. See EARTH.

EARTH CURRENT. Current flowing in the conductor or conductors forming the earth circuit. See EARTH, EARTH CIRCUIT.

EARTHING. Term denoting the connexion of a circuit point or points to earth. See EARTH, EARTH SYSTEM.

EARTH LEAD. In a radio sender or receiver, the single conductor which connects the earth terminal of the apparatus to the earth system. See EARTH, EARTH SYSTEM.

EARTH POTENTIAL. Potential of a point or terminal which cannot be sensibly changed in potential. The term may also be used to describe the potential of a point of common connexion in an apparatus or equipment which has the lowest potential and the least impedance with respect to a terminal at the earth potential. See EARTH.

EARTH-RETURN CIRCUIT. In a transmission line, the part of the circuit which is completed by conduction of currents through the earth itself. A line and an earth-return is an example of an unbalanced transmission line (Fig. 3). See BALANCING AERIAL, EARTH, UNBALANCED CIRCUIT, UNBALANCED TRANSMISSION LINE.

EARTH SYSTEM. Any system of conductors or conductive material in direct physical connexion with the earth. It is of great importance in most electrical circuits to ensure that certain circuit points shall be held at the same, and nearly zero or virtually zero, potential (see EARTH).

It is justifiably assumed that the potential of the globe on which we live cannot be raised in potential by any electrical system devised by man. This does not mean that localized points cannot be raised in potential; indeed it is possible, with a sensitive amplifier, to detect differences in potential between conductors stuck in the ground a few yards apart.

The assumption that the earth cannot be raised in potential is perhaps better expressed by saying that if the earth is connected to one terminal of a source of alternating e.m.f. and a non-earthed system is connected to the other, then the unearthed system will vary in potential by far greater amounts than the earthed. Thus the aerial of a sender may execute large variations of potential; but the earth system, to which the earth terminal of the sender is connected, stays at virtually the same potential because it is in direct contact with the earth.

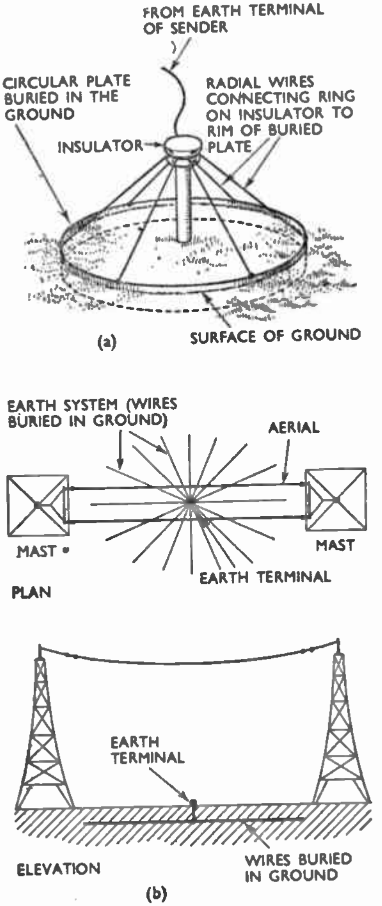


Fig. 4. Two forms of earth system: in (*a*) a circular plate is buried one or two feet in the ground with its upper rim projecting; in (*b*) wires are laid radially along furrows in the ground.

There is inevitably some resistance formed in making connexion between the conductive system buried in the earth and the earth itself. Power is wasted in senders by this resistance and everything possible is done to minimize it. Fig. 4 shows two typical earthing systems used at senders. The loss due to high-resistance earth systems in receiving aerials is of no particular importance, provided the receiver embodies a radio-frequency amplifier.

The signal-to-noise ratio is the chief factor determining the efficiency of reception always provided that the receiver has adequate amplification. The earth system, good or bad, generally makes little or no difference to signal-to-noise ratio, although a bad earth sometimes increases noise. With a crystal receiver—one which does not embody valves—it is very important that the earth system shall be efficient, because the received signal strength is proportional to the currents set up in the aerial, and these may be reduced by a high-resistance earth.

Earth systems are used in other applications of electrical engineering; telephone exchanges, power stations, cable stations and so forth all require a good earth. See AERIAL, COUNTERPOISE, EARTH.

EARTH TERMINAL. Terminal joined to the conductor or conductors which terminate on an earth system. See EARTH, EARTH LEAD, EARTH SYSTEM.

EARTHY. Term describing any circuit point which has the least impedance or the smaller of two impedances to earth. In other words, a circuit point which is not likely to vary in potential so

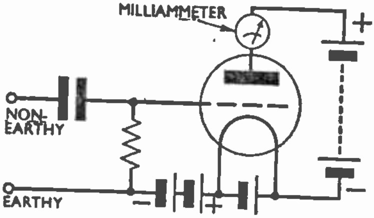


Fig. 5. The earthy terminal of a valve voltmeter is that which has the greater capacitance to earth.

much as another which is part of the same circuit, but which may not be directly connected to an earth lead or to earth. One of the terminals of a valve voltmeter may be labelled "earthy." This is the terminal which is connected to cathode or to the filament in a battery valve. This terminal of the voltmeter has, therefore, a greater capacitance to earth than the grid and its potential cannot, therefore, be varied so readily as that of the grid (Fig. 5).

The voltmeter may be used to determine the potential between two circuit points. The potential at one of these points may vary less than that of the other and it is preferable to connect the earthy terminal of the voltmeter to the circuit point showing the least variation in potential. Thus in measuring the potential between the anode and cathode of a valve using current feedback, it is advisable to connect the earthy terminal of the voltmeter to the earthy terminal (i.e. the cathode) of the source (Fig. 6).

Put in another way, an earthy terminal has a lower impedance to earth than a non-earthy one and is therefore connected to points having an effectively lower internal resistance. See EARTH, EARTH SYSTEM.

EBONITE. Vulcanized rubber, frequently used as insulating material. It should not be used in contact with copper, which it attacks.

ECHO. Wave which has been reflected and reaches a certain point later than the wave which travels in a straight line between the source and the point in question.

ECHO PATH. Path followed by RADIO ECHO (q.v.).

ECHO ROOM. Highly reverberant room or chamber used to add artificial echoes to sounds. The room contains a loudspeaker and a microphone; the output from the studio microphone is taken through two paths, one directly to a mixer and the other via the loudspeaker and microphone in the echo room to the same mixer (Fig. 7). Thus the sounds made in the studio are repeated by the loudspeaker in the echo room, and are given a reverberant character. The reverberant sounds are picked up by the echo microphone. Thus the mixer has two inputs containing the same basic character; one represents the normal and small reverberation of a studio, the other a highly exaggerated reverberation.

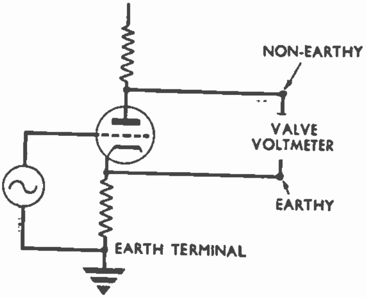


Fig. 6. Although the cathode of the valve shown is not earthed, it has less impedance to earth than has the anode; hence the earthy terminal of the voltmeter is connected to the cathode.

The adjustment of the mixer determines the proportion of reverberation in its output. This is judged by the operator of the mixer according to the nature or sequences of the programme. The mixing of a constant but small reverberation with orchestral music may produce a more pleasing effect; in dramatic presentations, a twist of the mixer may, in effect, take a character from outdoors into a cathedral or from an apparently distant part of a room to a place seemingly closer to another character in the same room.

ECHO-SUPPRESSOR. In a four-wire telephone channel, a circuit comprising valves and relays designed to permit speech currents to pass in one direction only. The device prevents the speaker from hearing echoes of his voice reflected from the distant end of the circuit.

EDDY CURRENT. Circulating current induced in a mass of conducting material by a moving or varying magnetic field. The effect may be compared with the action of a transformer in which currents are induced in the secondary winding by the varying magnetic field due to the primary current. The secondary currents represent a load on the primary circuit, and eddy currents similarly represent a load on the source of magnetic field. Eddy currents may cause serious losses in high-frequency apparatus; they compel the designer to pay careful attention to the spacing between all inductors and any metallic objects, especially screening compartments (Fig. 8).

Even in low-frequency A.C. practice there are circumstances in which the eddy currents must be minimized, notably in the iron cores of transformers, inductors and electromagnets. These are built up of thin laminations, more or less insulated from each other, so that eddy currents of appreciable magnitude cannot build up in the core.

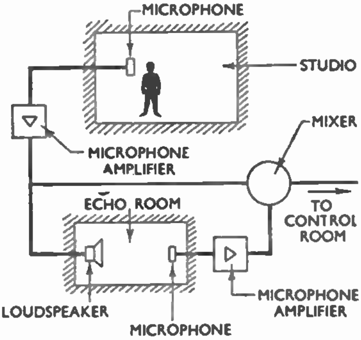


Fig. 7. Output from the studio microphone finds two paths to the mixer, one direct and one through a highly reverberant echo room. The mixer can be adjusted to mix to any desired degree the direct studio output with a reverberant version of the output.

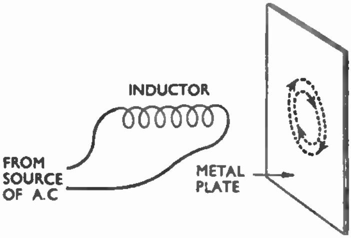


Fig. 8. Circulating eddy currents, due to electromagnetic induction, are set up in a metal plate located near the end of a winding in which alternating currents are flowing.

Although eddy current is generally regarded as a nuisance to be suppressed, it has certain useful applications as in the eddy-current brake, in which circulating currents are used to absorb power from a driving motor and so enable the machine to be tested under load.

EDISON ACCUMULATOR. Synonym for nickel-iron-alkaline accumulator which was invented under the direction of Thomas Edison.

EDISON EFFECT. Emission of charged particles from a heated filament which makes conduction of electricity possible between an anode and the filament. Edison was one of the first technicians to demonstrate the conduction of electricity through a rarefied gas.

Early types of electric lamps used a carbon filament, and it was noticed that, after a time, the bulb blackened on the inside of the glass. In investigating this phenomenon, Edison proved, by putting a small conductive plate in a lamp and making a connexion to it, that charged particles were emitted from the filament. It was seen that the path between the plate (anode) and the filament (cathode) gave unilateral conduction. In effect Edison made the first diode.

The apparatus for demonstrating the Edison effect (with which most physics laboratories were provided) was used by Sir Ambrose Fleming to make a D.C. instrument measure radio-frequency current; this led to the first diodes used for detection of radio signals, and the Lee de Forest audion. See AUDION, DIODE, RECTIFIER.

EFFECTIVE BAND WIDTH. Arbitrarily chosen frequency-band characterizing the performance of a band-pass or band-stop filter and within which the filter attenuation does not vary more than a specified amount. A typical attenuation characteristic of a band-pass filter is shown in Fig. 9; f_1 and f_2 are the true cut-off frequencies, but owing to loss in filter elements, unmatched termination and so on, the attenuation is greater at these frequencies than at the middle of the pass-band.

The effective band width might be specified as the frequency band lying between frequencies at which the attenuation is, say, equal to or less than 6 db. or 3 db. Fig. 9a and Fig. 9b bring out these points in diagrammatic form. For a band-stop filter, the limit is given as so much less than a maximum attenuation. See BAND-PASS FILTER, BAND-STOP FILTER.

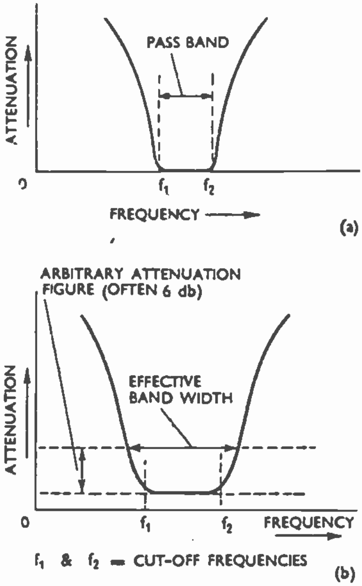


Fig. 9. Attenuation/frequency characteristic of (*a*) an ideal band-pass filter, and (*b*) that which results in practice, the effective band width being chosen as the example shown.

EFFECTIVE HEIGHT. Height that an earthed, vertical wire should attain in order to radiate the same field along the horizontal as is present if the wire carries a current that is constant along its entire length, and of the same value as at the base of the actual aerial. The formula for the power radiated by a vertical quarter-wavelength aerial is:

$$\text{Total power radiated} = \frac{320\,\pi^2\,h^2\,I^2}{\lambda^2},$$

where *h* is the height of aerial in

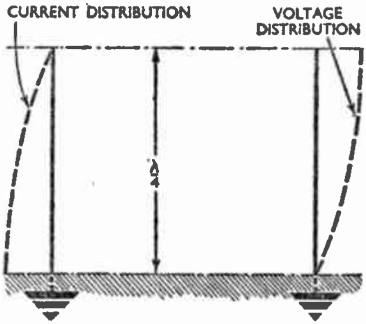


Fig. 10. Current and voltage distribution in a quarter-wave vertical aerial. Effective height is governed by the fact that current is not uniform and has the effect of reducing the amount of power radiated, making the aerial equivalent to a shorter one with the same current.

metres, I the r.m.s. value of aerial current in amperes and λ the wavelength in metres.

The formula is based on the assumption that the amplitude of the aerial current is the same at all points along the aerial. This is not the case in practice, the current distribution usually being sinusoidal, as shown in Fig. 10. In such a case, the effective height may be taken as the actual height multiplied by the ratio of the average value of the current to its peak value, which, for sinusoidal distribution, is $2/\pi$. For other types of distribution, similar allowance must be made. See AERIAL, AERIAL-ARRAY, RADIATION.

EFFECTIVE RESISTANCE. Total equivalent resistance of a circuit or component of a circuit, consisting of the ohmic resistance of the conductor or conductors plus the effect of circuit losses, expressed as a resistance.

EFFECTIVE VALUE. Value of a direct current which has the same heating effect as the alternating current in question. It is usually expressed as a fraction of the peak value. The effective value is the root-mean-square value of the alternating current.

EFFICIENCY. In general, the ratio of the energy obtained from any device to the energy applied to it. It is often expressed as a percentage. For example, the efficiency of a dynamo is the ratio of the electrical energy developed at the output terminals to the mechanical energy necessary to give this output. The anode efficiency of a valve is the ratio of the alternating power developed in the anode load to the power drawn by the anode circuit from the H.T. source.

EIGHT-ELECTRODE VALVE. Synonym for OCTODE.

E-LAYER. Region of ionized gases at a variable height of some 50–90 miles above the surface of the earth. The ionization appears to be mainly due to direct electron bombardment from the sun, although ultra-violet radiation probably accounts, for some of the ionization. The mean height at which the ionization exercises an appreciable effect upon radio-wave propagation is about 70 miles, but the lower limit is not sharply defined and varies from winter to summer and between night and day.

The E-layer is responsible for the reflection of most waves in the medium-frequency band, and for reflection at the lower frequencies of the high-frequency band. It is less intensely ionized than the F-layer, but because the gas pressure is higher, it is more stable and less dependent upon the sun's influence than is the F-layer. See IONOSPHERE, IONOSPHERIC REFLECTION, IONOSPHERIC REFRACTION, KENNELLY-HEAVISIDE LAYER, MEDIUM-FREQUENCY WAVE.

ELECTRICAL COMMUNICATION. See TELECOMMUNICATION.

ELECTRICAL RECORDING. Recording sound by electrical, as distinct from acoustical, means. It implies the use of a microphone, an amplifier and a recording machine for the conversion of sound waves into electrical energy, and use of that energy to produce a sound track on a moving medium, for example, cellulose-coated discs, steel tape or film.

Recording systems used by radio broadcasting organizations fall into three groups: gramophone, including direct-disc recording; magnetic recording; and sound film.

The original acoustic system of gramophone recording had two inherent disadvantages. The first was that it required the performers to be grouped around a horn, which made satisfactory musical balance difficult and limited the choice of programme material. The second disadvantage was that frequency response was limited to a range of approximately 300 to 3,000 c/s.

Modern technique, which simulates that of broadcasting studios, has developed along two lines, namely, commercial recording for the production of gramophone records, and direct-disc recording for immediate playback.

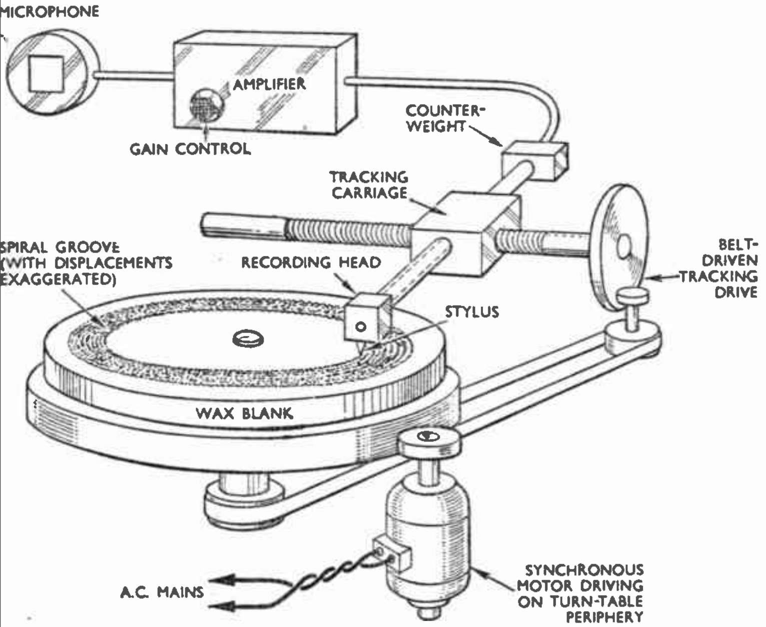


Fig. 11. Essentials for electrical gramophone recording. Sounds picked up by the microphone are amplified and applied to the recording head, the stylus of which vibrates, forming a sound track on the rotating wax blank. The tracking carriage is moved slowly across the blank, producing a spiral groove.

The essential principles of both systems are illustrated in Fig. 11. Sounds produced in the studio are converted by a microphone into electrical pressure variations which are amplified and passed to the recording head. The latter is designed on the principle of a gramophone pick-up, and may have a moving-iron, moving-coil or piezo-electric movement.

The head is fitted with a cutter or stylus (usually of synthetic sapphire) which, when signals are applied to the head, vibrates laterally at the frequency of the initial sounds. The turntable, on which is placed the recording material, a soft wax blank or a cellulose-coated disc, is driven at a constant speed (33⅓ or 78 r.p.m.) by an electric motor. The recording head is mounted on a carriage which, when the turntable revolves, moves radially across the blank. (On some machines this process is reversed, the head being stationary and the turntable platform moving.)

When the recording head is lowered, the stylus contacts the blank, cutting a groove in the form of a spiral. If, at the same time, signals are applied to the head, the lateral vibration of the stylus causes the groove to be displaced on either side of its mean position, the displacements having a wave form similar to that of the sounds picked up by the microphone.

The distance between adjacent grooves is regulated by the speed at which the recording-head carriage traverses the radius of the blank. The groove spacing is called the pitch and is usually adjustable. If the pitch is too fine, adjacent grooves will overlap at large stylus displacements, breaking the continuity of the spiral and rendering satisfactory reproduction impossible.

From the recorded wax blank, copies are produced by processing. A metal master copy is first produced from the recorded wax blank by electro-plating processes and, from the master, metal stampers are made. A heated plastic, e.g. clay, shellac and copal, is placed under a stamper and the final record produced. A thousand or more copies can be made from each stamper.

In the direct-recorded disc system, wax blanks are not used, because they deteriorate rapidly if played back before processing. Therefore, a direct-recorded disc is made of a harder material; it consists of a rigid base (metal, glass or other suitable material) coated with a lacquer produced from cellulose nitrate.

The hardness of this lacquer must be such that it can be cut easily by a sapphire stylus, and must also be capable of reproduction by an ordinary gramophone needle without the groove being damaged. The thickness of the coating must be uniform and sufficient to prevent the tip of the stylus from penetrating to the metal base (0·008 in. meets normal requirements). If copies are needed, a direct-recorded disc may be processed to produce the stamper.

A modern transportable disc-recording equipment is shown in Fig. 12. Power supplies for the turntable and amplifier-valve filaments are taken from a heavy-duty, 12-volt battery. The amplifier H.T. supply is derived from a motor-generator, housed in the supply unit below the amplifier and driven by the 12-volt battery.

Essential requirements for faithful recording are: full-range audio-frequency response, low-percentage harmonic distortion, adequate volume range and constant turntable speed. The first two of these requirements are functions of microphone, amplifier and recording-head design; the third largely depends upon adequate groove spacing, and the fourth is usually achieved by the use of a synchronous motor.

Magnetic recording was first used by Poulsen for recording morse signals

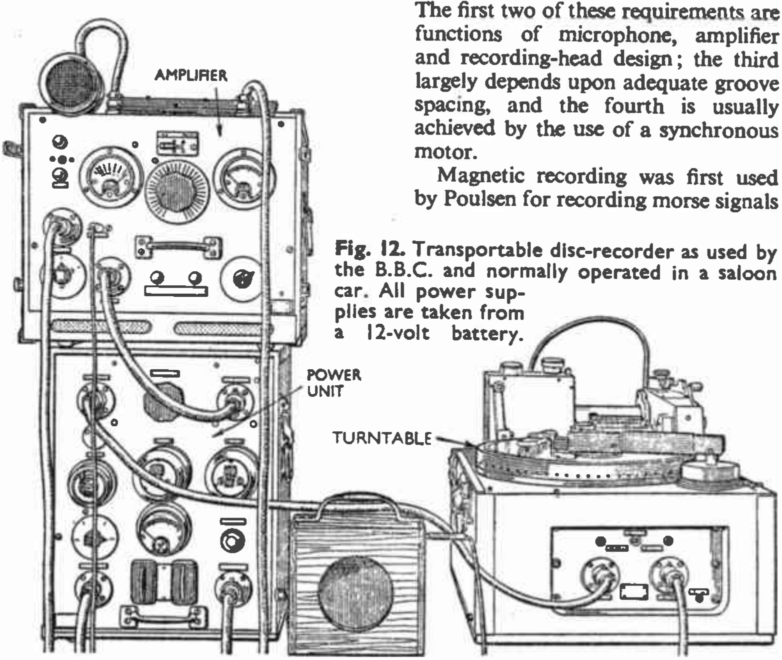


Fig. 12. Transportable disc-recorder as used by the B.B.C. and normally operated in a saloon car. All power supplies are taken from a 12-volt battery.

at high speed over a telegraph system. In this system, the signals at the receiver could be recorded magnetically and reproduced at a slower speed. A steel wire was driven through a solenoid, the electric current through the solenoid being interrupted by a morse key. This is a simple application of the law of magnetic induction, the moving steel wire becoming magnetized by the current in the solenoid.

The principle was applied to the recording of sound in 1924 by Stille, a German engineer. A steel tape (Fig. 13) was first magnetized to saturation by a magnetizing, or wiping, head energized by direct current, and then partially de-magnetized by another head connected to a D.C. source and to the output of the recording amplifier. When signals were applied to this head, the intensity of magnetization on the tape after it had passed by the pole-piece varied on either side of the value fixed by the D.C. de-magnetizing field; that is, it depended on the combined effect of the D.C. and A.C. signal currents passing through the coil of the head.

By passing the tape through a reproducing head, the magnetic variations were transformed into electric potentials, which were then amplified and applied to a loudspeaker, producing signals corresponding to the original sounds picked up by the microphone.

A machine, designed to operate on these principles and called a Blattnerphone, was used in 1930 by the B.B.C. for recording and reproducing broadcast programmes. Since that date other machines have been developed, notably the Marconi-Stille (British), the Magnetophon (German) and a small, portable steel-wire recorder (American).

Sound is recorded on film either by a photographic process or by an inscribing process. Where it is required to synchronize sound signals with a motion picture, it is customary to use a photographic film as the recording material. Light is projected through a narrow slit on to the film, and either the intensity of the light or the width of the beam is varied about a mean value at the frequency of signals applied to the recording amplifier.

If the light intensity is varied, the method is known as *variable-density* recording. It is achieved by

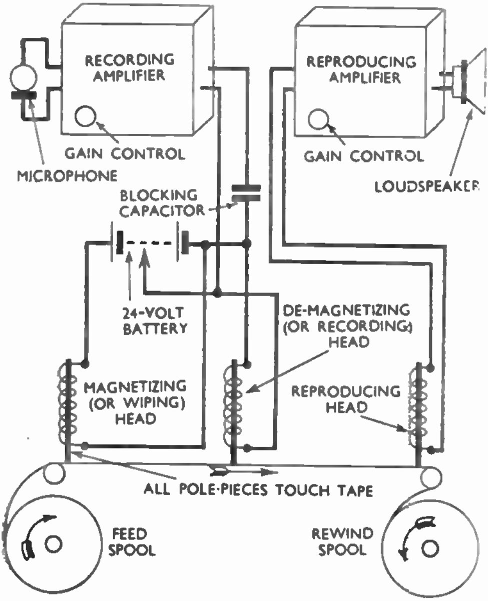


Fig. 13. Schematic diagram of magnetic recorder. The tape, first magnetized to saturation, is partially de-magnetized by D.C., the degree of de-magnetization being varied by signals applied to the recording head. The sound track is invisible and consists of magnetic variations on the steel tape, such variations being proportional in frequency and amplitude to the applied signals.

connecting the output of the recording amplifier to a light valve, the function of which is to vary the amount of light passing through a narrow slit interposed between the light source and the film. The light intensity at any instant will, therefore, be proportional to the signal e.m.f.s, and there is recorded on the moving film a sound track having density variations which correspond to the wave form of the sounds picked up by the microphone.

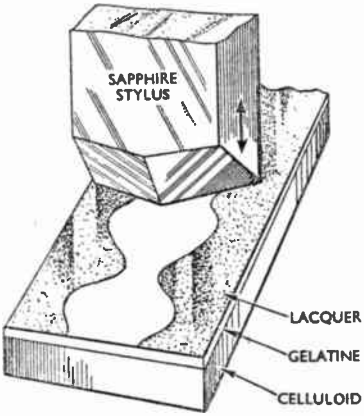


Fig. 14. In the Philips-Miller recorder, perpendicular movement of the cutter inscribes a variable-area track in the thin opaque lacquer. The gelatine layer prevents the cutter tip from becoming blunted on the celluloid base of the film.

With the *variable-area* method, the output of the recording amplifier is connected to a device which operates a mirror galvanometer, the light source being reflected on to a slit of constant width. The intensity of the light remains constant, but the width of the reflected beam varies in direct relationship to the values of the signal e.m.f.s. Thus the film is exposed to a light beam of constant intensity but of variable area.

With both these systems the sound is reproduced from the track by driving the film through a sound gate, comprising a narrow slit on one side of which is an exciter lamp and on the other a photocell. E.m.f.s are thus produced at the output of the photocell which are proportional to the variations in density or area of the sound track.

In the Philips-Miller system of film recording, a variable-area sound track is inscribed by a sapphire stylus on film coated with a very thin layer of black mercuric sulphide (Fig. 14). The movement of the stylus is in a direction perpendicular to the surface of the film and is controlled by the signals from the recording amplifier. A sound track having a width proportional to the signal e.m.f. is therefore cut on the film. Reproduction in this case is also by means of a photocell.

Comparisons between different recording systems must be based on overall performances; deficiencies in recording are often compensated for in reproduction.

A good recording system should have an over-all frequency response which is level between 30 and 10,000 c/s, harmonic distortion less than 1 per cent, and a driving speed constant to within 0·2 per cent. A further requirement is a signal-to-noise ratio of at least 40 db.

In gramophone recording, such a frequency response is possible on the outer diameter of the disc, but there is a tendency to reduced reproduction of the higher audio frequencies as the centre of the disc is approached. This is because the cutting speed decreases as the diameter decreases. The recorded wavelengths in inches are equal to $\pi dn / 60f$, where d is the diameter of the disc in inches, n the turntable speed in r.p.m. and f the signal frequency in cycles per second.

At the smaller diameters, the wave forms become cramped, and the reproducing needle finds difficulty in tracing the recorded grooves. This tracing distortion may be partly offset by progressively increasing the amplitude of the cutting stylus movement at high frequencies as the centre of the disc is approached. This is called radius compensation. It becomes ineffective at very small diameters and may cause serious harmonic distortion.

Harmonic distortion may be as low as 2 per cent for a well-designed disc recorder, and speed constancy is assured when synchronous motors are used to drive the turntable. Signal-to-noise ratio is higher for direct-recorded discs than for pressings, and the former offer the facility of immediate playback.

Magnetic recording avoids tracing (high-frequency) loss; the tape travels at a constant speed of approximately 90 metres per minute throughout recording. A frequency response of 100–7,000 c/s is obtainable. Harmonic distortion is low, but surface noise, except in the case of the Magnetophon, tends to be high. The tape can be de-magnetized and used many times.

Film recording generally has good frequency response and surface noise characteristics, and provides a high-fidelity system where running costs are a secondary consideration. It is the most suitable system for synchronizing sound recording with moving pictures, the picture and sound tracks being carried on the same film. See ELECTRICAL REPRODUCTION, GRAMOPHONE PICK-UP, MARCONI-STILLE RECORDER, PHOTOCELL.

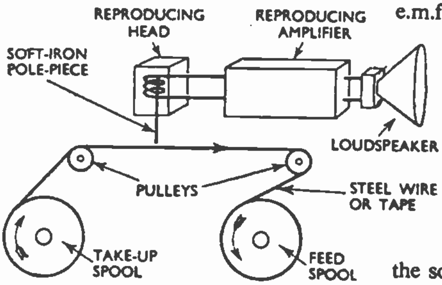


Fig. 15. Principles of magnetic sound reproduction. The sound track is in the form of magnetic variations on the wire; when the wire is driven past the pole-piece, alternating e.m.f.s corresponding to the recorded signals are induced in the coil and reproduced through an amplifier.

ELECTRICAL REPRODUCTION. Reproduction of any recorded sound track by electrical as distinct from acoustical means. Excepting gramophone records, all modern recording systems are reproduced electrically; gramophone records are reproduced by either electrical or acoustical means.

The essential requirements for electrical reproduction are: a reproducing head, means of moving the recording medium, an amplifier, and a loudspeaker or headphones. The type of reproducing head varies with different systems: a pick-up for gramophone records or discs (see GRAMOPHONE PICK-UP), a simple electromagnet for magnetic recordings, and a photocell for sound films.

The principle of reproduction applied to magnetic recordings is that of simple electromagnetic induction. The reproducing head consists of an electromagnet, the pole-piece of which either touches or lies in close proximity to the tape (Fig. 15). As the tape is driven past the pole-piece, the latter is subjected to the varying degrees of magnetization imparted to the tape during the recording process.

The varying flux densities, thus set up in the pole-piece, cause alternating e.m.f.s to be induced in the coil, such e.m.f.s having the same frequency as the sounds applied to the microphone during recording. The e.m.f.s are amplified electronically, the amplifier being equalized to correct for the inherent attenuation distortion of the tape.

With most magnetic recording systems, reproduction is marred by high surface noise, the signal-to-noise ratio corresponding roughly to that of a badly worn gramophone record. In recent years, the development of

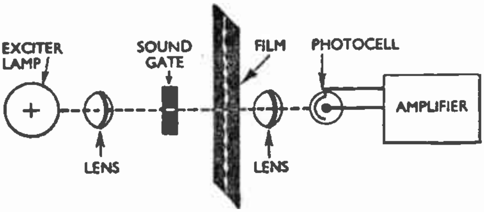


Fig. 16. Principles of sound reproduction from film by the Philips-Miller system. Variations in sound-track area cause varying intensities of light to fall on the photocell, producing small e.m.f.s which are then amplified.

plastic tapes, impregnated with iron oxide, has contributed to the reduction of surface noise (see MAGNETIC RECORDING, MARCONI-STILLE RECORDER).

The reproducing, or sound, head used for transforming the sound track of a film into electrical energy consists of a light source, a focusing lens, a sound-gate, consisting of a narrow slit, and a photocell. A schematic arrangement of the Philips-Miller system is given in Fig. 16. Similar principles apply to the reproduction of photographically recorded films.

Light is projected through the lens and slit on to the moving film. As the film is driven past the slit, the photocell is subjected to light of varying intensity, the variations corresponding to the density or area variations exposed on the film during the recording process. Since electronic emission within the cell is proportional to the quantity of light falling upon it, minute alternating e.m.f.s are produced between anode and cathode of the cell, the frequency of such e.m.f.s being similar to those of the recorded sounds.

As with other systems, the output of the reproducing head is connected to an equalized amplifier to obtain the correct frequency response and output volume.

In photographic sound films the original copy is a negative, from which numerous copies are taken for commercial distribution. In this process, some attenuation distortion is introduced owing to a decrease in definition, and signal-to-noise ratio is reduced because of the relatively coarser grain of the positives. In the Philips-Miller system, used for recording radio programmes, this problem does not arise, because processing is unnecessary. See ELECTRICAL RECORDING, PHOTOCELL.

ELECTRICAL RESONANCE. Condition in a circuit containing inductance and capacitance in which the inductive and capacitive reactances are equal. In general, there is only one frequency at which this condition exists, and it is known as the RESONANT FREQUENCY (q.v.). In a simple series circuit of inductance and capacitance the impedance is a minimum at resonance; in a parallel circuit of inductance and capacitance the impedance is a maximum at resonance.

ELECTRIC COMPONENT. Electric-field component of an electromagnetic wave. The principles of the radiation of electromagnetic energy are based on the laws that a moving magnetic field creates an electric field, and that a moving electric field creates a magnetic field. The created field at any instant is in time-phase with its parent field, but is at right angles to it in space. See POLARIZATION, RADIATION.

ELECTRIC CURRENT. Drift of free electrons through the substance of a conducting material. See CONDUCTOR, ELECTRON.

ELECTRIC DISCHARGE LAMP. Synonym for GLOW-TUBE.

ELECTRIC DISPLACEMENT. Synonym for ELECTRIC FLUX DENSITY.

ELECTRIC ELEMENT. Conductor which is heated by the passage of a current; the element is used for heating purposes, as in an electric cooker or iron. It is usually made of nickel-chrome resistance wire. The term "electric element" may also be used to denote any resistor, capacitor or inductor forming part of an electrical network.

ELECTRIC FIELD. Region, occupied by forces emanating from an electric charge, or in which they act. For example, an electric field exists in the space between two adjacent charges of opposite sign. See ELECTROSTATICS.

ELECTRIC FIELD STRENGTH. Intensity of an electric field at a particular point measured by ascertaining the force of attraction or repulsion on a unit charge placed at the particular point in the field.

ELECTRIC FLUX. Lines of electric force composing an electric field. See ELECTRIC FIELD, ELECTRIC FLUX DENSITY, ELECTRIC FORCE.

ELECTRIC FLUX DENSITY. Measure of the intensity of an electric field integrated over some particular unit of area in the field, this unit of area being assumed to be arranged so as to intercept the field of force at right angles to its direction of action.

ELECTRIC FORCE. Force of attraction or repulsion exerted between adjacent electric charges.

ELECTRIC OSCILLATIONS. Oscillations in an alternating-current-operated circuit, the frequency of such oscillations being determined by the constants of the components forming the circuit. The oscillations may have constant amplitude, as in the case of continuous-wave radio sending, or the amplitude may decrease rapidly, as in a spark-sending system. See OSCILLATION.

ELECTRIC RELAY. Device used in electrical circuits by means of which the current in one circuit opens or closes contacts which control the flow of current in a second circuit.

ELECTRIC SCREEN. Conducting electrode, in the form of a solid plate or a fine wire mesh, used to reduce or prevent the penetration of an electric field into a certain region. When used to prevent the establishment of an electric field between two conductors, the screen is placed between them and is earthed, resulting in cancellation of the capacitance between them. See SCREENING.

ELECTRIC STRENGTH. Ability of an insulator to withstand an electric stress without breakdown. A measure of the electric strength of a material can be obtained by determining the voltage at which breakdown occurs under standardized conditions.

ELECTRIC STRESS. Stress occurring in an insulating material when a difference of electrical potential exists across it.

ELECTRIC WAVE. Synonym for ELECTROMAGNETIC WAVE.

ELECTRODE. Conductive element, of a valve, which may emit, collect or control the flow of electrons or ions and electrons. The electrodes of a valve are usually insulated one from another, but in pentode valves the suppressor grid may be connected to cathode or control grid inside the valve.

Electrodes of a valve are an anode, a cathode, which emits electrons, and grid-type electrodes, which may collect electrons or control their flow between cathode and anode. The control grid is often operated at a negative potential with respect to cathode and does not, in such circumstances, collect electrons; but it does, according to its potential, exercise the greatest control on the electron current. See ANODE, CATHODE, ELECTRODE CURRENT, ELECTRODE IMPEDANCE, GRID, SLOPE RESISTANCE, VALVE.

ELECTRODE A.C. CONDUCTANCE. Synonym for SLOPE CONDUCTANCE.

ELECTRODE A.C. RESISTANCE. Synonym for SLOPE RESISTANCE.

ELECTRODE CAPACITANCE. Capacitance of an electrode to earth or to other specified electrodes. In valve operation, the capacitance of one electrode to another or to earth may have a profound effect upon the behaviour of the valve (see AMPLIFIER, MILLER EFFECT, TETRODE). The limitations imposed upon the highest frequencies of waves that may be amplified by a resistance-capacitance amplifier are largely due to electrode capacitance.

The introduction of the screen grid into the triode to form the tetrode was made to minimize the effects of the capacitance between control-grid and anode. The decrease of control-grid impedance, as the frequency of the wave applied to this electrode is increased, is due to the grid-electrode capacitance.

Electrode capacitance decreases as the dimensions of the electrode structure, hence valves are made smaller.

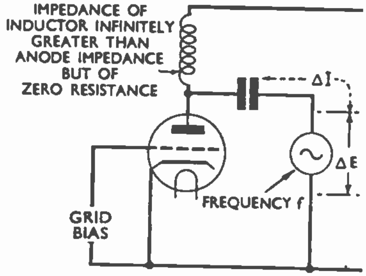


Fig. 17. If the impedance of the inductor is assumed to be infinite and its resistance zero, electrode (anode) impedance may be determined from knowledge of the frequency *f*, the alternating voltage ΔE and the current ΔI.

This reduction of overall size does not affect the amplification factor of a valve, and small valves may thus be used for amplifying waves of very high radio frequency. The leads connecting the valve pins to the electrodes add to electrode capacitance, and special designs are necessary in valves used for the amplification of waves of very high frequency. See AMPLIFIER, FOOTLESS CONSTRUCTION, MILLER EFFECT, TETRODE.

ELECTRODE CONDUCTANCE. See SLOPE CONDUCTANCE.

ELECTRODE CURRENT. Current flowing to and from an electrode. The electrode current forms part of the space current. The current used to heat the cathode is not termed an electrode current, but filament or heater current. See SPACE CURRENT.

ELECTRODE D.C. CONDUCTANCE. Reciprocal of ELECTRODE D.C. RESISTANCE.

ELECTRODE D.C. RESISTANCE. Resistance measured by the ratio of electrode voltage to electrode current. See SLOPE RESISTANCE.

ELECTRODE DIFFERENTIAL CONDUCTANCE. See SLOPE CONDUCTANCE.

ELECTRODE DIFFERENTIAL IMPEDANCE. See ELECTRODE IMPEDANCE.

ELECTRODE DIFFERENTIAL RESISTANCE. See SLOPE RESISTANCE.

ELECTRODE DISSIPATION. Power dissipated in the form of heat by the electrode of a valve (see ANODE DISSIPATION). The anode electrode usually dissipates the greatest heat due to bombardment by electrons, but other electrodes also rise in temperature; for instance, the cathode, as well as the anode in a glow-tube, is liable to get hot due to positive ion bombardment. Screen grids, when carrying a large current, may become hot also. In general, however, if the anode can safely dissipate the heat developed, no other electrode gets hot enough to be damaged. Thus in a cooled valve, the cooling of the anode helps to keep the other electrodes at a safe temperature. See COOLED VALVE, RATED ELECTRODE DISSIPATION.

ELECTRODE IMPEDANCE. Impedance between an electrode of a valve and another specified point in a circuit. Sometimes the reference point is not mentioned (as in the phrase "anode impedance"); in such cases the point may be taken to be at cathode or earth potential. The impedance is obtained by varying the electrode potential by a small amount ΔE and by noting the corresponding change in electrode current ΔI; the impedance is then given by $\Delta E/\Delta I$.

It is important that all electrode voltages and currents should have their normal values when the measurement is made; otherwise the value of impedance obtained is not that which applies under working conditions. There is usually a small capacitance between any one electrode of a valve and the other electrodes. Similarly, most electrodes have a small value of inductance. These two properties of the electrode can modify the impedance, but their effects are negligible at very low frequencies.

At low frequencies, therefore, ΔI is in phase with ΔE and the impedance is predominantly resistive. As frequency is raised, however, the effects of electrode capacitance and inductance become more important, and ΔI is no longer in phase with ΔE. Division of ΔE by ΔI thus gives a complex quantity indicating that the impedance now has a reactive component.

The basis of a method of measuring the anode impedance of a valve is shown in Fig. 17. A battery connected to the grid applies the normal value of grid bias to the valve. The anode is connected to the H.T. supply through an inductor, and an A.C. generator applies potentials to the anode by way of a fixed capacitor. The generator applies the small alternating potential ΔE at the frequency at which the anode impedance is to be measured.

The reactance of the capacitor must be very small at the frequency of measurement, compared with the anode impedance, so that the full value of ΔE reaches the anode. Since the valve and the inductor are effectively in parallel, the alternating current ΔI taken from the generator includes two components, one of which flows through the anode-cathode path of the valve and the other through the inductor. The latter current is made very small by choosing an inductor which, at the frequency of measurement, has a reactance very large compared with the impedance of the valve. As ΔI is current in the valve only, the impedance is given by $\Delta E/\Delta I$.

ELECTRODE POTENTIAL. Voltage acting between an electrode and earth, or the voltage acting between any two specified electrodes if neither is earthed. The anode voltage is the voltage between anode and cathode; the control-grid voltage may be that between control grid and earth, or between grid and cathode. If nothing is stated to the contrary, the electrode potential or voltage is the potential difference between the electrode and earth.

ELECTRODE RESISTANCE. See SLOPE RESISTANCE.

ELECTRODE SLOPE-CONDUCTANCE. See SLOPE CONDUCTANCE.

ELECTRODE SLOPE-RESISTANCE. See SLOPE RESISTANCE.

ELECTRODE VOLTAGE. See ELECTRODE POTENTIAL.

ELECTRODYNAMIC LOUDSPEAKER. Synonym for MOVING-COIL LOUDSPEAKER.

ELECTRODYNAMIC MICROPHONE. Synonym for MOVING-COIL MICROPHONE.

ELECTROLYTE. Liquid or paste used in voltaic cells. The conduction of electricity through the electrolyte between electrodes in contact with it takes place by virtue of a transfer of ions from one electrode to another. See ACCUMULATOR CELL.

ELECTROLYTIC CAPACITOR. Form of capacitor in which the dielectric is deposited on one or both of the metallic electrodes by electrochemical means. See FIXED CAPACITOR.

ELECTROLYTIC CONDENSER. Synonym for ELECTROLYTIC CAPACITOR.

ELECTROLYTIC DETECTOR. Early form of detector based on the polarization of an electrolyte. The circuit arrangement is shown in Fig. 18. When the battery is connected to the cell, the current which flows through the liquid breaks up the molecules, due to the process of electrolysis, and a thin film of gas is formed over the electrodes, after which the current ceases. An increase in the applied voltage will break down this film and allow more current to flow.

For use as a detector, the battery voltage is adjusted to a value just below the breakdown point of the film. If a radio-frequency signal is then added to the battery voltage, the positive half-waves of the signal will break down the film and allow a small current to flow, while the negative half-waves will not be able to overcome the polarization and will, therefore, produce no effect.

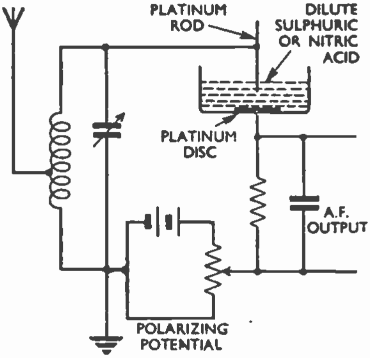


Fig. 18. Circuit arrangement illustrating the principles of operation of the electrolytic detector.

ELECTROLYTIC RECTIFIER. Rectifier in which the asymmetrical conduction is due to the chemical action taking place between an electrolyte and an electrode or electrodes immersed therein.

In one form of electrolytic rectifier, shown in Fig. 19, the electrodes are made of aluminium and lead and the electrolyte is a solution of aluminium phosphate. The electrolytic rectifier has a limited power efficiency and is little used in practice, though it has been used for detection of spark signals. See RECTIFICATION.

ELECTROMAGNET. Core, usually of ferro-magnetic material, which serves as a magnet only so long as an electric current flows through a coil surrounding the core; as distinct from a permanent magnet, which, having been magnetized, retains a large part of the magnetism. An electromagnet provides a means of converting electrical force or energy into mechanical force or work. For this reason, electromagnets form an essential part of many and diverse kinds of electrical apparatus, including meters, vibrators, motors, and loudspeakers. The term is particularly associated with electromagnetic relays. See ELECTROMAGNETISM, ELECTROMAGNETIC RELAY.

ELECTROMAGNETIC COMPONENT. Component of the field existing around a radiating aerial which is at right angles to the conductor, and which represents the radiated energy. The other important component is electrostatic, or electric. See ELECTRIC COMPONENT.

ELECTROMAGNETIC DEFLECTION. In a cathode-ray tube, the deflection of the electron beam by the magnetic field set up by current-carrying coils placed in close proximity to the tube but external to it.

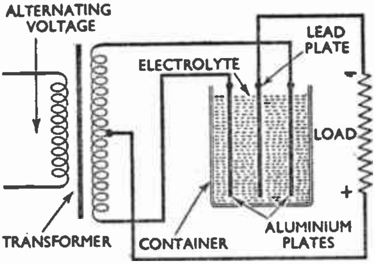


Fig. 19. Electrolytic rectifier connected for full-wave rectification so that a unidirectional current flows in the load.

ELECTROMAGNETIC INDUCTION. Phenomenon which causes an e.m.f. to be set up in any conductor which is crossed by a moving magnetic field or by one changing in magnitude. This can be demonstrated with a winding of a few hundred turns of wire on a cardboard tube, a bar magnet, and a sensitive galvanometer (Fig. 20). If the winding is connected to the galvanometer, the instrument will give a momentary deflection when the magnet is thrust inside the tube, and another in the opposite direction when it is withdrawn. If the magnet is kept in regular to-and-fro movement, the instrument will reveal a corresponding regular succession of currents.

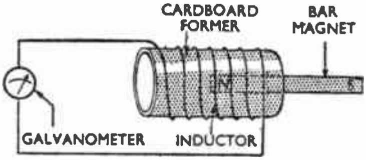


Fig. 20. Electromagnetic inductor formed by several turns of a conductor round a cardboard-tube former; the needle of the galvanometer will "kick," thus registering a momentary current, each time the magnet is moved into or is withdrawn from the tube former.

If the bar magnet is replaced by a second winding on a small tube, and this second inductor is energized with a direct current, exactly the same result will be produced. Further, if an alternating current is used instead of a direct one, there will be no need to move the small tube in and out of the bigger one; the continuous rise and fall of the alternating current in the second winding will cause its magnetic field to cut across the first one all the time. An alternating e.m.f. will, in fact, be induced in the secondary winding. This is the principle of the transformer. See ELECTROMAGNETISM.

ELECTROMAGNETIC LOUDSPEAKER. See MOVING-IRON LOUDSPEAKER.

ELECTROMAGNETIC MICROPHONE. See MOVING-IRON MICROPHONE.

ELECTROMAGNETIC PICK-UP See GRAMOPHONE PICK-UP.

ELECTROMAGNETIC RELAY. Switch operated by an electromagnet. Those used in telephone and telegraph equipment are typical. Relays used in telephone practice may be fitted with several contact units. By their aid, the current in one circuit can be made to control a number of other circuits simultaneously. Because of this feature, they are extensively used in telephone-exchange circuits and also for remote-control purposes generally.

The British Post Office 3,000-type relay (Fig. 21) is typical. It is non-polarized, that is, the operation is independent of the direction of flow of current through the energizing winding.

A core, on which is wound a coil, carries a pole-piece at one end and is attached to a yoke at the other. An armature is pivoted on the yoke close to the pole-piece but spaced from it by a small air-gap. The pole-piece, core, yoke and armature constitute the magnetic circuit. All are made of soft iron having a low value of residual magnetism.

When a current flows through the winding, the armature is attracted towards the pole-piece, but is prevented from striking it by a "residual"

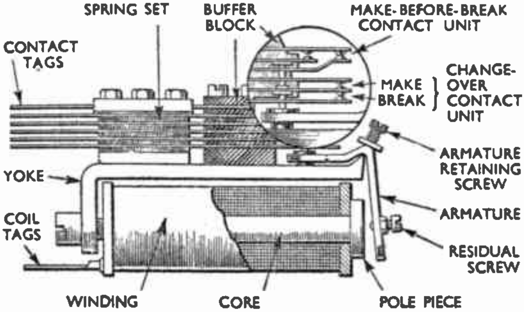


Fig. 21. Details of the 3,000-type electromagnetic relay; it is non-polarized and is a typical example of the relays employed in telephone-exchange circuits.

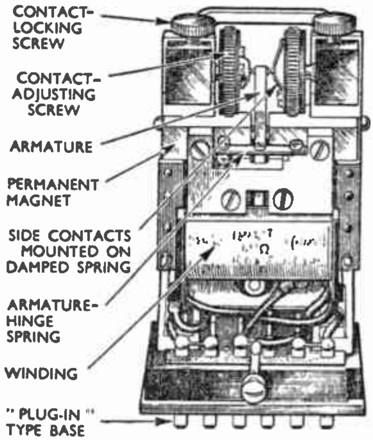


Fig. 22. Carpenter polarized type of electromagnetic relay (as produced by the Telephone Manufacturing Co., Ltd.) for use in telegraphic systems.

stud or screw of non-magnetic material. The purpose of this small residual air-gap is to reduce any tendency for residual magnetism to hold the armature to the pole-piece when the current in the coil ceases to flow. The armature, by means of an extension piece acting as a lever, deflects the movable contact springs of the contact units.

The contact units are of four kinds: "make," "break," "change-over" (break-before-make), and "make-before-break." The last two of these are illustrated in the positions occupied when no current is flowing in the winding, a convention which is adopted when making circuit diagrams.

An assembly of contact units is called a "spring set." Two spring sets are mounted on the yoke. Each contact unit has one movable contact spring and either one or two "fixed" springs. The movable spring nearest the yoke has a lifting pin resting on the armature lever, and another supporting the next movable spring and so on throughout the spring set. Insulating discs on the armature lever and on alternate movable springs and clearance holes in the "fixed" springs prevent short-circuiting.

The fixed contact springs have side lugs which rest against a locating support called a "buffer block" with a force sufficient to ensure a contact pressure of about 20 g. In operation, the movable springs lift the fixed springs from the buffer block and, during the movement, the contact points slide one upon the other so that the surfaces rub sufficiently to ensure a good electrical contact. The contact points themselves are dome-headed rivets made of precious metal to minimize wear by arcing. The metal is generally silver, but for heavy duty platinum may be used. Each contact spring is divided at the free end to form two fingers, and each finger carries a contact point. Such "twinning" of contacts minimizes faults caused by dust.

It is sometimes required, in circuit design, that one contact unit should operate before (X-operation) or after (Y-operation) the other units in a set. X-operation is achieved by shortening the lifting pin of the contact unit nearest to the yoke, and Y-operation by shortening the lifting pin of the contact unit farthest from the yoke. Relays incorporating either of these features are called two-step relays.

The number and kind of contact units determine the mechanical load on the armature lever and, in consequence, the value of the magnetic flux (and the current) required to operate the relay. The operating time is the time required for the flux to build up to the operating value. This is indirectly proportional to the time constant (inductance divided by resistance) of the operating circuit and to the applied voltage.

The releasing time is the time required for the flux to fall to the releasing value. The releasing time depends upon the margin between the working and releasing values of the flux and also on eddy currents induced in the various component parts.

Both operating and releasing times of a general-purpose relay are of the order of 20 millisec. Both can be prolonged by magnetically coupling a circuit having a large time constant. This usually takes the form of a thick-walled copper cylinder (or "slug") threaded on to the core to occupy part of the winding space. It acts as a single short-circuited turn of very low resistance. The effect on the operating time is a maximum when the slug is fitted at the armature end of the core.

The releasing time can be reduced and, to a much lesser extent, the operating time increased, by increasing the residual gap. The holding current and, to a lesser extent, the operating current are both increased by this last adjustment. Operating and releasing times and currents are of great importance in the design of automatic telephone-exchange circuits and in most relay applications.

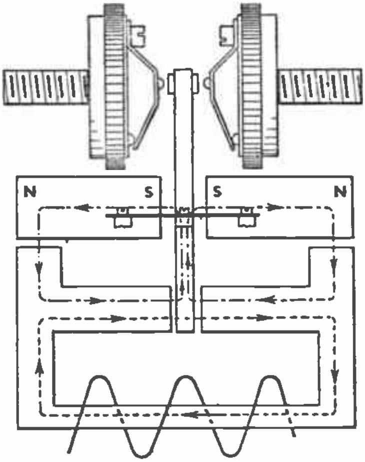


Fig. 23. Diagram showing the magnetic circuit of the Carpenter telegraphic relay which is illustrated in Fig. 22.

The construction of telegraph relays is very different from that of telephone relays. They are polarized, more sensitive, more rapid in operation and made with greater precision. Their prime purpose is to respond to feeble telegraph signals (that is, current pulses of variable duration) and to operate a contact unit so that, in a suitable circuit, it may reproduce the signals with a minimum of time distortion.

A typical relay is shown in Fig. 22, and the magnetic circuit and contact unit in Fig. 23. The magnetic circuit is symmetrical and includes two permanent magnets, the other parts being made of soft iron. When there is no current flowing in the operating winding, the magnetic fluxes on each side of the armature are equal and opposite, and the armature tends to remain in the central (neutral) position shown. In practice, this is an unstable equilibrium and the armature normally rests against one or other of the two fixed contacts.

Passage of current through the operating winding augments the flux through the centre limb on one side of the foot of the armature, and opposes that on the other. The foot of the armature is attracted towards the side carrying the most flux and the remote extremity carrying the contacts moves to the opposite side. The contact gap is made very small, of the order of 0·001 in. By so limiting the movement of the armature from the central position of equilibrium, the sensitivity is increased and the transit time reduced to less than 1 millisec.

Biasing the relay, that is, making the operating current for one direction of movement greater than the other, may be effected by displacement of the "fixed" contacts; upsetting magnetic equilibrium with the aid of a magnetic shunt across one of the air-gaps; or by passing current through an auxiliary biasing winding.

ELECTROMAGNETIC RETROACTION. Synonym for INDUCTIVE FEEDBACK.

ELECTROMAGNETIC SCREEN. Earthed, solid, screen of conducting and, possibly, magnetically permeable material, used to reduce or prevent the spread of electric and magnetic fields into a particular region. See SCREENING.

ELECTROMAGNETIC SYSTEM OF UNITS. System based on the use of electromagnetic phenomena as an integral part of the unit definitions. An example is the absolute ampere. See AMPERE.

ELECTROMAGNETIC-WAVE PROPAGATION. Radiation of electromagnetic waves from a sending aerial to a distant receiving point. See RADIATION.

ELECTROMAGNETIC WAVES. Space fields in which electric and magnetic fields at right-angles to each other travel in a direction at right-angles to both. See POLARIZATION, RADIATION.

ELECTROMAGNETISM. Magnetism produced by the flow of an electric current. Any movement of electrons produces a magnetic field, but the field around a straight conductor is comparatively weak. Strong fields are produced only if the conductor is coiled up into the form of an inductor, when the lines of magnetic force from one turn of wire join up with those of the next turn (and so on through the winding) to produce a total result which is in proportion to the ampere-turns of the inductor; that is, the product of the current and the number of turns.

A current of 1 amp. passing through an inductor of 100 turns produces the same intensity of magnetic field as one of 2 amp. in a winding of 50 turns, and so on; always assuming that the two inductors are of the same characteristics in other respects.

If a long tube of small diameter is wound with a suitable number of turns of wire and a direct current is passed through the winding, the device is equivalent in its magnetic effects to a bar magnet. Its magnetic polarity depends on the direction in which the current passes round the tube, and can be determined by hanging the tube up on a thread, and making flexible connexions to its winding with fine wires attached at the centre. The tube will then, if the suspension is sufficiently delicate, behave like a compass needle and come to rest with its axis in a north-south direction. It may be shown that, with respect to the end which is turned to the north, the electron flow is clockwise round the winding (Fig. 24). There is a simple method for finding the polarity of an electromagnet: place the palm of the left hand on the surface of the winding with the fingers pointing in the direction of the electron flow (from negative to positive of the current source), and the outstretched thumb will then point to the north pole of the magnetic system.

The simple inductor carrying direct current is the electromagnet in its elementary form. For practical purposes, the air-core form is not often used; some material of higher magnetic permeability than air is inserted in the centre of the winding, and a magnetic field many times as strong is obtained (see PERMEABILITY). The material commonly used for this purpose was soft iron, but in modern practice various special ferrous alloys are generally employed because of their still higher permeability.

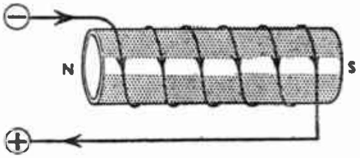


Fig. 24. A fundamental of electromagnetism is the fixed relationship between direction of electron flow in a winding and the resulting magnetic polarity.

A special advantage of the iron or alloy core is that, by means of shaped and extended pole-pieces, the magnetic field can be led away from the energizing winding and closely applied to some object such as the armature of a dynamo, so as to concentrate the lines of force just where they are wanted (Fig. 25). The magnetic force follows the high-permeability path as far as the iron or other material will carry it, and only emerges into the air when it comes to a gap in the metal.

Electromagnets have innumerable uses in electrical work. In fact, they are used in almost all cases when electrical energy is required to set something in motion. The electric motor uses them in special form; the armature, in many types, consists of a series of electromagnets which are successively energized so that the attraction and repulsion effects between their fields of force and those of the poles of the field magnet set the armature turning to deliver power.

In a particularly wide range of applications, the electromagnet is used to move an object between two possible positions. An instance is the relay (more often called a contactor when it is designed to control large currents). Here the electromagnets attract an iron armature when they are energized; this armature serves to open or close a pair of contacts which make or break the circuit of the current which is to be controlled. In this way, a comparatively small local current, such as can readily be applied through a push-button, can be made to turn on and off a current of such magnitude that it would otherwise have to be handled by a large manually-operated switch (see ELECTROMAGNETIC RELAY).

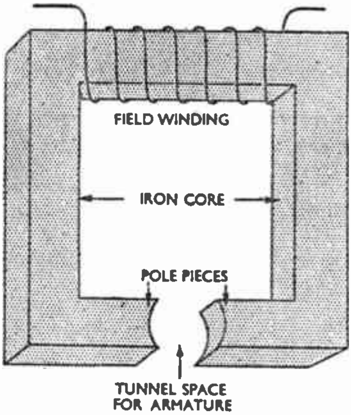


Fig. 25. Simplified diagram of the electromagnetic circuit of a dynamo, showing how the magnetic flux produced in the iron core by the field winding is led by pole-pieces to where it is to act on the revolving armature.

The elements of a contactor-switch are shown diagrammatically in Fig. 26, which illustrates a pair of electromagnets with windings arranged to produce a north pole at one free end and a south pole at the other; an iron yoke joins the iron cores' other ends and so completes the magnetic circuit. The armature is a piece of soft iron on a strip of spring steel. When current is applied to the electromagnets, the armature is pulled down towards them against the resistance of the steel spring. The contact plunger dips then into the mercury cup and completes the circuit that is to be switched on.

When the local current is cut off from the electromagnets, they release the armature, which is lifted again by the spring and withdraws the plunger, which interrupts the main current. (In a practical case, the mechanical arrangements would be more elaborate than the sketch shows, particularly in the provision of adjustable stops to control the travel of the main contacts, and a more effective kind of spring control for the armature.)

The same basic arrangement of an armature moving under the influence of electromagnets is used in two other common devices, the overload release and the no-volt release, or cut-out. In a crude form of the overload release, the strength of the electromagnetic pull on the armature is so adjusted that, under normal working conditions, the armature does not move. But if the load in the circuit rises above a selected value, the current through the electromagnet windings increases so much that the armature is pulled down and causes a pair of contacts to open and so switch off the load.

The no-volt release is simply the charging cut-out found in the electrical

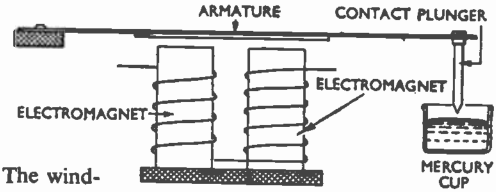


Fig. 26. Contactor-switch operated by electromagnetism, shown in simple diagrammatic form; operation of this unit—a relay—is explained in the text.

system of every motor car. The windings of the electromagnets are connected directly across the output terminals of the charging dynamo, and when the voltage rises sufficiently they pull down the armature. This in turn closes a pair of contacts and connects the dynamo to the battery; charging then begins. When the engine slows again the dynamo voltage falls, the cut-out armature is released, and so the battery is prevented from discharging through the dynamo. There are innumerable applications of the principles of electromagnetism in controlling electrical circuits, but those given serve to illustrate the basic methods.

The electric crane is an example of another interesting range of industrial applications. Although the lifting motive power of the electric crane may, in fact, be steam, the name is explained by the device for grasping the load to be lifted; this is an extremely big and powerful electromagnet, controlled by a switch in the operator's cab. For handling various iron and steel objects the electromagnetic grab has obvious advantages. Another application of the high-power electromagnet is in the magnetic brake used on some electric railways and tramways; in this, the adhesive force between brake shoe and rail is a magnetic one; the shoe is the pole-piece of an electromagnet, and grips the steel rail when energized.

ELECTROMALUX. Tube containing a mosaic which emits electrons when exposed to light as in a television camera. See VISION PICK-UP.

ELECTROMECHANICAL DRIVE. Oscillator used as a carrier source in a sender, and in which the frequency-determining element is a mechanical device such as a tuning fork.

ELECTROMOTIVE FORCE. Driving force which sends an electric current round a circuit. Common instances are the electromagnetic-induction effect of a magnetic field cutting across a winding, or the electrochemical action in a primary or secondary battery. The abbreviation e.m.f. is often used as a synonym for voltage.

ELECTRON. Negatively charged particle of matter; or minute unit of electricity which, in certain circumstances, behaves as though it were possessed of the properties of an exceedingly small and light particle of matter. The electron is part of the complicated structure known as an atom; the number of the electrons and their arrangement play a part in deciding the chemical properties of a particular atom.

Some of the electrons in the atom are attached only loosely, and can move from atom to atom, as when they form an electric current through a conductor. Again, they can emerge from their material source, as when they are ejected by heat from the cathode of a thermionic valve or of a cathode-ray tube.

ELECTRON BEAM. In a cathode-ray tube, or similar device, the narrow stream of electrons emitted through the electron gun and focused on the screen. See CATHODE-RAY TUBE, ELECTRON GUN.

ELECTRON BUNCH. Concentration of moving electrons such as that produced in a Klystron tube. See BUNCHER, CATCHER, KLYSTRON.

ELECTRON CAMERA. Vision pick-up employing electronic scanning, but not the mosaic principle of a storage camera. See IMAGE DISSECTOR.

ELECTRON COUPLING. Coupling between two circuits in which a flow of free electrons is controlled by one circuit, the current carried by the electrons passing through the other circuit. The term could be used to describe a valve amplifier in which coupling between the input (grid) circuit and the output (anode) circuit is provided by the electron stream through a valve.

Since amplifiers have a terminology of their own and because this seldom includes electron coupling, the term is seldom used. It may be used, however, to describe the coupling of an external circuit to an oscillator. The oscillator may be a tetrode with the output taken from the screen grid. The advantage of electron coupling is that changes in the external circuit cause only small changes in the frequency of oscillation. See AMPLIFIER, COUPLING, OSCILLATOR.

ELECTRON DISCHARGE. Passage of electrons through an evacuated space; in other words, it is the electrode current.

ELECTRON DISCHARGE VALVE (OR TUBE). See GLOW-TUBE.

ELECTRO-NEGATIVE. Synonym for NEGATIVE.

ELECTRON GUN. Arrangement of electrodes in a cathode-ray tube which produces an ELECTRON BEAM (q.v.). An ELECTRON JET (q.v.) is emitted by a cathode electrode, passes through an aperture in an electrode and is formed into a beam by one or more focusing electrodes. See FOCUSING ELECTRODE.

ELECTRONIC OSCILLATIONS. In a valve, the very high-frequency oscillations of electrons as they pass between cathode and anode.

ELECTRONIC RECTIFIER. Synonym for VALVE RECTIFIER.

ELECTRONICS. Any technology concerned with the movements of free electrons in a virtual vacuum, or with ion and electron movement in a gas.

The basic tools in electronic technology are hard-vacuum valves and gas-filled valves. The technology of the valve, glow-tube, X-ray and cathode-ray tube is complex and widespread; not only is the valve the heart of all modern practice in telecommunications, but it is also extensively used in industry and in pure physics.

Thus the term electronics covers a wider field than communication, although probably the chief use of the valve is to extend our powers of hearing and seeing by the use of the telephone, broadcasting, telegraphy, television and facsimile. See VALVE.

ELECTRONIC VALVE. Synonym for VALVE.

ELECTRON JET. Term applied to a narrow stream of electrons, whether focused or not. See CATHODE-RAY TUBE, ELECTRON GUN.

ELECTRON LENS. Name given to the arrangement for focusing the electron stream in a cathode-ray tube.

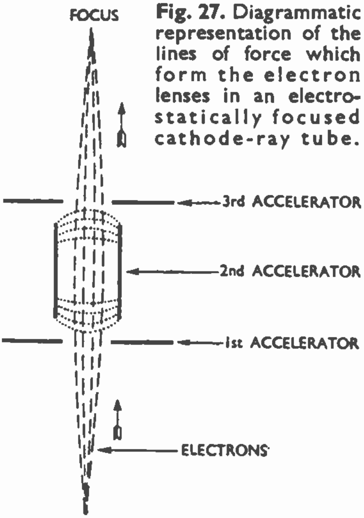


Fig. 27. Diagrammatic representation of the lines of force which form the electron lenses in an electrostatically focused cathode-ray tube.

The electron lens may be either electrostatic or electromagnetic, and is formed by the field created either between the first and second, and second and third accelerators (see ACCELERATOR), or by the field from a focusing coil placed round the neck of the tube.

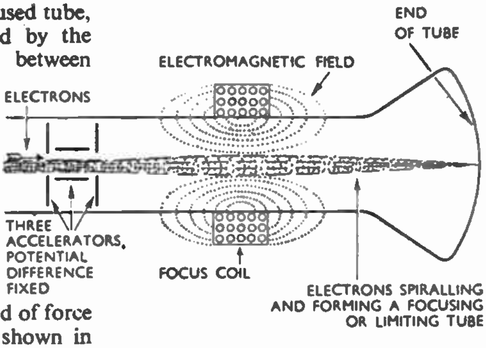


Fig. 28. An electron lens may be in the form of an electromagnetic field produced by a coil surrounding the cathode-ray tube. The diagram shows the "spiralling" effect that this has upon the electrons.

In the electrostatically focused tube, the focusing field is formed by the electrostatic strain created between adjacent accelerators, the field of force being shaped somewhat as shown in Fig. 27. The effect is to make the electrons bunch towards the centre of the field and so form a narrow beam.

In electromagnetic focusing, the field is so arranged as to be parallel with the path of the electrons. Electrons moving parallel with the field are not deflected, but those that stray from the parallel path tend to be deflected at right angles to the field, and will describe a circular path. Thus, all electrons not travelling parallel with the field will take up a spiral path as they go towards the screen, and by correct adjustment of the field strength can be brought to a focus at the screen (Fig. 28).

In electrostatic focusing control of focus is provided by varying the voltage between the accelerator electrodes, and in electromagnetic focusing by the current passing through the coils forming the lens.

ELECTRON MULTIPLIER. Type of photocell in which high gain is obtained by use of secondary emission. Under the stimulus of light, the photo-sensitive cathode emits electrons which are attracted towards a positively charged anode (Fig. 29). On striking the anode, these primary electrons release secondary electrons which, by suitable choice of anode material, can be made to exceed the primary electrons in number. The secondary electrons are attracted towards a second anode which is more positively charged than the first, and, on striking it, these electrons release an even greater number of secondary electrons. So the process continues to the final anode.

If m secondary electrons are emitted for each primary electron, the stage gain of the electron multiplier is m^n, where n is the number of anodes.

ELECTRON OPTICS. Name given to the use of electromagnetic and electrostatic fields for the purpose of focusing electron streams. It has been found that, in highly evacuated cathode-ray tubes, these fields have a similar effect upon the beam to that of lenses on a beam of light.

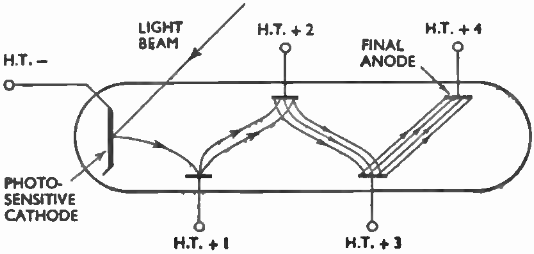


Fig. 29. Principle of the electron multiplier. The H.T. potential applied to the anodes is increased progressively from H.T. + 1 to H.T. + 4. In practice there may be more than the four anodes shown in this simplified diagram.

By means of successive anodes, each being at a potential higher in relation to the cathode than the last anode, the electron stream is not only speeded-up in its path from the cathode, but a curved electrostatic field is caused between the anodes. This, if the tube is properly designed, can be used to bring the electron beam to a focus at a particular point.

The greatest care has to be taken that the dimensions, shape and mutual disposition of the electrodes of a cathode-ray tube are correct if accurate focusing is to be obtained.

Alternatively, magnetic fields created by coils outside the neck of the tube can be used to effect focusing. A great deal of research has been carried out in connexion with the question of focusing, it being especially concerned with the problem of reducing the diameter of the spot caused by the beam on the screen. The smaller the spot, the greater the number of lines that can be used in television and the higher the degree of definition.

Other uses of the cathode-ray tube, notably in radar, also demand the smallest spot possible. So far, by very accurately made anodes, the electron optics of the cathode-ray tube have been successful in reducing the spot to a minimum of about ¼ millimeter in diameter.

ELECTRON RELAY. See GAS-FILLED VALVE, GLOW-TUBE.

ELECTRON STREAM. Synonym for ELECTRON BEAM or ELECTRON JET.

ELECTRON TUBE. Synonym for VACUUM TUBE or VACUUM VALVE.

ELECTRON VELOCITY. Velocity attained by an electron travelling in a vacuum and accelerated by electric or magnetic fields, or by a combination of both. The electrons in an ordinary receiving valve attain velocities of tens of millions of miles per hour; naturally these velocities are possible only when the electron travels in a vacuum or through extremely rarefied gas. An electron urged by an electric field is accelerated just as a body falling from a height is accelerated by gravity; thus it is sometimes said that electrons or ions "fall" through such and such a distance between electrodes, or down a potential gradient.

The graph of Fig. 30 shows electron velocity plotted against voltage. The velocity is that attained by an electron starting from rest, and falling through a potential difference of the amount given on the x axis of the graph. The velocity is plotted as a ratio to the velocity of light (186,000 miles per second, that is, 3×10^{10} cm./sec). It will be noted that increasing the potential gradient does not proportionately raise the electron velocity. This is due to the fact that the effective mass of the electron increases with its velocity; the effect begins to be noticeable at velocities much less than the velocity of light.

The values of velocity expressed in miles, feet or centimetres per second are so cumbersome that it is usual to express velocities in terms of a potential difference. Thus we speak of an electron velocity of, for example,

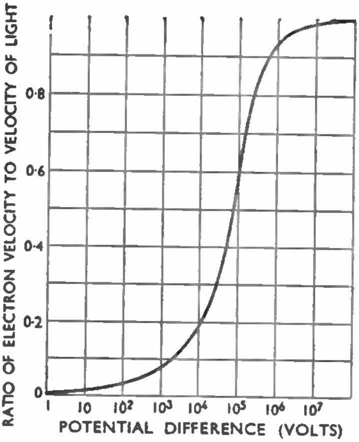


Fig. 30. Graph produced by plotting the difference of potential accelerating electrons (horizontal axis) against the ratio of the electron velocity to the velocity of light.

10, 150 or 10,000 volts, rather than in terms of space and time. See ELECTRON, VALVE.

ELECTRO-POSITIVE. Synonym for POSITIVE.

ELECTROSTATIC COMPONENT. See ELECTRIC COMPONENT.

ELECTROSTATIC DEFLECTION. In a cathode-ray tube, the deflection of the electron beam, as it passes between two deflector plates, by virtue of the electrostatic charge existing between them.

ELECTROSTATIC ERROR. That component of the total error of a direction-finder which is due to unbalanced capacitance effects, such as unequal capacitance to earth of the two loops of a Bellini-Tosi system. See BELLINI-TOSI DIRECTION-FINDER.

ELECTROSTATIC FIELD. Region in which the forces produced by electric charges act. More particularly, the electrostatic field is that space between opposite charges, or between a charge and an earthed or neutral body. There is, for example, an intense electrostatic field between the plates of a charged capacitor. See CAPACITANCE.

ELECTROSTATIC FOCUSING. In a cathode-ray tube, the focusing of the electron beam into a very small area of the screen by means of the electrostatic fields between two or more electrodes.

ELECTROSTATIC KERR EFFECT. Rotation of the plane of polarization of a light beam in its passage through a transparent medium subjected to an electric strain. This effect is utilized in a number of light-modulation systems, notably the KERR CELL (q.v.). See also KERR EFFECT.

ELECTROSTATIC LOUDSPEAKER. Synonym for CAPACITIVE LOUDSPEAKER.

ELECTROSTATIC MICROPHONE. Synonym for CAPACITIVE MICROPHONE.

ELECTROSTATIC RETROACTION. Synonym for CAPACITIVE FEEDBACK.

ELECTROSTATICS. Science which investigates the properties of electrical charges and voltages. The electric charge, sometimes called static electricity, has been known as a phenomenon from very early times; some of its manifestations, particularly those associated with charges produced by the friction of certain surfaces, are noticeable in everyday life. A simple experiment will demonstrate one of them: tiny scraps of paper are attracted by a vulcanite fountain pen rubbed briskly on a piece of cloth for a few seconds; the vulcanite will pick up the bits of paper in the way a magnet picks up iron filings. This phenomenon occurs because the friction between cloth and vulcanite generates a static charge; if the pen is rubbed by a finger, the effect disappears.

Static charges produced by such methods have been known as "frictional electricity," and much ingenuity has been devoted to devising apparatus to generate it. Some, such as the Wimshurst machine, are capable of producing quite high potentials—up to tens of thousands of volts—and yield sparks of impressive energy. Dry hair and fur when brushed will often yield small sparks—stroking a dry cat in the dark will sometimes produce minute but clearly visible and audible sparks between fur and fingers.

It was early discovered that there appear to be two kinds of electric charge and they are still known as positive and negative, although modern theory teaches that there is, in fact, only one kind of electricity; a charged body is simply one with an excess or deficiency of electrons above or below the normal complement. An excess of electrons means a negative charge, and a deficiency is a positive charge. Simple experiments enable the properties of static electricity to be investigated, and the first rule which is then discovered is that there is a physical force of repulsion between like charges and of attraction between unlike ones.

An instrument known as the gold-

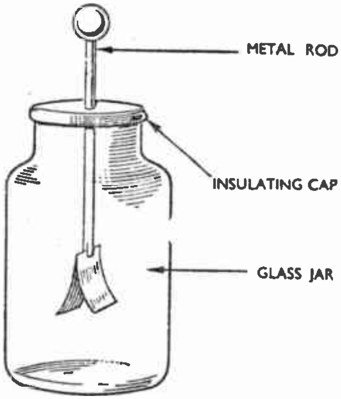


Fig. 31. Gold-leaf electroscope which indicates the presence of an electrostatic charge; when a charge is applied to the rod, the leaves receive a "like" charge and repel each other.

leaf electroscope demonstrates the repulsion between like charges; the essential part of the device is a pair of small slips of gold leaf suspended from the end of a metal rod, so that they hang side by side. The rod is fitted through the insulating cap of a glass bulb (Fig. 31) so that electric charges can be introduced by making connexion with the metal knob on top.

If a negative charge is applied to the rod, it will at once spread itself over the rod and the two thin metal leaves. On each leaf there is now a small charge, and since both charges are negative, they repel each other and the leaves move apart. The main purpose of the electroscope is, of course, merely to detect the presence of electric charges, not to illustrate the principle of repulsion between identical charges.

In the same way that one charge repels another of the same sign, the constituent elements of a particular charge repel each other. Thus if a negative charge is placed on a hollow metal sphere, the individual electrons repel each other and the charge spreads itself uniformly over the outer surface, leaving the interior neutral. Fig. 32 shows how this can be proved with the aid of two electroscopes. One of these is connected to the outer surface of the sphere and shows the presence of a charge by the divergence of the leaves. The other instrument is connected to the inner surface by means of a long wire probe, and the leaves hang down without movement, showing the absence of any charge.

Electrostatic induction is another manifestation of the repulsion of electrons by electrons. If a metal ball is charged negatively and then brought near to a neutral metal ball, the concentration of electrons on the first begins to repel the uniformly distributed normal complement of electrons on the second, and drives them to the farther side of the ball. A negative charge is thus created on the far side of the previously neutral ball, and since there is now a deficiency on the side nearest the first one, the final result is a positive charge there.

If the charged ball is now taken away, the electrons on the second ball distribute themselves uniformly again and the charged condition disappears. If, when the two spheres were close together, a connexion to earth had been made on the far side of the second

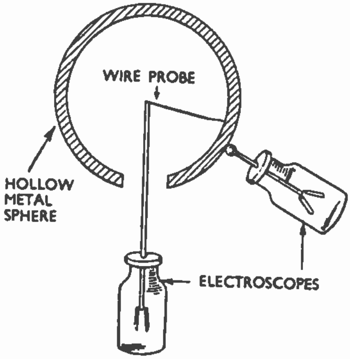


Fig. 32. Experiment in electrostatics which demonstrates that a static charge concentrates itself on the outer surface of an object.

ball, the repelled electrons would have escaped; and on removing the connexion to earth and taking away the first sphere, the second one would be found to have a permanent positive charge, being now short of its normal number of electrons.

Suppose the earth connexion is restored; as the ball is short of electrons, and there is no repelling force in the neighbourhood as at first, electrons flow from earth to bring the potential of the ball back to zero again. Formerly it was said that the positive charge had escaped to earth, but the explanation in terms of electron excess or deficiency gives a much clearer picture of the mechanism of these processes. More information on the implications of these experiments will be found under CAPACITANCE.

Static charges, as such, have little practical application in electrical work; but there are occasions when they must be guarded against as a nuisance or even a danger. For example, one of the ways in which they can be produced is by the evaporation of liquids, and if a steam boiler is operated in conditions which insulate it from earth—on a road locomotive fitted with rubber tyres for instance—it may acquire a charge. If no precautions are taken, anyone touching the vehicle in dry weather while standing on the ground would receive a violent shock. To prevent this, some earthing device, such as a short length of chain trailing on the ground, is provided. See CHARGE OF ELECTRICITY, COULOMB'S LAW, ELECTRIC FIELD, ELECTRIC FORCE, ELECTRON, UNIT CHARGE.

ELECTROSTATIC SCREEN. Synonym for ELECTRIC SCREEN.

ELECTROSTATIC SYSTEM OF UNITS. System based on the use of electrostatic phenomena as an integral part of the unit definitions. More precisely, one which starts by fixing a unit of charge as being that which exerts unit force of attraction on an equal and opposite charge held at unit distance.

ELEMENT. See CIRCUIT-ELEMENT.

ELEMENTAL AREA. Synonym for PICTURE-ELEMENT.

ELEVATED H-TYPE ADCOCK DIRECTION-FINDER. Adcock direction-finder employing vertical half-wave dipoles, with the receiver hut raised to the level of the dipole centres (Fig. 33). The resultant complete symmetry of the aerial-system is helpful in minimizing certain types of error. See POLARIZATION ERROR.

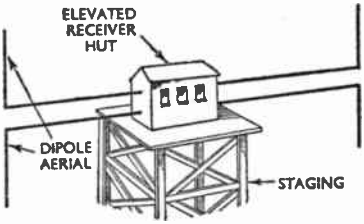


Fig. 33. Elevated H-type Adcock direction-finder. The hut is raised on a staging at such a height that the aerials can be arranged as dipoles; polarization errors on the horizontal lines are thus largely balanced out.

ELIMINATOR. Synonym for BATTERY ELIMINATOR.

ELLIPTICALLY POLARIZED WAVE. Radio-wave whose plane of polarization is rotating and whose amplitude varies according to the direction of polarization. In the process of reflection from the ionosphere, the plane of polarization of the wave is affected. It is usually found that the plane is rotating; thus, at any receiving point, one wave of the electric field may be vertical but the plane of next wave may be slightly rotated, and so on until after a time the wave is horizontally polarized. The process now repeats itself but in the opposite direction. Such a wave is said to be circularly polarized, and the great majority of waves reflected from the ionosphere are of this form.

As well as being circularly polarized, most waves are also elliptically polarized. The actual strength of the wave varies according to the direction of polarization; for example, the field strength may be at a maximum when the wave is horizontally polarized and at a minimum when vertically polarized, thus producing a cyclic variation in amplitude. See CIRCULARLY POLARIZED WAVE, PLANE OF POLARIZATION. POLARIZATION.

e.m.f. Abbreviation for ELECTROMOTIVE FORCE.

EMISSION. Liberation of free electrons from a hot cathode (see also SECONDARY EMISSION). A valve is basically a means of controlling the flow of electrons without introducing any device which has mechanical inertia (see VALVE). Essential to the valve is a supply of electrons to form a conductive path between cathode and other electrodes, the most important of these being the anode.

Conduction of electricity in a conductor is made possible by the existence of free electrons in the conductive substance. Normally, these do not escape the boundaries of the conductor carrying current. But if the conductor is raised to a sufficiently high temperature, the extra energy given to the electrons enables a few to escape; the most convenient way to heat the conductor is by an electric current.

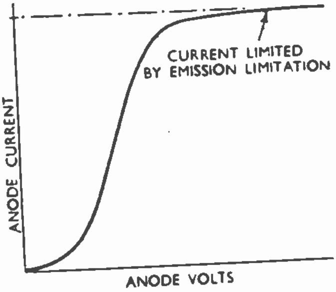


Fig. 34. Anode-volts/anode-current characteristic of a valve, showing the effect of emission limitation. The anode current attains a constant value at a certain anode voltage because the cathode is able to emit only a limited number of electrons.

The electrons, once they leave the conductor, must be free, or they will recombine with positively charged nuclei. If the heated conductor is in a vacuum, the electrons which escape from it form in a cloud around it unless attracted away from the conductor by a positively charged electrode.

Emission is a term associated with the property of a metal or substance which causes it to emit electrons when heated. Some metals give off electrons more easily than others; tungsten is a metal which emits electrons freely, but it has to be raised to a relatively high temperature. Coating tungsten to make thoriated tungsten increases its efficiency as an emitter. Certain oxides are better emitters than tungsten or thoriated tungsten.

Oxide emitters are not always used because the degassing of a valve cannot be so complete when such emitters are used; even if a better vacuum were obtainable, the residual gas would still contain enough positive ions to bombard the oxide and break it up if the anode voltage were large.

Thus pure tungsten, which is the most robust emitter, is used for valves handling from tens to hundreds of kilowatts when the anode voltage is high; thoriated tungsten is used for valves handling hundreds of watts; and oxide-coated cathodes, usually of the indirectly heated type, are used for small valves. See CATHODE, CATHODE EFFICIENCY, EMISSION LIMITATION, FILAMENT, INDIRECTLY HEATED CATHODE, SPACE CHARGE.

EMISSION LIMITATION. Limitation of space current in a valve due to a limitation in the supply of electrons provided by the cathode. Obviously, if due to any one of many possible causes the cathode is emitting electrons as fast as it can, then the current flowing from the cathode cannot be increased (Fig. 34).

The limitation may be due to the fact that the temperature of the

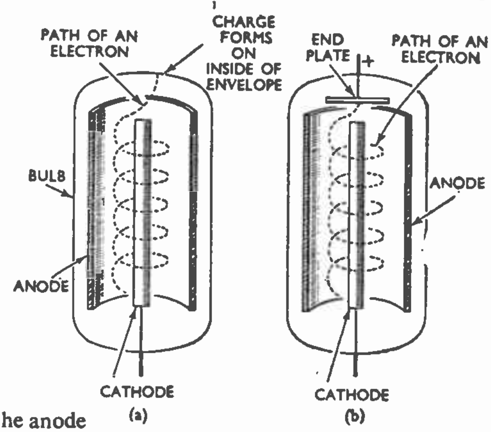


Fig. 35. Diagrams illustrating (*a*) how an electron in a magnetron may trace a helical path and "escape" to strike the inside of the glass envelope, and (*b*) attraction of the electron to a positively charged end plate.

cathode is not high enough because the filament or heater current is not sufficient. If in a diode, for instance, the anode volts are so great as to demand that each electron, immediately it is emitted, shall fly to the anode, no surplus is then available and the anode current cannot be increased beyond a limiting value. See DIODE, GAS-FILLED VALVE, VALVE.

END-FIRE ARRAY. Assembly of aerials so arranged that the direction of maximum radiation, or most efficient reception, is along the line of the array, in distinction from the broadside array. See BROADSIDE ARRAY, YAGI AERIAL.

ENDODYNE. Synonym for AUTO-HETERODYNE.

END PLATE. Electrode structure used in a MAGNETRON (q.v.) to remove electrons which would otherwise collect on the inside of the bulb. Electrons in a magnetron rotate round the cathode. Some may follow a spiral path and escape from the space between anode and cathode (Fig. 35). But for the positively charged end plate, those electrons not eventually drawn to the anode would hit the inside of the glass envelope and cause a negative charge to build up there. The end plate is, therefore, one means of stopping the formation of a charge on the inside of the bulb.

ENERGY. Capacity of a body to do work. Energy is either potential or kinetic, and is measured, as is work, in ergs or in foot-pounds.

ENERGY COMPONENT. Synonym for ACTIVE CURRENT.

ENVELOPE. Synonym for BULB.

ENVELOPE OF MODULATION. Synonym for MODULATION ENVELOPE.

ENVELOPE VELOCITY. Velocity of the whole of the wave front of an electromagnetic wave. In free space, this is the same as the velocity of light, approximately 186,000 miles per second. In media other than free space the velocity is different and is always less than in free space. See WAVE VELOCITY.

EQUALIZER. Quadripole which, for a constant input, gives an output which varies in a predetermined manner over a certain frequency band. An equalizer, as its name implies, is a network which is used to equalize, compensate for, or "flatten" the attenuation-frequency characteristic of another network, such as a transmission line, or to equalize any other source of power having a variable output over a band of frequencies.

The assumed frequency-response graph of any network or of a line and the result of the use of an equalizer, and the necessary response of an equalizer to compensate for the falling characteristic, are shown at Fig. 36.

Fig. 37 shows some very simple equalizers and their frequency-response characteristics. Some of these equalizers are called constant-resistance equalizers, because the impedance at the

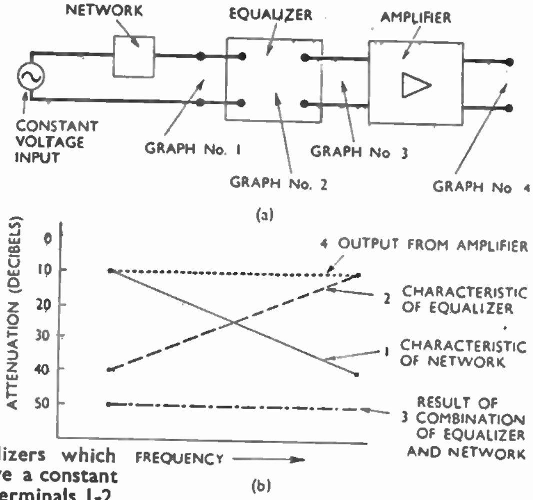
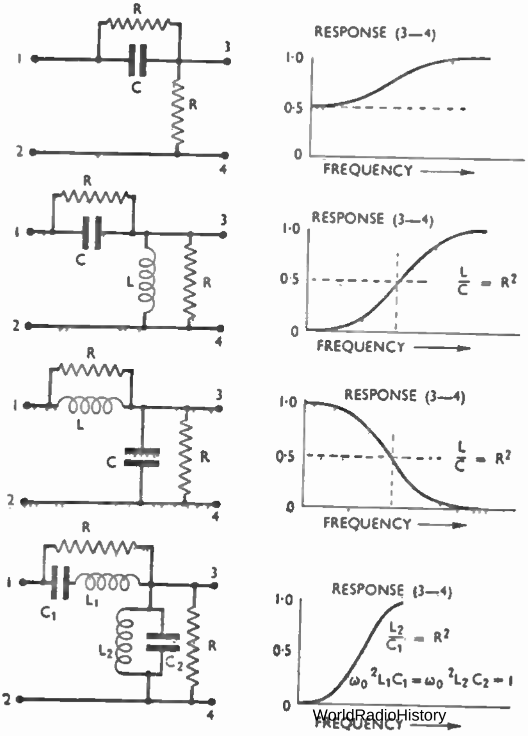


Fig. 36 (*right*). Constant-voltage-fed network whose output passes to an equalizer before amplification (*a*), and attenuation-frequency characteristics (*b*). After amplification by 40 db., the output from the amplifier is the same as the input to the network.

Fig. 37 (*below*). Examples of equalizers with their respective frequency-response graphs, the voltage at the input terminals 1-2 being assumed constant. The three equalizers which show zero response have a constant resistive impedance at terminals 1-2.



input and output terminals may be made constant over a band of frequencies. This is a very useful property when it is desired to equalize a network and terminate it in a resistance. Equalizers are used in line transmission at repeater stations and, at each station on the line, the level is raised and the frequency characteristic is equalized, or "flattened out."

There is some resemblance between an equalizer and a filter because each gives an output which varies with frequency, for a constant-voltage input. The basic difference is that, in the design of a filter, a certain attenuation is wanted at a certain frequency in the attenuation band, and the slope of the attenuation-frequency characteristic at frequencies outside the effective band width does not greatly matter.

In the design of an equalizer, however, the absolute amount of attenuation at any given frequency does not greatly matter, but the shape of the attenuation-frequency characteristic is important because this must be complementary to the shape of the attenuation-frequency curve of the network to be equalized.

The "tone control" in a radio receiver is hardly an equalizer; it more nearly resembles a variable low-pass filter which cuts off the higher frequencies, but the frequency-response characteristic changes less rapidly than in a classic type of filter with reactance elements and resistive termination. The network which compensates for the falling response in a gramophone record between, say, 50 and 250 c/s, is in every sense of the term an equalizer. See FILTER, QUADRIPOLE, TRANSMISSION LINE.

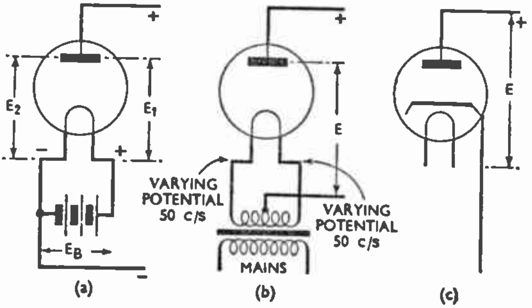
EQUIPOTENTIAL CATHODE. Term describing a characteristic of an indirectly heated cathode. A filament is not an equipotential cathode. From Fig. 38a it is clear that one end of a filament, heated by current from a battery, has a higher positive voltage than the other. The anode-cathode volts therefore differ according to which point of the filament is chosen as a reference. In Fig. 38b, the anode volts are constant if the centre point of the transformer (the electrical centre point of the filament) is considered to be the cathode potential. The potential at the two ends of the filament varies, and it is thus not an equipotential cathode.

When, as in Fig. 38c, the cathode is indirectly heated, the cathode obviously has the same potential along all parts of it and is therefore an equipotential cathode; so is any cathode which has the same potential at all parts of it—the cold cathode of a glow-tube, for example. See CATHODE, FILAMENT, INDIRECTLY HEATED CATHODE.

EQUIPOTENTIAL SURFACE. Any surface on which there are no differences of potential from point to point. It does not follow that such a surface carries no charge, or that there are no potential differences between the surface and its surroundings. For example, a charge on a perfect sphere isolated in space distributes itself uniformly over the surface of the sphere to form an equipotential surface.

EQUI-SIGNAL BEACON. Navigational aid, chiefly for use in aircraft, which enables a pilot to decide whether he is on the intended course; and if not, to which side he has diverged. The beacon lays down a zone of characteristically modulated radiation on each side of the course. These two zones interlock in the central (on-course) zone to produce a third type of sound in the aircraft receiver.

For instance, the beacon might radiate a series of dashes in one



(a) (b) (c)

Fig. 38. With the equipotential cathode (*c*) the anode volts are constant; but, in the other arrangements shown, (*a*) the anode volts are less by E_B than E_2, and (*b*) the anode volts E are constant as regards the electrical centre of the transformer, but vary between the two ends of the filament.

marginal zone and dots in the other, while in the central zone, where both signals are heard, the dots and dashes merge into a continuous note. Systems of this type are popularly known as beam-navigation systems.

EQUIVALENT NETWORK. Network which, while different from one it replaces, behaves nevertheless in substantially the same way. The term is one used more in the theory and practice of line transmission than in radio. An artificial line might be called an equivalent network, except that it must slightly alter the performance of the system external to it. The same applies to the artificial or dummy aerial. See ARTIFICIAL LINE, DUMMY AERIAL, NETWORK.

EQUIVALENT SINE WAVE. Sine wave which is equivalent to some non-sinusoidal current or voltage, in that it is of the same frequency and has the same r.m.s. value.

ERG. Unit of work based on the centimetre-gramme-second system of fundamental units. It is the amount of work done when a force of one dyne moves its point of application by one centimetre.

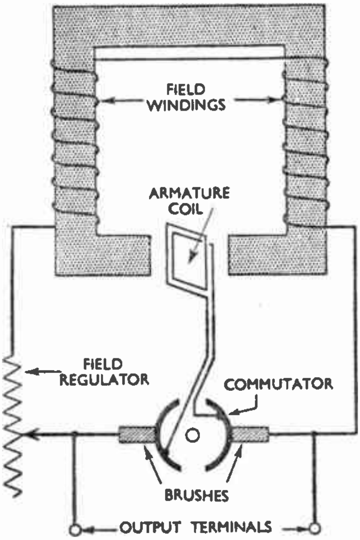


Fig. 39. Excitation circuit which energizes the field magnets in a simple form of shunt-wound dynamo.

ETHER. Non-material medium, assumed to permeate all space, which allows the passage of electromagnetic waves. It is difficult to conceive a wave motion without a tangible medium in which it is passed on from point to point, and so the postulation of an ether came about. The conception of the ether is another way of saying that space, empty of all material substance, still possesses the property of passing electromagnetic waves through it.

When considering the sending of radio waves, empty space is known as "free ether," but when the waves are travelling through material media such as brick houses, the ether is no longer free, but is modified by the presence of the material, and the velocity of the wave is altered while passing through the material.

EUPHON QUILT. Quilt constructed from layers of paper or canvas packed with glass-silk threads. It is used for the absorption of sound waves. See CABOT QUILT.

EUREKA WIRE. Type of wire used for winding resistance coils and heater elements, constructed from a copper and nickel alloy. It can withstand high temperatures without deterioration.

EXCITATION. Current which sets up the magnetic field to perform some electromagnetic operation. Excitation is more strictly defined as the magnetomotive force, but in common usage the current is meant. For instance, the excitation of a D.C. generator or dynamo refers to the current which energizes the field magnets. Fig. 39 shows the circuit arrangement, suitably simplified, of a shunt-wound dynamo; this is the type in which the field winding, which produces the magnetic field through the armature, is connected in parallel (shunt) with the output terminals. The current through any working electromagnet or solenoid is also called the excitation current. See ELECTROMAGNETISM.

EXCITER. Synonym for ACTIVE AERIAL.

EXPANDER. Amplifier or radio receiver which extends the volume range, thus compensating the effects produced by a compressor used in the transmitting chain. See COMPANDER, COMPRESSOR.

EXPONENTIAL HORN. Horn attached to the diaphragm of a loudspeaker or acoustic gramophone, the shape of the horn being such that its cross-sectional area increases progressively in conformity with a logarithmic law. As in Fig. 40, the cross-sectional area may be doubled for each distance of one foot towards its mouth. See ELECTRICAL REPRODUCTION.

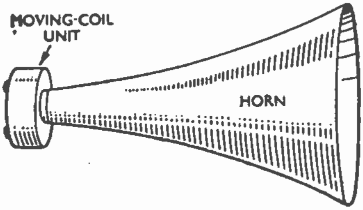


Fig. 40. The cross-sectional area of what is called an exponential horn is doubled for each successive unit increase in length. This design ensures good bass response.

F

F. Abbreviation for FARAD(S).

FACSIMILE. Process of sending and receiving photographs, drawings, and handwritten or printed matter by radio. Modern systems of facsimile are used daily for the sending and reception of photographs between London and America, Australia, India, South Africa, Canada and other countries.

The facsimile machine consists of a cylinder which rotates, at a speed which is controlled by a quartz crystal, and at the same time moves forward along a shaft. On this cylinder is placed the picture to be sent or the photographic film on which a received picture is to be reproduced. The motion of the cylinder is such that a spot of light impinging on the cylinder would trace a helix along it. For sending, a source of light is focused on the picture and the reflected light is directed on to a photocell, the output of which varies in relation to the amount of light picked up from the picture.

Movement of the drum is such that the picture is scanned at about 100 lines per inch and the rotation is set at a speed of between 60 and 90 r.p.m. A quartz crystal controls the motor speed, the crystal being cut for 108 kc/s. A frequency divider reduces this to 10·8 kc/s, which in turn drives a second frequency divider to produce 1,800 c/s. This voltage is used to drive a push-pull motor drive stage and is also applied to a mirror galvanometer for interrupting the light beam on transmission.

The light beam is used to amplitude-modulate an audio-frequency carrier of 1,800 c/s, final modulation being frequency modulation with a deviation of 200 c/s. The deviation to 1,600 c/s represents black, and that to 2,000 c/s represents white, other tone-densities being represented by intermediate frequencies. The frequency-modulated signal, known as the sub-carrier, may be sent over a line or radio channel by normal amplitude modulation, which gives an improved signal-to-noise ratio and greater freedom from distortion. The principal components of facsimile equipment are shown in

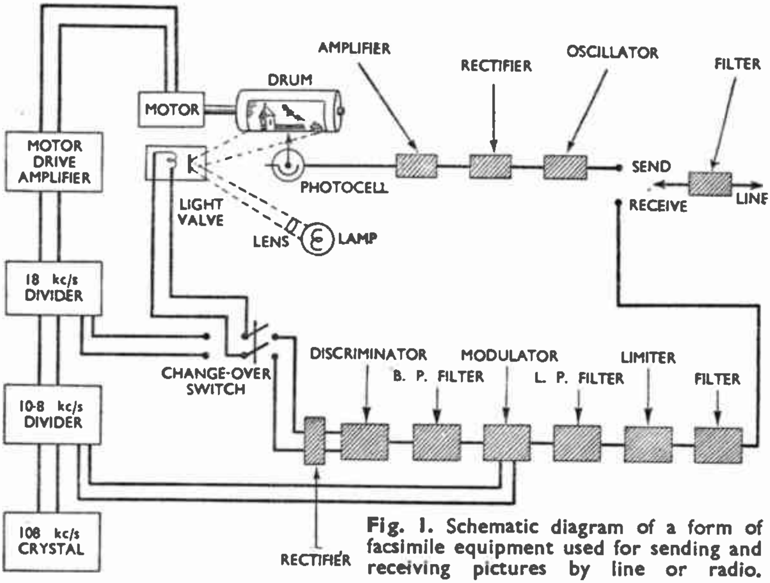


Fig. 1. Schematic diagram of a form of facsimile equipment used for sending and receiving pictures by line or radio.

the above schematic diagram (Fig. 1).

The term "final modulation" has been used in stating that frequency modulation is employed. The amplitude-modulated carrier of 1,800 c/s from the photocell circuits is rectified and the resultant D.C. used to frequency-modulate a beat oscillator which consists of two high-frequency oscillators, the frequency of one being fixed, and that of the other modulated by the picture signal. The frequencies of the two oscillators are usually adjusted so that, with no modulation (no output from the photocell, the picture being black), the beat note is 1,600 c/s. With full modulation (white), the beat is arranged to rise to 2,000 c/s.

On reception, the frequency-modulated sub-carrier is limited to remove all trace of amplitude modulation and is then passed to a frequency-discriminator which reproduces an amplitude-modulated audio-frequency carrier. This signal is rectified and utilized to operate a light valve controlling the amount of light falling on a photographic film carried on the receiver drum which is rotating at the same speed, and in the same phase, as the sending drum.

FACSIMILE TELEGRAPHY. System for transmission of still pictures, printed matter, etc., over an electrical circuit.

FACTOR OF SAFETY. Number specifying the ratio of two quantities, one giving normal working conditions and the other a condition at which breakdown of the apparatus will probably occur. Thus, valves and capacitors are given figures to specify safe working conditions, and manufacturers give test conditions which exceed these figures; but few speak of factor of safety in this connexion and the term is seldom used in radio engineering.

FADE-IN. Term used in broadcasting when sound or vision signals are gradually brought up from zero intensity to that intensity required for the normal working of the system. Fade-in is frequently used to add artistic effect to studio productions.

FADE-OUT. Reverse of FADE-IN. In sound, the signals are gradually brought from normal level to the point of inaudibility; in vision, the picture is reduced from normal brightness to darkness.

FADER. In general, a volume control. In broadcasting, the instrument used for fading-in or fading-out sound or vision signals. It may consist of the gain control of an amplifier, or a completely separate volume control operated at a remote point.

In construction, it may take the form of a continuously variable resistor (when the slider makes physical contact with the resistor element), or a tapped resistor winding, the slider moving over contacts to which the tappings are connected. In the latter case, the tappings are so arranged as to produce small signal changes between adjacent studs. Common values of change are 0·5, 1·0 and 2·0 db. See VOLUME CONTROL.

FADE-UNIT. Fader designed to cross-fade from one programme source to another. It usually consists of two or more faders mounted on a single panel, as illustrated in Fig. 2. The controls may be individually operated or ganged in pairs to give two-channel fade-unit, four-channel fade-unit, etc. The fade-unit is sometimes called a mixer.

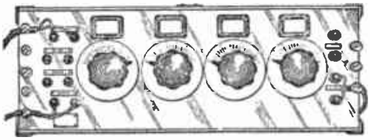


Fig. 2. Four-channel fade-unit, or mixer, as used by the B.B.C.; it contains four constant-impedance faders for connecting four microphones to the input terminals of one amplifier.

FADING. Variation in signal strength at the receiver. There are two different types of fading: that which causes complete disappearance of signals for several hours or even days, and that giving slow or rapid variations in signal strength.

Complete fading is due to magnetic-storm activity caused by solar eruptions and sunspot activity. The ionization intensity of the E- and F-layers is increased to such a degree that complete attenuation of the ionospheric wave occurs, reception being possible only within the range of the ground wave. This type of fading is also known as Dellinger effect.

Slow or rapid variations in signal strength can be caused, first, by interference between the ground wave and the ionospheric wave; second, by changes of wave polarization.

The first type is usually experienced in this country when the reception of medium-frequency continental broadcast stations is attempted at night. It is apparent during the reception of high frequencies at all times, when the signal arriving at the receiving aerial is not a single ray, but may be made up of two or more rays arriving by different paths.

In the case of medium frequencies at night, the signal at the receiver may consist of one or more rays arriving via the ionosphere, and the ground ray. The path distance of the ionospheric ray will naturally be greater than that of the ground ray (Fig. 3), so the rays reaching the receiver may or may not be in phase. If the rays arrive at the receiving aerial in phase with each other, then the field strengths will be additive and at a maximum, but, if they are out of phase, the resultant field strength may be zero.

The resultant signal is thus the vector sum of all the arriving rays, and its value depends upon their relative phases and amplitudes. If the ionosphere were a stable medium, the vector sum would be constant and no fading would occur. Unfortunately, the ionospheric conditions vary from instant to instant, the phase of the ionospheric rays varies likewise, and fading, which may be either rapid or slow, results. At high frequencies, the ground ray is a matter of no importance; it is the changing phase-relationships between ionospheric rays which cause fading.

The second type of fading, due to change of wave polarization, concerns the ionospheric rays only and is therefore most important at high frequencies where reception is normally by means of the ionospheric wave.

Assuming a vertical sending aerial, the radiated wave would normally be vertically polarized, and the signal strength at the receiver, if a vertical receiving aerial were used, would be a maximum. Unfortunately, during the process of reflection in the ionosphere, it is found that the plane of polarization of the wave is usually made to rotate; for instance, it may emerge from the layer vertically polarized at one instant and horizontally polarized a second later. Field strength may also vary with the plane of polarization. The voltage induced in our vertically polarized receiving aerial will therefore vary considerably, and may at times be zero.

It is also possible for the carrier wave to be affected when the sidebands are not, which results in unpleasant distortion. This action is known as selective fading. Thus, in short-wave communication, fading is generally the most difficult feature to combat; but much can be done by the judicious use of special aerial-systems and automatic gain-control. See ABNORMALLY POLARIZED WAVE, AUTOMATIC GAIN-CONTROL, DIVERSITY RECEPTION, IONOSPHERE, MAGNETIC STORM, POLARIZATION, SELECTIVE FADING.

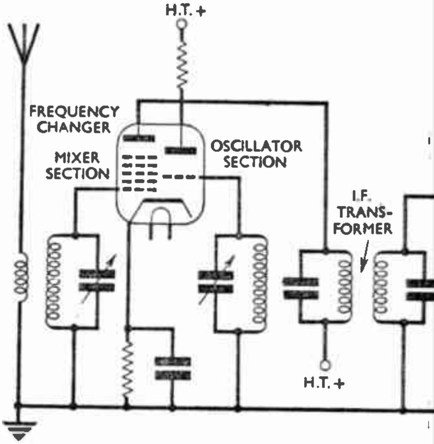


Fig. 4. Fault-finding technique follows a logical step-by-step process; and this diagram of the essential components of a four-valve superheterodyne receiver for A.C.-mains operation illustrates the method of tracing faults described.

FAN AERIAL. Almost obsolete aerial-system composed of wires which radiate upwards from a point at or near ground level to form a flat fan.

FARAD. Unit of capacitance. It denotes that capacitance which, when charged with one coulomb, is raised

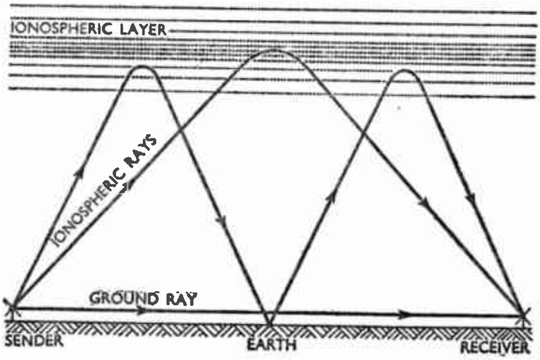
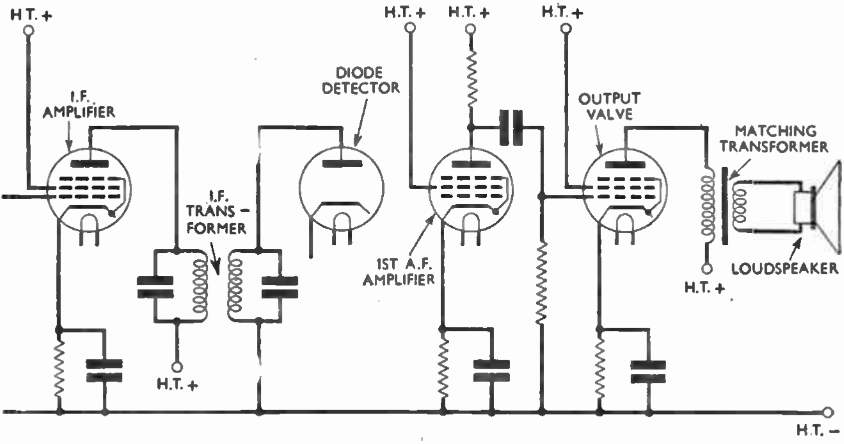
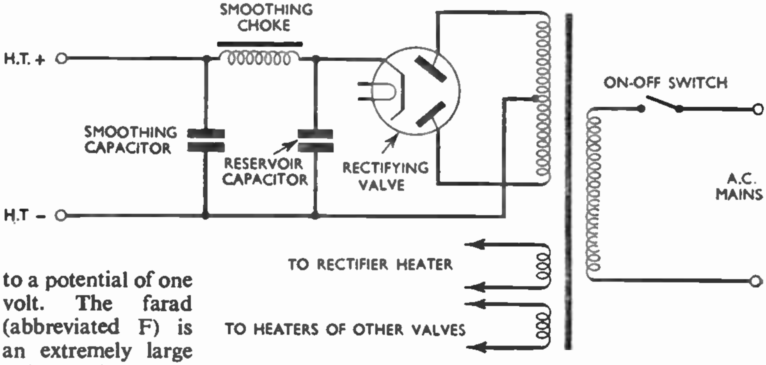


Fig. 3. Rays which combine to form the wave arriving at a radio receiver. Each ray has a final phase-relationship depending upon its path distance, which is continually varying; thus the received signal varies in amplitude.





to a potential of one volt. The farad (abbreviated F) is an extremely large unit, and is therefore commonly used only in a subdivided form such as the microfarad (abbreviated μF).

FARADAY CAGE. See SCREEN.

FARADAY'S LAW. Law named after its enunciator which states that, in the process of electromagnetic induction, the magnitude of the induced voltage depends on the rate of change in the number of magnetic lines of force which link with the conductor in which the voltage appears. The law indicates that in, say, a dynamo the induced voltage is related in a precise manner with the strength of the magnetic field in which the armature turns, with the number of turns of wire on the armature and with the speed at which the armature rotates. See ELECTROMAGNETIC INDUCTION.

FAULT-FINDING. Detection of faults in the component parts or the wiring of equipment. Certain of the faults commonly occurring in electronic equipment have such obvious symptoms that they are detected at once on inspection of the apparatus, whereas others are so subtle that a long and systematic search is sometimes necessary before they are detected. In particular, intermittent faults are frequently very difficult to trace.

If a fault is not obvious, it can sometimes be found by certain tests on particular sections of the equipment, particularly if the apparatus is a very familiar one, but, in general, a systematic process of elimination is the quickest method of fault-finding. To illustrate the methods of fault-finding a conventional four-valve superheterodyne receiver for A.C. mains is here used as an example, and a simplified diagram is given at Fig. 4.

Suppose the receiver is completely silent when connected to the mains and switched on, there being no trace of hum in the loudspeaker. If the valves are not alight, a fault is indicated in the mains lead, in the mains transformer or in the on-off switch, and a continuity test (Fig. 5) applied to each of these in turn should indicate where the fault lies.

If the valves light and the loudspeaker is silent, a measurement should be made of the H.T. supply at the smoothing capacitor. If this is zero, the rectifying or smoothing equipment is clearly at fault, and continuity tests should be made of the H.T. secondary winding of the mains transformer and the smoothing choke. The reservoir and smoothing capacitors should be tested for short circuits and open circuits. If no fault is found, the rectifier valve should be replaced.

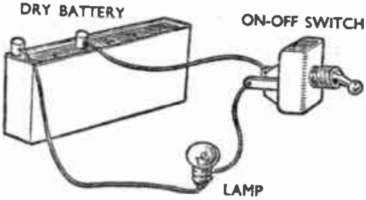


Fig. 5. Simple continuity test, using a lamp and battery, which may be applied to an on-off switch that is suspected of being faulty.

If the H.T. supply at the smoothing capacitor is satisfactory, measurements should be made at the anodes and the screen grids of all the valves. If zero readings are obtained anywhere, an open-circuited anode or screen lead, or a short-circuited decoupling capacitor should be suspected and appropriate tests made (see TESTING).

If correct readings are obtained at all points, all anode currents should be measured. It is not necessary to break any connexions to do this, for the anode currents can be checked by measurements of the p.d. across the automatic bias resistors in the cathode circuits. Such tests also check that the grid-bias values are correct, and that the resistors themselves are of correct value. If any anode currents are found to be markedly different from the normal value, the valve should be tested or replaced by another which is of the same type and known to be satisfactory.

If the fault is still undetected, it is a good plan to inject signals into the amplifying chain at various points to determine in what section of the receiver the fault lies. An audio-frequency oscillator is very useful for this purpose.

First a large output from the oscillator is applied to the primary of the loudspeaker-matching transformer. If no sound is heard from the loudspeaker, the transformer windings and the speech coil should be tested for open and short circuits. If the oscillator output is heard satisfactorily, the output of the oscillator is transferred to the grid of the output valve and the sound should, of course, now be heard at much greater volume.

If the loudspeaker is silent, the output valve may be faulty or the grid leak may be short-circuited. Tests should be carried out on both. If the output valve is functioning correctly, the oscillator output should be transferred to an earlier point in the A.F. chain. If the fault is in the A.F. chain it should be possible, by this method, to determine at what stage it occurs; the components at that point, including the valve, should be subjected to individual tests (Fig. 6).

If the A.F. section of the receiver is working satisfactorily, the fault clearly lies in the I.F. or R.F. sections or in the oscillator. To test the I.F. amplifier, a signal generator is necessary. A modulated R.F. signal of about one volt in amplitude, and at the intermediate frequency of the receiver, is applied to the detector anode and, if the modulation frequency is heard at the loudspeaker, should then, of course, be transferred to the grid of the I.F. amplifier. If signals in the loudspeaker now cease, the fault lies in the I.F. valve or in the I.F. transformer between this valve and the detector, and both these components should be given individual tests for open and short circuits (and mistuning in the case of the I.F. transformer).

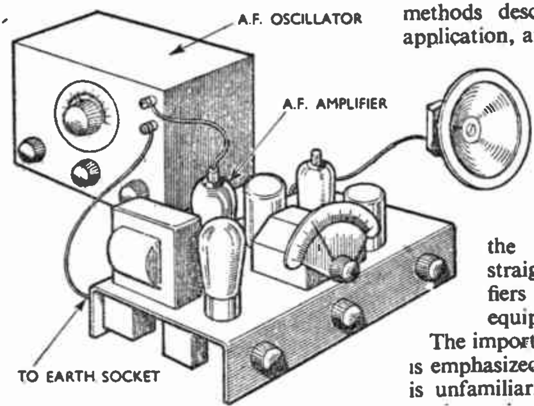


Fig. 6. Method of testing the audio-frequency amplifier of a receiver by means of an A.F. oscillator.

If the I.F. stage is functioning satisfactorily, the modulated test signal is transferred to the grid of the frequency-changer and the frequency of the signal must be adjusted to agree with the tuning of the receiver. If no sound is heard, it is possible that the oscillator section of the frequency-changer is not functioning. This may be checked by noting the reading of a D.C. voltmeter connected between oscillator anode and H.T. negative as the oscillator grid is earthed.

If the oscillator is working correctly the voltmeter reading will alter appreciably when the grid is earthed. If results are satisfactory when the modulated signal is applied to the frequency-changer grid but not when it is transferred to the aerial terminal, the fault lies in the tuned circuits at this point, and simple continuity tests should enable the fault to be traced.

It will be appreciated that the methods described are of universal application, and they may be used for the detection of faults in straight receivers, A.F. amplifiers or any similar electronic equipment.

The importance of a circuit diagram is emphasized; if the faulty apparatus is unfamiliar, every effort should be made to obtain a circuit diagram of it before the location of the fault is undertaken. If no diagram is available the labour is increased enormously. See OSCILLOGRAPH, SERVICING.

FEEDBACK. Condition arising when energy is returned from the output to the input of an amplifier. The energy fed back may be positive, that is, in such a direction as to add to the normal input signal, thus increasing the amplifier output. This is known as *positive feedback*. Alternatively, the energy fed back may be negative, opposing the normal input signal and decreasing the amplifier output. This is known as *negative feedback*.

If positive feedback is permitted to exceed a certain critical value, the amplifier will oscillate. This principle is applied in most oscillators to maintain oscillation, the coupling between output and input being either capacitive or inductive (see CAPACITIVE-FEEDBACK OSCILLATOR, INDUCTIVE-FEEDBACK OSCILLATOR).

A typical example of positive feedback producing oscillation is the howl of a public address system when microphone and loudspeaker are placed too near each other. The output energy from the loudspeaker adds to the normal sound energy applied to the microphone, causing the whole circuit to oscillate at an audio frequency.

Negative feedback reduces harmonic and attenuation distortion, and tends to stabilize an amplifier. It also has the effect of stabilizing oscillators when it is less than the positive feedback necessary to maintain oscillation. See CURRENT FEEDBACK, NEGATIVE FEEDBACK, POSITIVE FEEDBACK, VOLTAGE FEEDBACK.

FEEDBACK AMPLIFIER. Amplifying apparatus or valve in which some major part of the gain comes from the phenomenon of regeneration. For instance, a triode detector provided with a reaction circuit may be described as a feedback amplifier. The term is also used to denote an amplifier with negative feedback. See FEEDBACK, NEGATIVE FEEDBACK, REGENERATION.

FEEDBACK CIRCUIT. That part of a feedback amplifier circuit in which the positive or negative feedback currents flow. For example, in a regenerative detector circuit, such as the Reinartz (Fig. 7), the feedback circuit comprises the variable capacitor which controls the degree of feedback, and the coupling winding which transfers the energy back to the grid circuit of the valve. See FEEDBACK, REGENERATION, REINARTZ CIRCUIT.

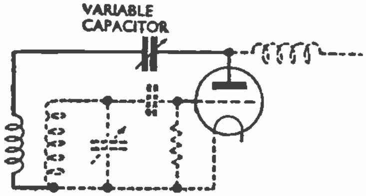


Fig. 7. Feedback circuit, comprising an inductor winding and a variable capacitor (shown in full line), in a detector circuit of the Reinartz type.

FEEDBACK LOOP. Synonym for FEEDBACK CIRCUIT.

FEED CURRENT. See ANODE-FEED CURRENT, ELECTRODE CURRENT.

FEEDER. In general, any connexion between aerial and the sender or receiver; but the term is most often used to denote some form of connexion in which due regard has been paid to its surge impedance in relation to the impedances at either end.

Thus, in the typical case of the necessary connexion between a sender and a distant half-wave dipole, a twin-feeder system (Fig. 8) may very possibly be used, and practical considerations of insulation and weather resistance will probably indicate stout bare wire strung between ceramic insulators, mounted on poles for the ground run, and on wooden cross-members at intervals along the mast or tower for the vertical section. With a reasonable spacing between the pair of wires, a feeder line of this sort will have an impedance of perhaps 300 or 400 ohms, and it must be matched at one end to a dipole whose impedance in the centre is something like 80 ohms, assuming that the feeder is intended to work in travelling-wave fashion (see TRAVELLING-WAVE AERIAL).

The necessary match can be obtained with the aid of a quarter-wave line or "matching stub" close against the aerial, and a similar quarter-wave transformer device between line and sender, although, in many cases, it is just as effective to tap the feeder line across a suitable fraction of the inductor in the output circuit of the sender.

The open-wire, twin-feeder system has numerous advantages for use on the higher frequencies; with usual spacings, it is comparatively non-radiating and, if the pair of wires is arranged side by side, the capacitance to earth from each conductor is equal, so preserving the state of balance which is so often desirable in practice.

With due attention to certain points of design, such a feeder can carry power to considerable distances with only moderate attenuation; feeder runs of half a mile in length are quite practicable.

The points of design requiring particular care are these: first, the spacing of the wires must be accurately maintained at the right figure to give the intended line impedance, this is fixed by the size of the wire and the spacing, and is equal to $276 \log_{10} \frac{d}{r}$, where d is the distance between wire centres and r is the wire radius. It is necessary to take some pains to keep the spacing constant, because variations represent changes of impedance which will set up reflection effects in the radio-frequency currents travelling along the feeder.

Second, a satisfactory set of insulating mountings is essential. Here again impedance discontinuities must be avoided, and this means that the insulators, besides serving their principal purpose with efficiency in both dry and wet weather, must not be designed so that they place masses of dielectric material in the space between the two wires which they are supporting. Stand-off insulators mounted on angle-irons (Fig. 9) are an effective way of meeting this requirement.

In order further to minimize the effects of the insulators it is often considered advisable to adopt a fairly wide spacing, say 6–10 inches, for the pair of wires. Small spacings are sometimes used, but generally only in special cases in which a feeder line of unusually low impedance is desired, perhaps to facilitate matching to a large array of dipoles; or because it will be used for both sending and receiving and it is required that as little energy as possible shall be picked up by the feeders.

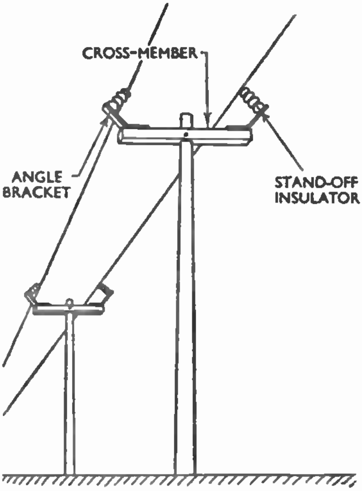


Fig. 9. One method of carrying an open-wire feeder on poles which are fitted with suitable cross-members to support the mounting insulators.

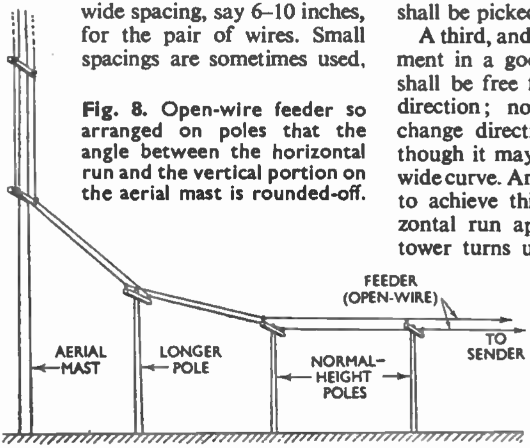


Fig. 8. Open-wire feeder so arranged on poles that the angle between the horizontal run and the vertical portion on the aerial mast is rounded-off.

A third, and often neglected, requirement in a good feeder line is that it shall be free from abrupt changes of direction; nowhere should the run change direction in a sudden angle, though it may be brought round in a wide curve. An attempt should be made to achieve this even where the horizontal run approaching the mast or tower turns upward into the vertical section (Fig. 8). Also, when a feeder run of any length is being planned, it is good practice to set the supports at intervals which are *odd* multiples of a quarter-wavelength; this, too, helps to reduce reflection effects and hence standing waves.

These are the major considerations in the arrangement of the twin open-wire feeder. But there is another type, the concentric, wherein the conductor is a single strand of wire enclosed in an earthed metal tube or other form of screening sheath (see CONCENTRIC TUBE FEEDER). A feeder run consisting of a pair of such conductors is far less complicated from one point of view because the distance between the pair is now immaterial, moderate bends are fairly harmless, and the impedance value is fixed by the construction of the material.

On the other hand, the true tubular type demands careful upkeep to prevent the entry of moisture, and much skill in installation, especially in making joints and connexions to the ends—it is otherwise easy to introduce impedance discontinuities at these points. Also, unless large and expensive tubes are employed, the small space between conductor and tube limits severely the amount of power that can be passed through the feeder.

More power can be handled by concentric feeders of a slightly different type. In these, the outer screening sheath is of metallic braiding, and the insulation between this and the central conductor is of some solid dielectric material, or partly of such material and partly of air. In this way, robust cables suitable for use on mobile equipments, on aircraft and so on, have been produced in great variety.

Their obvious convenience has led to wide use in the Services, as they permit properly matched feeders to be installed with a minimum of difficulty, but in actual efficiency they do not compare with a good open-wire system; their attenuation is considerable, and they are therefore used only where the run from sender or receiver to aerial is comparatively short. On permanent installations where conditions allow their use, the open or air-spaced tubular feeder is usually preferred.

For receiving purposes and low-power sending, amateurs often use a feeder consisting of twin lighting flex. The attenuation of such material is somewhat severe on high frequencies, but it has one considerable attraction, its impedance is in the general neighbourhood of 80 ohms. The exact figure naturally depends on the number and size of the strands of wire and the kind and thickness of the insulation, but it is near enough to that of a centre-fed dipole to make a tolerable match without need for any special devices such as stubs.

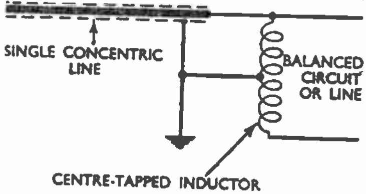


Fig. 10. Method of effecting the change-over from balance to unbalance when, for instance, it is desired to take an unbalanced feeder line to a centre-fed half-wave dipole.

It is sometimes necessary to change from a balanced (two-wire or two-sided) line or circuit to a single-wire unbalanced feeder line. For instance, it may be desired to take an unbalanced feeder to a centre-fed half-wave dipole. The change from balance to unbalance can be effected in the manner shown diagrammatically in Fig. 10. See HALF-WAVE DIPOLE, ZEPPELIN AERIAL.

FERROCART. Proprietary name for ferro-magnetic material having low eddy current and hysteresis losses, which render it suitable for high-frequency uses.

FERRO-MAGNETIC. Property of having a magnetic permeability which is substantially greater than that of air, and which is to some extent a function of the actual flux density. The term is derived from the fact that steel and iron are the typical examples of ferromagnetism. See PERMEABILITY.

FESSENDEN DETECTOR. Another name for the electrolytic detector, which was originally proposed by R. A. Fessenden.

FIDELITY. Degree to which electrically or acoustically reproduced sounds resemble their original counterparts. A high-fidelity system should be capable of reproducing all sounds within the audio range at their correct relative intensities.

FIELD. See ELECTROSTATIC FIELD, MAGNETIC FIELD.

FIELD COIL. Coil of insulated wire used for exciting a field magnet of an electric motor, generator, converter or loudspeaker. Shunt field coils have a large number of turns but carry a small current, while series field coils have few turns and carry a heavy current. See MOTOR.

FIELD-FREQUENCY. Synonym for PICTURE-FREQUENCY.

FIELD STRENGTH. Value of the electric field of a radio-wave at a given point, usually at the receiver site. It is measured in volts per metre (V/m). 1 V/m is equivalent to a potential of one volt induced in an aerial wire one metre long in the direction of the electric field. Since the V/m is too large a unit for practical purposes, the millivolt per metre (mV/m) and microvolt per metre (μV/m) are more frequently used. For example, if 100 microvolts are induced between the ends of an aerial wire one metre long, when a radiated wave cuts across it, the field strength is 100 μV/m.

A signal with a field strength as high as 100,000 μV/m is obtained at short distances from a high-powered sending station. A simple receiver can give a loud signal with a field strength of 10,000 μV/m. But at lower field-strength values, R.F.-amplification stages are required; a signal of 100 μV/m field strength, for instance, necessitates the use of several such stages and a superheterodyne receiver would give better reception. 1 μV/m is the minimum signal which can be received by the G.P.O. Radio Telephony Service, and the reception of such a signal demands exceptionally sensitive heterodyne sets with a number of R.F. and I.F. stages.

The field strength to be expected within the ground-wave range of a sender at distances up to about 300 miles is given, in μV/m, approximately, by the formula:

$$\mathrm{V} = \frac{0{\cdot}377 \times 10^6 \times hI}{\lambda d},$$

where *h* is the effective height of the sending aerial in metres, *I* the r.m.s. value of aerial current in amperes, λ the wavelength in kilometres, and *d* the distance from sender in kilometres.

This formula makes no allowance for absorption effects during propagation; various factors, such as that due to Austin and Cohen, may be used to compensate for these losses. Such a formula can, therefore, give only approximate results which often differ considerably from measured values of field strength.

The distribution of field strength around an aerial system is usually exhibited on maps of the area surrounding the aerial. The field strength is measured at a large number of places in the service area of the sender, and places of equal field strength are linked by lines or contours. The shape of these contours is determined by the polar diagram, that is, the directivity of the aerial system, and by features, such as reflections and absorption, in the local terrain. See ABSORPTION, AUSTIN-COHEN FORMULA, ELECTRIC COMPONENT, POLAR DIAGRAM, RADIATION.

FIELD WINDING. Complete set of field coils used in a motor, generator or converter.

FIGURE-OF-EIGHT RECEPTION. Reception based on a polar diagram in which there are two major directions of maximum efficiency at 180 deg. to each other, and, midway between them, two directions of minimum reception, the polar diagram having a figure-of-eight form. The ordinary loop aerial approximates to these properties, as does a horizontal half-wave dipole. See POLAR DIAGRAM.

FILAMENT. Cathode consisting of a conductor, usually of circular cross-section. A current is passed through the conductor, or filament, to heat it. The filament emits electrons and becomes the primary source of electrons. These electrons are available to conduct a current through the valve of which the filament forms the cathode (see CATHODE, VALVE).

The first valves used filaments made of pure tungsten wire. These filaments had to be heated to a high temperature before they gave a sufficient emission, and as the bulb of a valve in those days was clear, the valve gave a certain amount of light (the French called it *une lampe*).

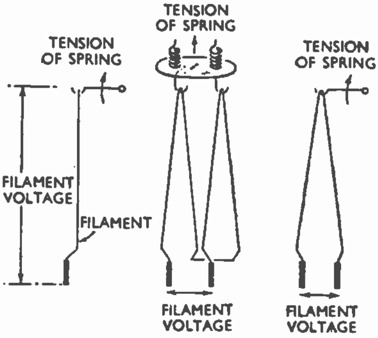


Fig. 11. Various methods of mounting a filament so that its tension is maintained as it expands when heated by the passage of current through it.

Valves with directly heated filaments rated at 1·4 volts or 2·0 volts are in general use in battery receivers. The filaments are coated with a mixture of metallic oxides which give a copious supply of electrons at quite low temperatures. Thus there is practically no glow from these valves and they were originally known as dull-emitters to distinguish them from the bright emitters described.

The valves used in mains-operated receivers are almost always of the type with indirectly heated cathodes. Such cathodes cannot, however, be used in valves handling very high power, such as those required in high-power senders. This is because the bulb cannot be completely evacuated and the small amount of gas present becomes ionized when the anode-cathode potential is applied, and a cathode would be destroyed by bombardment by positive ions which strike it at high velocity under the action of the high anode-cathode voltages used.

Thus a filament is employed in such valves. For powers of up to about 1,000 watts a thoriated-tungsten filament may be used, but for higher powers it is essential to use pure tungsten. Neither tungsten nor thoriated tungsten is such a good emitter as metallic oxides, but other considerations make their use essential (see CATHODE EFFICIENCY).

Fig. 11 shows various forms of filament. The mechanical difficulties introduced by the use of a filament are chiefly those concerned with expansion when the filament gets hot. Arrangements are therefore made to take up the slack by springs. See CATHODE BIAS, EMISSION.

FILAMENT CURRENT. Current flowing in a filament, or the current specified as necessary to produce the required emission from the filament of a specified valve. See FILAMENT, HEATER CURRENT, VALVE CHARACTERISTIC.

FILAMENT EFFICIENCY. Cathode efficiency of a filament-type cathode. See CATHODE EFFICIENCY.

FILAMENT SATURATION. Synonym for EMISSION LIMITATION.

FILAMENT VOLTAGE. Voltage acting across a filament, or the voltage specified as necessary to set up the required filament current of a specified valve. See FILAMENT, HEATER VOLTAGE, VALVE CHARACTERISTIC.

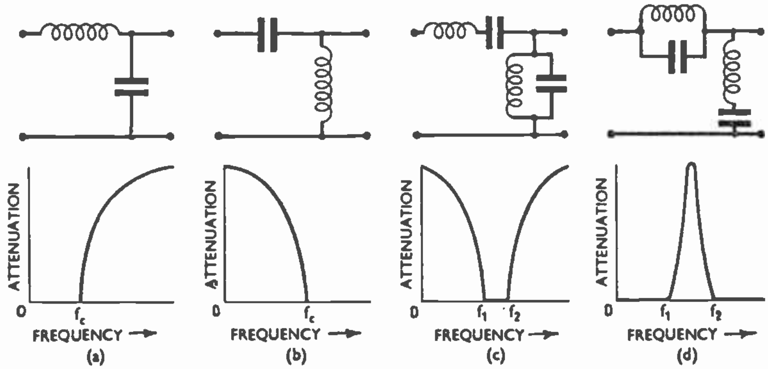


Fig. 12. Filters are classified as (*a*) low-pass, (*b*) high-pass, (c) band-pass, and (*d*) band-stop. Below the diagrams of the basic configurations are shown the attenuation-frequency characteristics of each type of filter, assuming it to be ideally terminated; f_c, f_1 and f_2 represent the frequency at cut-off.

FILTER. Network which freely transmits waves within a certain frequency band or bands, and attenuates waves of other frequencies not lying within the transmission bands. Thus a filter is a device which allows waves of certain frequencies to pass freely through it while stopping the passage of others.

Filters are used in every form of transmission technique. Radio receivers must have filters to make them selective (see RESONANCE, SELECTIVITY, TUNING). Similarly, in sending several messages simultaneously over transmission lines, filters are used to pass the band of frequencies representing one message and attenuate all others, so that only the one message is reproduced without confusion.

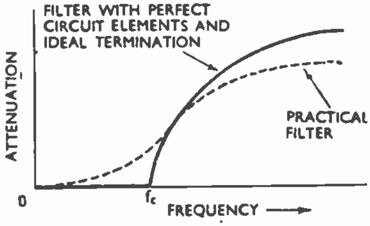


Fig. 13. Diagrammatic representation of the effect of loss (finite Q-factor) in the inductor(s) and capacitor(s) of a low-pass filter; f_c is cut-off frequency.

Filters are characterized in terms of the nature of the bands they pass. A low-pass filter passes waves having a frequency less than a cut-off frequency; a high-pass filter passes waves of frequency greater than a cut-off frequency. A band-pass filter passes waves lying between a lower and an upper cut-off frequency; a band-stop filter attenuates waves lying between a lower and an upper cut-off frequency (see CUT-OFF FREQUENCY).

Fig. 12 illustrates the characteristics of the basic forms of filter: low-pass, high-pass, band-pass and band-stop. The diagram plots attenuation against frequency and shows characteristics applicable to filters built from reactances assumed to have zero loss (power factor = 0, Q-factor = infinity) and to be ideally terminated. There is no such thing as a pure reactance, and the effect of using practical inductors and capacitors in a low-pass filter is shown as a comparison with the ideal graph in Fig. 13. The rounding off of the characteristic about the cut-off frequency occurs in all filters; the low-

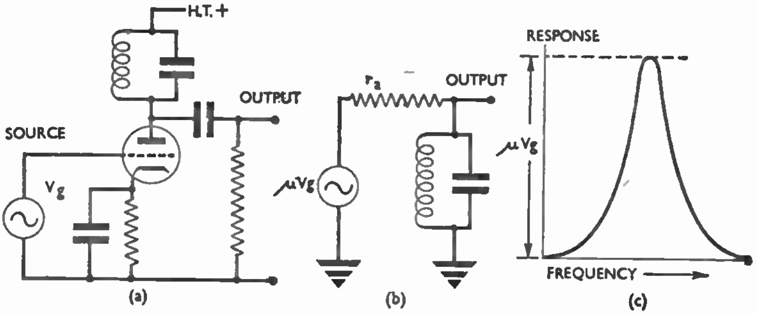


Fig. 14. Valve circuit including a tuned-anode filter (*a*), its electrical counterpart (*b*), and a representative response curve (*c*). The source of e.m.f. is μV_g, where μ is the amplification factor of the valve and V_g the grid/cathode input voltage to the circuit. The resistor marked r_a in the circuit (*b*) is equivalent in value to the slope resistance of the valve in circuit (*a*).

pass filter is chosen only as an example.

Filters are made up from sections containing a series arm and a shunt arm. The circuits in Fig. 12 show what is called the configuration of a filter section; essentially, the series arm of a low-pass filter is an inductor, and the shunt arm a capacitor. Conversely, in a high-pass filter the series arm is a capacitor and the shunt arm an inductor, while tuned circuits form the arms of band-pass and band-stop filters.

A filter is used to transmit waves lying within certain frequency bands so that power can be delivered to some circuit or transducer making use of it. Thus the filter may be inserted between a generator and a load. Ideally, the filter absorbs no power from the source for wave frequencies within the pass or transmission band; the degree to which this ideal is fulfilled is measured by the insertion loss of the filter (see INSERTION LOSS). Over the pass-band, the filter transmits the waves freely; in the attenuation band the filter absorbs no power but prevents power from being delivered to the load. The filter is designed with reference to its cut-off frequency and its termination, symbolized by f_c and R respectively (see FILTER SECTION).

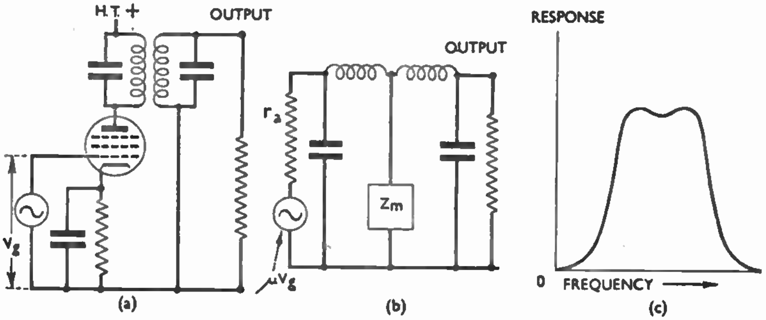


Fig. 15. Inductively coupled band-pass filter (*a*) as used in an I.F. amplifier; its equivalent circuit is a series-and-shunt-arm filter (*b*), impedance Z_m being the mutual inductance between the inductors; (c) is a typical response curve.

The foregoing has dealt with what are called Zobel filters, which are used in all transmission technique, notably in connexion with carrier or transmission lines. The radio engineer is likely to find the filter circuit of Fig. 14a more familiar; as shown by its equivalent circuit (Fig. 14b), the series arm is a pure resistance.

In Zobel-filter design it is usual to express the insertion loss and frequency-attenuation characteristics in terms of decibels attenuation, but in radio engineering the response curves are generally plotted in terms of voltage (Fig. 14c). This is because the filters in radio engineering are generally used to feed valve-input circuits

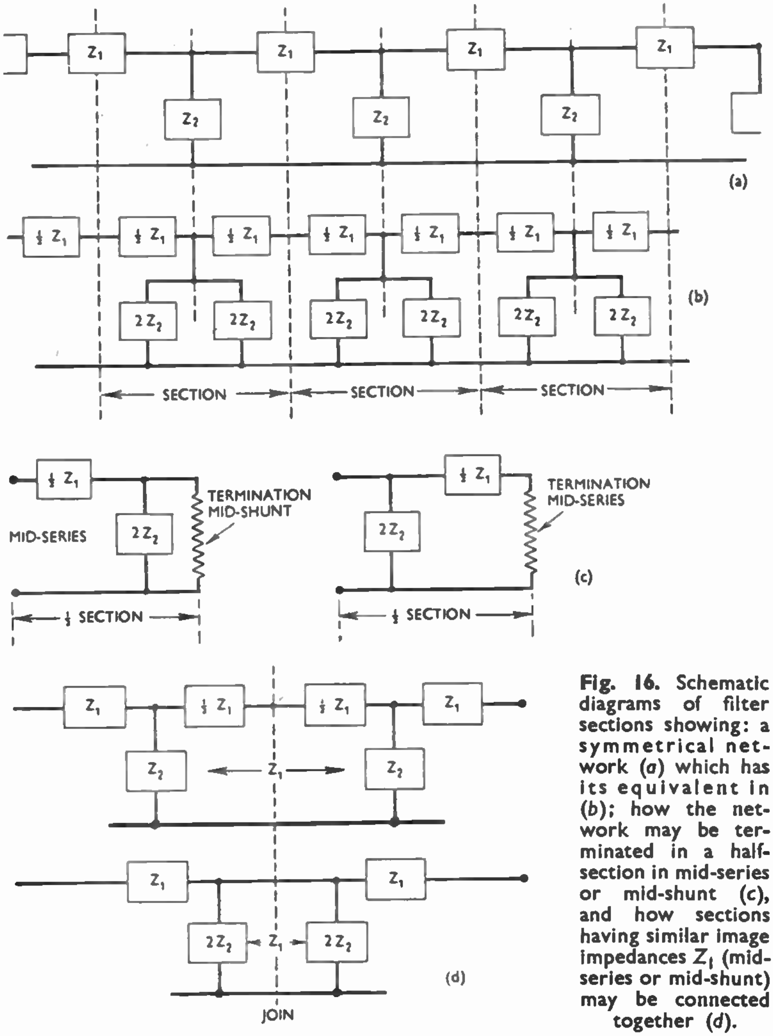


Fig. 16. Schematic diagrams of filter sections showing: a symmetrical network (*a*) which has its equivalent in (*b*); how the network may be terminated in a half-section in mid-series or mid-shunt (*c*), and how sections having similar image impedances Z_I (mid-series or mid-shunt) may be connected together (*d*).

and valves respond only to the voltage applied to the grid, irrespective of the impedances across which they are developed and irrespective of the power concept implicit in the decibel (see DECIBEL). Fig. 15a shows another circuit familiar to designers of radio receivers, since it is used in the I.F. circuit of a superheterodyne receiver (see BAND-PASS FILTER). This can be likened to a Zobel filter, as a mutual inductance forms the shunt arm (Fig. 15b).

Finally, it should be remembered that an equalizer and a filter each give an output which is a function of frequency, but there is a fundamental difference between them: the filter is designed to give a certain attenuation at a certain frequency, with little reference to the shape of the graph between this frequency and the cut-off frequency, while the equalizer is designed to give a particular shape of attenuation-frequency response, the absolute attenuation being relatively unimportant. See BAND-PASS FILTER, BAND-STOP FILTER, CHARACTERISTIC IMPEDANCE, HIGH-PASS FILTER, ITERATIVE IMPEDANCE, LOW-PASS FILTER, TUNED CIRCUIT.

FILTER SECTION. Network containing, essentially, a series and shunt arm. Sections are designed so that several of them may be connected in cascade with the least possible loss due to mis-matching at the junctions. Fig. 16a shows a symmetrical network in which the series arms have an impedance Z_1 and the shunt arms an impedance Z_2. The network must have an input and an output, but in the diagram (a) this is not shown. In (b), however, it is seen how the network can be considered as made up of series arms containing two impedances in series, each of $\frac{1}{2}Z_1$; and shunt impedances in parallel, of $2Z_2$. Fig. 16c shows how the network can be terminated by its characteristic impedance, in either mid-series or mid-shunt.

Fig. 16d illustrates filter sections considered always in terms of $\frac{1}{2}Z_1$ and $2Z_2$, and how sections can then be connected together without mis-matching at the junction.

The constants of filter sections are evaluated in terms of the characteristic impedance R, by which the filter is to be terminated and the cut-off frequency f_c. For example, the constants L and C of an L-type low-pass filter are given by the following expressions: $L = \frac{R}{\pi f_c}$, and $C = \frac{1}{\pi f_c R}$. If only a single section is used, the two capacitors would each be of value $C/2$, and in a multi-section filter the first and last capacitors would also be of value $C/2$. See CHARACTERISTIC IMPEDANCE, FILTER, IMAGE IMPEDANCES, ITERATIVE IMPEDANCE, MATCHING.

FIRST-CLASS BEARING. In direction-finding, a bearing believed to be accurate to within plus or minus two degrees. See SECOND-CLASS BEARING.

FIRST DETECTOR. See FREQUENCY-CHANGER.

FIRST INTERMEDIATE FREQUENCY. First frequency to which incoming signals are converted in a superheterodyne receiver which employs more than one such change. See SUPERHETERODYNE RECEPTION.

FISHBONE AERIAL. Form of end-fire array consisting of a series of elements arranged in end-to-end pairs, each element coupled to one side of a feeder-line through the capacitance provided by an insulator. A diagram

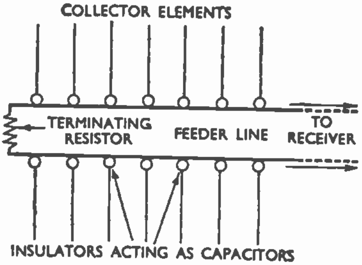


Fig. 17. Elements of the fishbone aerial, showing electrical arrangements but not the supporting devices.

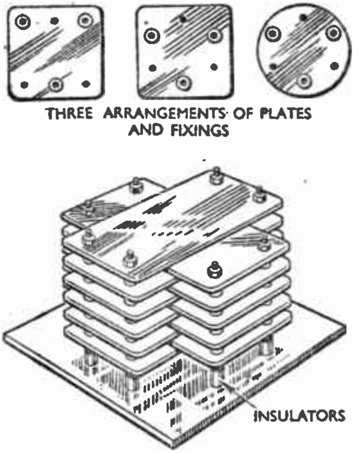


Fig. 18. Typical stacked assembly of conducting plates forming the electrodes of a fixed capacitor with fluid dielectric. The assembly is, of course, housed in a container when the dielectric takes the form of a liquid, vacuum, or gas under pressure.

of the arrangement is given at Fig. 17. Each element is about a third of a wavelength long and the spacing between elements is about a twelfth of a wavelength; there may be as many as 40 pairs of elements. See END-FIRE ARRAY.

FIVE-ELECTRODE VALVE. Synonym for PENTODE.

FIXED CAPACITOR. Capacitor in which no provision is made for varying its capacitance. It is commonly used for coupling and de-coupling A.C. circuits; for by-passing alternating currents; for smoothing rectified power supplies, and as a circuit element in a wave filter.

Fixed capacitors may be classified into several groups according to the dielectric used: vacuum, gas, liquid and solid. The first three have rather a large bulk per unit capacitance, but they have compensating merits which make them particularly suitable for handling the large powers at radio senders. They are being superseded to some extent for this purpose by solid dielectrics. For small transmitters and radio receivers, fixed capacitors having solid dielectrics are almost invariably used.

The first three groups have similar electrode systems, which consist of a stack of conducting plates equally spaced one from the other, and with alternate plates connected to one terminal and the remainder to the other. Typical assemblies are shown in Fig. 18.

Where the supporting rods of one set of plates pass through one of the plates of the other set, the latter is provided with holes large enough to preserve a clearance of the same order as the clearance between adjacent plates. The supporting rods are usually fixed into ceramic insulating plates, or into ceramic insulating bushes fixed to the framework.

Air capacitors designed to work under normal atmospheric conditions can be used in the open form illustrated in Fig. 18, but for vacuum or pressure capacitors, or for capacitors with liquid dielectric, the assembly must,

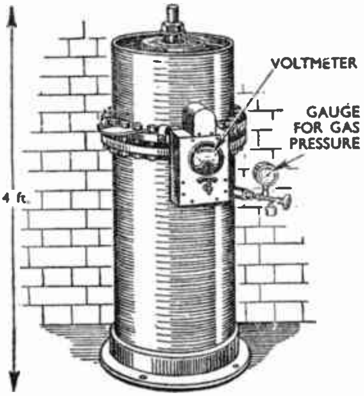


Fig. 19. Pressure container of a Dubilier gas-dielectric variable R.F. capacitor in which nitrogen can be maintained at 200 lb./sq. in. A similar capacitor without the voltmeter and the associated box construction is used, for certain applications, as a fixed capacitor.

of course, be housed in a container.

The container of a vacuum capacitor must be hermetically sealed and strong enough to withstand a collapsing pressure of one atmosphere. For a pressure capacitor, on the other hand, the container must be strong enough to withstand a bursting pressure which may be as high as twenty atmospheres. A typical container is shown in Fig. 19.

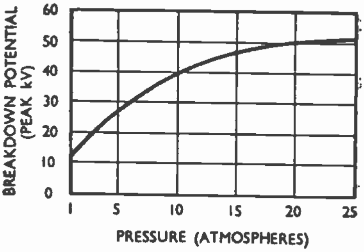


Fig. 20. Graph of the breakdown voltage at 1 Mc/s of a nitrogen-filled pressure capacitor at normal temperature.

To justify these expensive containers there must be some compensation such as a higher working voltage or smaller size, and Fig. 20 shows that breakdown voltage increases with pressure.

A capacitor with a liquid dielectric (for which mineral oil is commonly used) usually has a reservoir mounted above the container, and connected with it, to ensure that the latter is kept full of oil at all times. Any expansion or contraction of the oil with changes of temperature is taken up in the reservoir, which has a small air vent to prevent build-up of pressure. Sometimes a means is provided for circulating the oil to assist cooling and thus to increase the rating.

Compared with air, oil has a higher electric strength and a higher permittivity (about 2·2), but not such a good power-factor. It has the disadvantage that these properties vary with frequency and temperature.

Fluid dielectrics, in contrast with the solid types, have a "self-healing" property; that is to say, the inadvertent application of an excessive voltage for a short time causes no permanent damage. After the excess voltage is removed, the dielectric properties are restored.

The earliest capacitors had glass as the dielectric (see LEYDEN JAR), but its use is now rare. The materials in most common use as solid dielectrics are mica, ceramic and impregnated paper. Plastic films are being introduced and may find a wide application in the future. Electrolytic films, which must be classed as "solid," have a limited scope, but large application.

Capacitors with mica as the dielectric may be divided into foil and metallized types. The former consists of alternate laminations of mica and metal foil (see CAPACITOR), and the stack is held together with metal clamps. In radio types the clamps consist of pressed sheet metal, and the assembly forms the kernel of a synthetic-resin moulding with extending wires or terminal lugs for making the electrical connexions (Fig. 21). For precision purposes the clamps are made of steel plates bolted together, and the assembly is housed in a sheet-metal container filled with wax or bitumen.

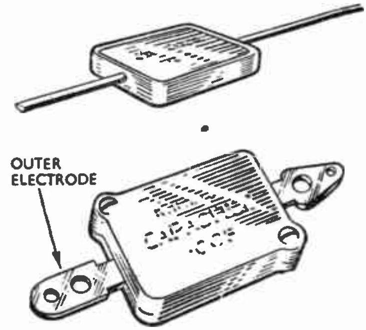


Fig. 21. Two forms of moulding-enclosed mica capacitor, showing provision for electrical connexions.

The electrodes of metallized mica capacitors consist of a film of metal, usually silver, deposited on either side

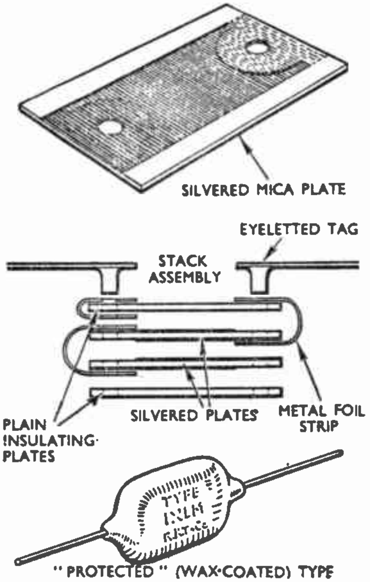


Fig. 22. Constructional details of a silvered mica capacitor, and external appearance of the wax-coated type.

of the mica plate, with clearances at the edges in order to minimize surface leakage and to reduce the possibility of breakdown between the opposite sides (Fig. 22).

To achieve a larger capacitance than that provided by a single plate, several plates may be stacked together and riveted through suitable holes by means of hollow rivets which also serve to attach the terminals. The method of finishing is either to embed them in a synthetic-resin moulding, as for the foil type, or to encase them in wax by a dipping process. The former kind is called moulded, and the latter is termed protected.

Silvered mica capacitors are very stable with respect to time and temperature. They have a very slight instability with change of frequency and voltage, which is of importance only in precision circuits. Its cause has not been fully explained, but it is thought to be associated with isolated particles of silver at the boundary of the metallizing.

Capacitors with ceramic dielectric have, almost invariably, metallized electrodes. The dielectric usually takes the shape of a disc, tube or cup, as shown in Fig. 23. Various grades of ceramic are available for specific purposes. The grade selected for radio senders is usually that having a low power factor. For radio receivers, a high permittivity is preferred so that the physical dimensions may be reduced; a permittivity of 100 or more is available commercially and of over 1,000 in the laboratory.

Several grades are available with large temperature coefficients of capacitance—some positive and some negative—and by judicious mixing during manufacture a wide range of values of the coefficient can be achieved. This is particularly useful for compensating the temperature coefficient of inductance in resonant circuits so that the latter can be made frequency-stable in spite of variations of temperature.

Paper absorbs moisture and is unsuitable as a dielectric unless it is

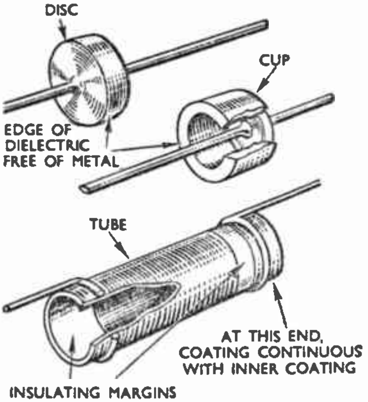


Fig. 23. Fixed capacitors employing a ceramic dielectric usually have metallized electrodes. The dielectric may be a disc, a cup or a tube.

first vacuum-dried and then impregnated with a suitable material. It can be manufactured in continuous lengths of thin and uniform quality (capacitor tissue having a thickness of 7 microns is commonly used) and, together with aluminium or tinfoil 6 or 8 microns thick for the electrodes, may be wound into a roll of large capacitance very cheaply (see CAPACITOR).

The power factor of paper is poor at radio frequencies, but at audio frequencies it is adequate for most purposes. In the range 0·001 to 0·5 μF, and in circuits unsuitable for electrolytic types, paper-dielectric capacitors are extensively used.

Paper is, however, a porous material; also it is impossible to manufacture thin tissue commercially without including a few particles of dust, which may consist of metal, carbon, or other conducting matter. British Standard No. 698 allows a maximum of ten such conducting paths per square foot. This defect may be overcome by superimposing two layers of paper. With this arrangement, the probability of a weak spot in one layer coinciding with one in the other layer is so remote as to be negligible, but the safe working voltage is no better than that of a single layer which is free from defects.

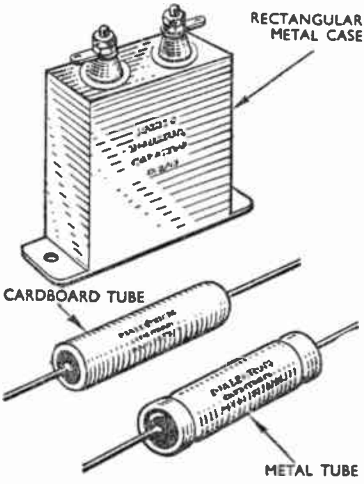


Fig. 24. Three forms of paper-dielectric capacitor. Metal-case types are usually of higher capacitance or higher voltage rating than the tubular ones.

The usual impregnating materials are mineral oil, petroleum jelly, paraffin wax and chlorinated naphthalene wax. The permittivity of the first three is of the order of 2 to 2·5 and of the fourth about 4·5. The permittivity of the cellulose of the paper is about 7 and the effective dielectric constant of the impregnated paper is of the order of 4 and 5·5 respectively, in the two cases. Chlorinated diphenyl has a limited use at power frequencies.

Capacitors having a small value of capacitance are usually tubular in form, but those of larger values are housed in a rectangular metal container as shown in Fig. 24. The construction of the former type is shown under the heading of CAPACITOR. The latter type is wound in a similar way, but on a comparatively large-diameter mandrel. The roll is pressed flat prior to impregnation, and several rolls are connected together in parallel inside a common assembly (Fig. 25).

When a voltage of magnitude sufficient to cause breakdown of the dielectric is applied to a capacitor of the conventional paper-and-foil type, the resulting current through the point of breakdown generates sufficient local heat to carbonize the paper. There is subsequently a permanent short-circuit which is irreparable.

If, instead of a metal foil, the electrode consists of an extremely thin layer of metal deposited on the surface of the paper (metallized paper) then, on rupture of the dielectric, the current is limited to the carrying capacity of the metal layer which fuses in the region of breakdown, where the current is most concentrated. Fusing continues until energy stored in the capacitor falls to a value insufficient to maintain the small arc which is formed. If the stored energy is not excessive and the short-circuit current from external sources is insufficient to maintain the arc, then the heat generated per unit area is so small that the paper dielectric surrounding the point of breakdown is little affected. This "self-healing" property can be used to isolate all the weak spots in a thin tissue, and the reduction in volume, compared with a conventional two-layer design, is 75 per cent.

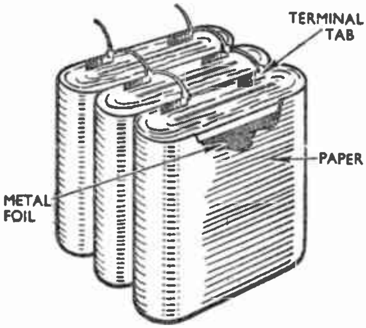


Fig. 25. Details of internal construction of the type of fixed capacitor in which the dielectric is composed of impregnated pressed paper.

The metallized paper usually associated with Mansbridge was invented in 1876 by Fitzgerald, who also described the first rolled type of construction. In 1900, at a time when metal foil was available in lengths of only about 4 ft., Mansbridge developed a commercial method of applying a continuous coating of tin to long paper strips. Prior to this the coating usually lacked continuity, but Mansbridge introduced a calendering process for spreading the separate patches of tin into one another.

With the introduction of thinner tissue, weak spots gave trouble and a method of burning them out prior to winding the metallized tissue into a capacitor roll (in a manner similar to that described above) was introduced. Because of the nature of the coating this technique was not entirely successful, and capacitors using thin tissue were always wound with at least one interleaving tissue, so that there was no intrinsic merit in the method. With the advent of aluminium and tinfoil in continuous lengths, the Mansbridge type of capacitor fell into disuse.

In 1934 Bosch developed a process for applying an extremely thin (0·1 to 1 micron) and uniform continuous coating of zinc to thin tissue by evaporating the metal under vacuum and condensing it on to a passing strip. The tissue was first varnished to fill all the pores and increase the electric strength. The process included a method of coating the edge of the tissue, or other parts required to be free from metal, with a volatile oil which prevented the deposition of the metal.

The technique made it possible to produce commercially, for the first time, capacitors with a dielectric consisting of a single layer of thin tissue. The method has been copied in Great Britain and in the U.S.A. and is finding a growing field of application.

Cellulose nitrate (celluloid) and cellulose acetate were the first plastic films commercially available, but neither they nor pure cellulose have sufficiently good electrical properties to compensate for their high cost in comparison with paper. Nor is it easy to make films thinner than 50 microns with the required degree of uniformity. Cellulose triacetate has been used to a limited extent for capacitors working at 100 deg. C.

Of the newer materials, polythene films are unsuitable mechanically, but polystyrene is most promising and has been used by the Germans as a substitute for mica. Its properties are better than mica in all respects except maximum working temperature, which is 70 deg. C., and temperature coefficient of capacitance. Its insulation resistance is extremely high and its absorption coefficient very low, making it an ideal material for capacitors for use in accurate timing circuits.

An electrolytic capacitor is one in which the dielectric is formed by electro-chemical means on one electrode which, in commercial types, is invariably made of aluminium. In theory, the dielectric can be made of molecular thickness and, in practice, it can be made so thin that, for a given capacitance, size and cost are very much less than of other types. This is particularly true of the capacitors designed for use at the lower working voltages of the commercial range which extends from 12 to 500 volts.

The dielectric is formed under D.C. conditions and, apart from the exceptions mentioned below, electrolytic capacitors are suitable only for polarized working; that is to say, one terminal must always be maintained at a positive potential with respect to the other. Reversal of polarity, even momentarily, causes breakdown of the dielectric, so that the polarized type is unsuitable for use in purely A.C. circuits.

A fluctuating unidirectional potential, however, is tolerable; for example, an A.C. potential superimposed on a D.C. voltage. There are many applications of this kind, such as in smoothing circuits of rectified A.C. supplies, and in decoupling and by-pass circuits. The relative magnitudes of the two must be such that the D.C. component is larger than the peak value of the A.C. component (to prevent reversal of polarity), and their sum must not exceed the rated working voltage. The permissible magnitude of the A.C. components is also limited by the temperature rise produced by the associated power losses acting in a small volume.

Reversible types are made and have a limited use. They consist of two capacitors connected in series, with the polarity of one reversed with respect to the other. The two capacitors are usually constructed as a single unit with one electrode common to both halves. This type can be used in A.C. circuits, but only on very intermittent service because of the large internal power dissipation.

There are two basic types of construction: the "dry" type and the aqueous, or "wet," type. In the dry type, the two electrodes of aluminium foil, one formed and one plain, are separated by a layer of paper impregnated with an electrolyte of a kind suitable for maintaining the chemical film on the electrode. The paper, in this case, is not an insulator but a carrier of the electrolyte, which, in effect, is an extension of the unformed electrode, carrying it into very intimate contact with the dielectric film on the formed electrode. The foils and paper can be wound into a roll in the manner of the paper-and-foil capacitor described earlier.

In the aqueous type the electrodes are spaced apart by insulating supports, and the intervening space is filled with a conducting fluid of the same nature as that used for impregnating the paper in the dry type.

The aqueous type is generally more reliable and less prone to suffer permanent damage as a result of applying a momentary voltage overload; but it is more bulky, and can be operated only in one position. The disadvantages of electrolytic types are their low insulance, high power factor, inconstancy of capacitance, and their ability to withstand only very limited surges of over-voltage. Nevertheless, there are many applications where these disadvantages are not of great consequence and are far outweighed by the considerable saving of size and cost over other types.

Fixed capacitors are marked with the value of capacitance, percentage tolerance and maximum safe D.C. working voltage. This latter figure should never be exceeded, particularly in the case of electrolytic types. Paper-dielectric capacitors are sometimes marked with the test voltage, which is usually about three times the working voltage, except in the case of metallized paper, for which the figure is twice, or even less.

Electrolytic capacitors are also marked with polarity, which it is very important to observe, and sometimes with the peak surge voltage, that is, the permissible voltage that may be applied (without causing damage) for a short period such as occurs when switching on a set. Very small mica and ceramic types, which are too small or inconvenient to mark in any other way, make use of a colour code (see COLOUR CODE).

Because of the internal generation of heat under A.C. working conditions, the maximum safe A.C. working voltage is usually much less than that calculated by assuming that the peak A.C. voltage is the same as the D.C. voltage.

A common fault in capacitors used for coupling the anode of one valve to the control-grid circuit of a following valve is low insulance which causes an excessively high anode current to flow in the second valve. In other applications, low insulance is not usually very important.

Open-circuit and short-circuit faults are serious in any circuit. The first, if suspected, may be proved by putting a known good capacitor in parallel with the suspected faulty one and checking whether the normal performance is restored. A short-circuit usually shows itself by an excessive current but, in cases of doubt, it can be detected by inserting a meter in series to record the current, or a known good capacitor to restore the normal conditions. In all cases, faulty capacitors should be replaced.

Electrolytic capacitors deteriorate with disuse, so that after a shelf life or idle period of six months (or a year at the most) they should be re-formed before use, otherwise they may break down rapidly in service.

Re-forming is effected by applying the working voltage through a current-limiting resistor of about 10,000 ohms for several hours or until the leakage current falls below a value given by the formula $\frac{CV}{5{,}000}$ mA, or 0·1 mA, whichever is the larger, where C is the nominal capacitance in microfarads and V is the working voltage. Thus an 8-μF, 450-V capacitor would be satisfactory if the leakage current did not exceed 0·72 mA.

The capacitance and insulance of electrolytic types fall with time, particularly if subjected to high temperatures, and it is usually necessary to replace them after a few years' service. See CAPACITANCE, DIELECTRIC.

FIXED CONDENSER. See FIXED CAPACITOR.

FIXED DIRECTION-FINDER. Direction-finder in which the aerial-system does not rotate, determination of direction being carried out by other means, for instance, the rotation of a radiogoniometer. See BELLINI-TOSI DIRECTION-FINDER.

FIXED INDUCTOR. An inductor in which no means is provided for varying its inductance. Fixed inductors are commonly used as elements of resonant circuits and wave filters, including simple circuits for discriminating between A.C. and D.C. They are also used for coupling valve circuits. Fixed inductors may be classified according to the nature of their magnetic core, as air-cored, iron-dust-cored, or iron-cored inductors. The choice of core is influenced by the working frequency. Iron cores are used at power and audio frequencies; certain types may be used at frequencies as high as 100 kc/s; iron-dust cores have a useful range from audio to medium-radio frequencies; air cores are used at radio frequencies and also at lower frequencies for special purposes, such as for standards of inductance.

An inductor has some degree of both resistance and capacitance. The conductor with which the coil is wound has intrinsic resistance which is increased by the skin and proximity effects as the working frequency rises. Up to about 1 Mc/s, the skin effect can be reduced in small inductors by employing Litz (stranded) wire. There are other causes of power loss, such as eddy currents induced in nearby conducting material (screens, for example) and, if the inductor has a ferro-magnetic core, eddy current and hysteresis losses in the material of the core.

At radio frequencies, dielectric losses in nearby insulating material, such as the wire-covering and coil former, may become of importance, particularly if the materials contain traces of moisture. There is distributed capacitance between the various parts of the inductor which may be of considerable magnitude in multi-layer coils; the upper value of the useful frequency range is limited to the resonance frequency of the inductance with this stray capacitance. It is the objective of good design to reduce to the lowest practical value all these effects which tend to modify the inductance and Q-factor.

Fig. 26 shows the effective circuit of a fixed inductor, the various losses being represented by series or parallel resistors. At any given frequency, this circuit can be reduced to a simple "effective" inductance in series or parallel with an "effective" resistance. The effective values are not the same in each case, but are related in the manner shown. The parallel values are the more easily measured at R.F. by resonating the inductor with a known parallel-connected capacitor at a known frequency. A.C. bridge methods are used at A.F., and either pair of values may be measured directly.

Fixed inductors for radio senders usually have to carry a current of high value, often at high voltage, and are termed *air-cored inductors*. The physical dimensions tend to be proportional to the power rating. Single-layer air-spaced coils are used which, compared with those used in receivers, have fewer and more widely spaced turns of much larger diameter. The conductor has to be of large section and is usually made of copper tubing. Dielectric losses in insulators must be avoided and coils are supported at as few points as possible by low-loss material. As the working frequency rises, the diameter and the number of turns falls. The power rating also tends to fall with rising frequency so that at V.H.F. the coil is often small enough to be self-supporting.

Receiver inductors have either single-layer coils or multi-layer wave-wound coils wound on cylindrical formers of circular or polygonal section. Single-layer coils are used in resonant circuits at medium and high radio frequencies, and in non-resonant circuits at V.H.F.

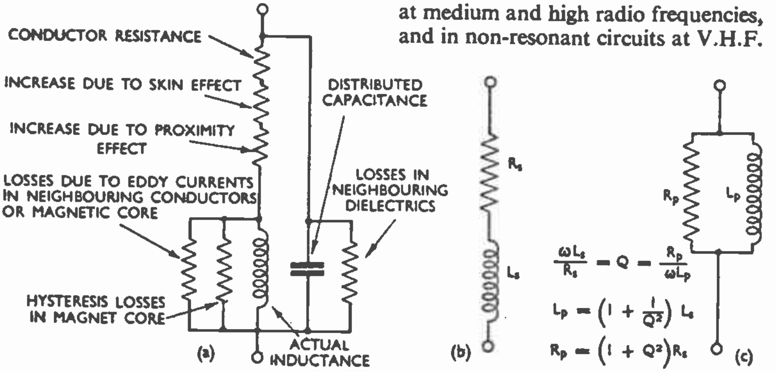
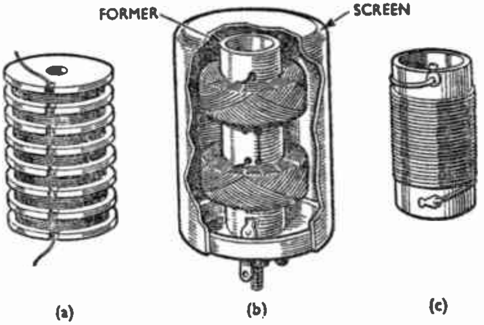


Fig. 26. Diagrams showing: (*a*) losses and capacitance associated with a fixed inductor; (*b*) equivalent series circuit, and (c) equivalent parallel circuit.

Fig. 27. Fixed inductors with air cores for radio frequencies: (*a*) a multi-layer winding on a multi-section bobbin; (*b*) two wave-wound coils in series, and (c) a single-layer winding.



Wave-wound coils are used in both resonant and non-resonant circuits at medium and lower frequencies. Multi-layer coils are also used as inductance standards for A.F. measurements. Air-cored inductors are wound with textile-covered copper wire. The Q-factor in the R.F. range is about 150 for types used in broadcast receivers, but higher values can be attained.

A common non-resonant application of fixed inductors is in the anode-feed circuit of a valve. A high value of inductance is necessary to reduce the flow of signal current into the power-supply circuit (whence the terms choke and choke feed). Often the inductor also serves as a coupling element between stages (inductive or choke coupling). The distributed capacitance must be sufficiently low to prevent self-resonance below the working frequency, but designers sometimes deliberately make it coincide with the working frequency in order to increase the impedance. The self-capacitance can be reduced and the resonance frequency increased by sectionalizing the winding, either by having two or more wave-wound coils on a common former, or by using a multi-section bobbin (Fig. 27).

Because of its high permeability, the use of a ferro-magnetic core, in what are known as *iron-cored inductors*, greatly increases the inductance of a coil of given size at zero frequency. As frequency rises, the core introduces an increasing power loss which very soon outweighs the benefit of increased inductance. Losses due to eddy currents induced in the core increase with frequency more rapidly than do hysteresis losses, and are more important. An early attempt to reduce eddy-current losses was made by constructing the core from a bundle of iron wires. The modern method is to build the core from laminations or to use compressed powder (dust cores) and to select material of high resistivity.

Silicon-iron alloys have higher permeability and lower losses than soft iron, and laminations about 0·015 in. thick made from these alloys are used for the cores of power and audio-frequency inductors. Nickel-iron alloys have still higher permeability and lower losses, and are used at audio and carrier frequencies.

The permeability of iron cores tends to change with magnetizing force, and hence with current, through the coil. The permeability first rises with magnetizing force from its initial to a maximum value, after which it falls, at first slowly and then more quickly, until a point is reached where the core is said to be saturated. This non-linear characteristic introduces both harmonic and intermodulation distortion. It is symmetrical about zero, so only odd harmonics are generated.

Another result of this non-linearity is the effect of a direct current upon the incremental permeability and inductance associated with a superimposed alternating current. Most iron-cored inductors are operated in this way, whether in power-supply smoothing circuits or A.F. valve circuits. The introduction of a very small air-gap in the magnetic circuit (Fig. 28) reduces the D.C. magnetization to such an extent that it more than compensates for the increased reluctance, and the incremental permeability and inductance are thus both increased. There is an optimum value of the air-gap beyond which the inductance decreases.

Dust-cored inductors are most frequently used in the wave filters of carrier telephone and telegraph equipment and for loading transmission lines and cables at those frequencies. They are usually toroidal in form (Fig. 29), but in the frequency range where line-carrier and radio systems overlap other shapes may be used. I.F. inductors for broadcast receivers, for example, sometimes have a dust-core in the form of a rod or slug along the axis of a cylindrical coil former. The size of dust-cored inductors tends to be inversely proportional to frequency. The Q-factor is in the range 200–400, but is less at A.F. The windings are usually sectionalized to reduce self-capacitance. See DUST CORE, INDUCTOR, IRON LOSS, LAMINATION, WAVE-WINDING.

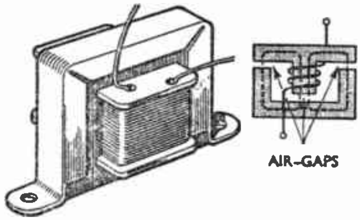


Fig. 28. Fixed inductor which has a laminated iron core assembled with air-gaps in the magnetic circuit.

FIXED RESISTOR. Resistor in which no means is provided of varying the value of its resistance, *R*. Fixed resistors may be put to many uses; they fall, for the most part, into one of the following groups: (1) for controlling or limiting the current, *I*, flowing from a source of e.m.f. *E*, according to the formula $I = E/R$; (2) for producing a potential difference proportional to, and in phase with, the current flowing through it, according to the formula $V = IR$; (3) for reducing the voltage from a source *E* to a value $E - IR$; (4) as an element in a passive network; and (5) for transferring surplus or unwanted energy into heat, according to the formula $W = I^2R$. Some of these applications are illustrated in Fig. 30.

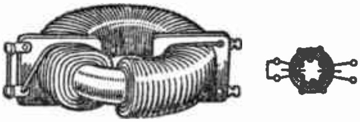


Fig. 29. Fixed inductor, with a toroidal iron-dust core and a two-section winding, widely used in wave filters of telephone and telegraph equipment.

In all applications, some energy is dissipated in the form of heat and the amount determines the design and size. Where the dissipation is less than 3W, metallized or wire-wound types may be used. Above 3W, wire-wound types are used almost exclusively. Metallized types have a very low residual reactance, both inductive and capacitive; they are also cheap and are extensively used in all kinds of electronic circuits. Wire-wound types are very constant in resistance and can be made to much closer tolerance; but they usually have appreciable residual reactance and their use is limited to comparatively low frequencies.

The description "metallized" is commonly used to cover three distinct methods of construction, two of which contain no metal except in the lead-out wires. Strictly, the term describes a design in which the resistive element consists of a thin film of metal deposited on the surface of a ceramic or glass rod. External connexions are made through wires either attached to metal ferrules, or wrapped around the ends of the rod in contact with the conducting film (Fig. 31). The resistance is controlled by varying the thickness of the deposit.

In practice, however, most metallized resistors either make use of a conducting film of carbon instead of metal, or employ a resistive element which consists of a rod moulded from a thermo-setting plastic composition or paste containing powdered carbon or graphite. Except for the high-stability designs described later, the film types are encased in a ceramic tube or a comparatively thick protective wall of moulded plastic and are provided with axial lead-out wires. These are called *insulated* resistors.

The composition types usually have wrapped-around radial lead-out wires. They are protected by a coat of paint (which should not be relied on to provide satisfactory insulation) and are classified as *non-insulated*. Both film and composition designs allow a very wide range of resistance. Film types are made commercially from a few hundreds of ohms to tens of megohms. Composition types are made from tens of ohms to almost the same high value.

The method of construction of the common designs of small carbon resistor does not allow of close resistance tolerance, the normal value of which is ± 20 per cent, but ± 10 and ± 5 per cent can be obtained by selection. To ensure that the number of values of resistance in common use is a minimum and that no carbon resistors are wasted through falling outside the tolerance limits, a system of preferred values has been devised and is generally accepted by industry.

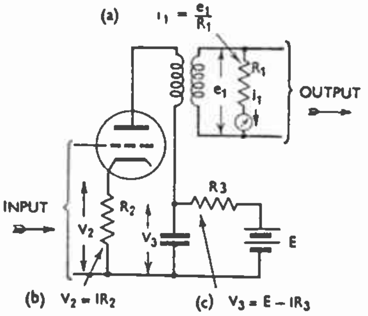


Fig. 30. Circuit diagram showing three applications of fixed resistors; at (*a*), (*b*) and (c) are the relevant formulae applicable to this valve circuit.

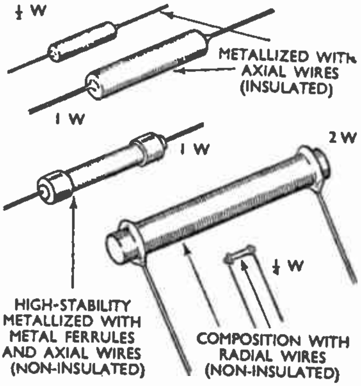


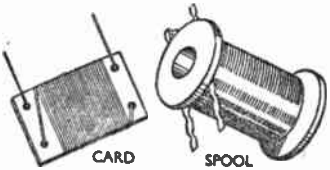
Fig. 31. Forms and relative sizes of the so-called metallized and composition types of fixed resistor.

Tolerances closer than ± 5 per cent are attained by a modification of the film method; a spiral cut is made in the film, having a length which can be adjusted to suit the resistance required. The method has the additional advantage of decreasing the width and increasing the length of the conducting path and, therefore, for a given resistance the thickness of the film may be very greatly increased. This gives improved stability with change of voltage and time, but tends to increase the inductance.

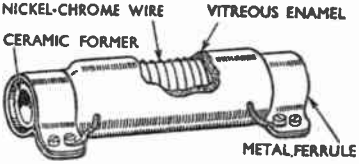
Most of the resistors so far described have the negative temperature coefficient of resistance associated with carbon as the conducting medium; they are also subject to changes of resistance under humid conditions. The resistance of the metallized (film) resistor is much more stable with changes of frequency than the composition type. As the working frequency is increased, composition designs are subject to two opposing effects. First, the normal skin effect tending to increase the resistance; and, second, the capacitance between partially insulated conducting particles tending to reduce the effective resistance. The latter predominates and the higher values of composition resistor show a marked drop in resistance at R.F. compared with the D.C. value.

The common power ratings are ¼, ½, 1, 2 and 3 W, but it should be noted that, for high values of resistance, the voltage rating is the limiting factor because the voltage required to reach full power loading is in excess of the safe permissible voltage gradient. The maximum permissible voltage is of the order of 250 V for the smallest size, rising to 1,500 V for the largest. The value of resistance and tolerance is usually indicated by bands of coloured paint (see COLOUR CODE).

Fixed *wire-wound* resistors (Fig. 32) fall into two categories: low-dissipation precision designs, and those capable of high power dissipation. The former are usually wound on a plastic or ceramic former or spool, using an enamelled or textile-covered nickel-copper alloy wire (see EUREKA WIRE). Various methods of winding are used in manufacture with the object of reducing the residual reactance. One method is known as DUOLATERAL WINDING (q.v.). Resistors for precision measuring equipment usually have the wire wound on to a flat rectangular former by the Ayrton-Perry method (Fig. 33).



LOW-DISSIPATION PRECISION TYPES



HIGH-DISSIPATION VITREOUS-ENAMELLED

Fig. 32. Examples of low-dissipation and high-dissipation types of wire-wound fixed resistor.

Above a 3-W rating, a non-insulated wire, usually of nickel-chrome alloy (see RESISTANCE ALLOY), is wound with spaced turns on to a ceramic tube provided with ferrules, screws, or lead-out wires. The wound resistor is protected either with lacquer or with vitreous enamel. The latter allows a high wattage rating because the permissible surface temperature is 250 deg. C. compared with only 130 deg. C. for lacquer. This high surface temperature and its effect upon neighbouring components must be borne in mind when arranging the lay-out of the components of a circuit. So that there may be maximum cooling by convection currents of air, the resistors should be mounted vertically and spaced apart. Hollow types should not have the ends closed.

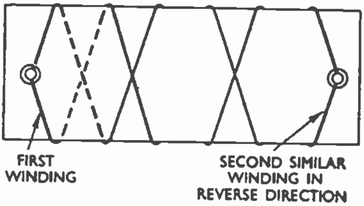


Fig. 33. Principle of the Ayrton-Perry method of winding non-inductive resistors for measuring equipment.

Fixed resistors can become either open- or, less frequently, short-circuited in service, but both faults are comparatively rare. Metallized resistors may become open-circuited as a result of overload; wire-wound types, as a result either of overload or of a faulty joint between the wire and the terminal (resistance alloys are difficult to solder and are usually spot-welded). Under certain adverse conditions the wire may possibly corrode and then break.

Occasionally, metallized and composition resistors are found to be "noisy" in service, due to spontaneous fluctuations of resistance, particularly when working near the full power rating. The fault is most troublesome in the coupling circuit between the first and second stages of a multi-stage amplifier. It is also known to cause short-term frequency instability in beat-frequency oscillators.

FLAGPOLE AERIAL. Aerial for use on very high frequencies, consisting of some form of unipole (see QUARTER-WAVE AERIAL) or end-fed half-wave dipole mounted on the end of a pole support which may, in fact, be a robust form of concentric feeder-line connected to the aerial. See HALF-WAVE DIPOLE, VOLTAGE-FED AERIAL.

FLARE. Term, usually applied to the shape of a loudspeaker or gramophone horn, implying that the cross-sectional area increases with increase in distance from the throat.

FLASH ARC. Arc which may form between the electrodes of a power valve (notably when the anode voltages are several kilovolts); obviously an unwanted condition which may well destroy the valve if it persists. In the early developments of the water-cooled valve, in which anode voltage was 5–12 kV, it was noticed that the anode current momentarily rose to hundreds of times its normal value and at the same time a bright flash occurred inside the valve; the overload breakers of the power-supply system could not act quickly enough to prevent considerable damage to valves and meters. It was supposed that these flash arcs were caused by tiny roughnesses on the inner surface of the anode; the concentration of electric field around these minute points caused ionization of the residual gas, while the arc, when it started, released more gas from the electrodes and so maintained itself. The effect no longer takes place, thanks to care in manufacture and a knowledge of what precautions to take against it. See IONIZATION, SPARK.

FLASHING. Part of the process of activation of a valve cathode. It consists in raising the cathode temperature to a high value for a short time. For instance, thoriated-tungsten filaments are flashed at 2,700 deg. K. for one or two minutes; the filament is then "glowed" at a little over 2,000 deg. K. for a few more minutes. The processes involved vary in all sorts of ways, but flashing invariably implies the raising of the cathode temperature to a higher value than used in normal working. See ACTIVATION.

FLAT-TOP AERIAL. Aerial of which a major part is horizontal, as in the inverted-L type.

FLAT TUNING. Relative term indicating that the resonance graph of a circuit or piece of apparatus is not sufficiently sharply peaked or has too-gently sloping sides to serve its intended purpose satisfactorily. The resulting poor selectivity is characteristic of circuits of high decrement. See RESONANCE, SELECTIVITY.

F-LAYER. Region of ionized gases which exists at a variable height of 100–250 miles above the surface of the earth and was discovered by Appleton in 1925. In this region the pressure of the gases—which are probably mostly helium—is very low, and the ionization is very intense. The ionizing agent is ultra-violet radiation from the sun. Because of the low gas pressure in the F-layer, it is much less dependent on the ionizing influence than is the E-layer, in which the gas pressure is much higher. Recombination of the ions in the F-layer usually takes several hours after the sun has set, and re-ionization occurs very rapidly after sunrise.

As the formation of the F-layer depends upon the sun, its height and density vary diurnally, seasonally, and in accordance with sunspot activity. During the daytime the F-layer splits into two separate layers, designated F1 and F2; and during the night the F1, which is the lower sub-layer, disappears, leaving only the F2-layer.

The F-layer is responsible for the reflection of most waves in the high-frequency band, the critical frequency being higher during the day than at night time and lower in winter than in summer. See CRITICAL FREQUENCY, HIGH-FREQUENCY WAVE, IONOSPHERE.

FLEMING VALVE. Diode named after Sir Ambrose Fleming, who first showed that a diode could be used for the rectification of radio-frequency signals; a D.C. meter could thus be used to measure them. The term is no longer used. See DETECTION, DIODE, EDISON EFFECT, RECTIFIER.

FLEWELLING CIRCUIT. Super-regenerative circuit (Fig. 34) in which the quenching action is obtained from a grid-leak howl adjusted to a frequency near the upper limit of audibility. A grid-leak howl is due to the negative charge on the grid of a self-oscillating valve provided with grid capacitor and leak, this charge first building-up to the point at which it stops the valve from oscillating, then leaking away so that the valve re-starts.

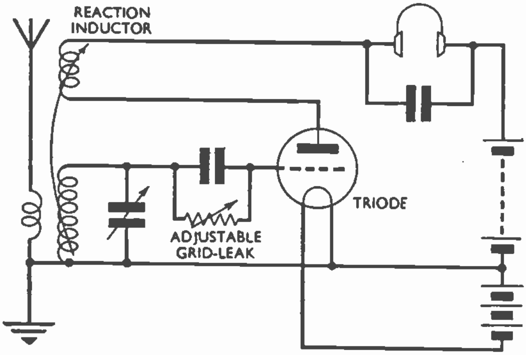


Fig. 34. Simplified diagram of the Flewelling circuit incorporating a variable grid-leak adjustment of the quenching frequency.

FLICKER EFFECT. In a valve, effect associated with shot noise. Flicker effect is caused by an intermittent change of emission at different places on the surface of the cathode, resulting in changes of electrode current. The consequent irregularities in output voltage are heard as noise from a high-gain amplifier. See SHOT EFFECT.

FLIP-FLOP CIRCUIT. Name popularly given to a MULTIVIBRATOR or RELAXATION OSCILLATOR.

FLOATING-CARRIER MODULATION. Modulation in which the amplitude of the carrier wave varies over large values according to the amplitude of the modulating wave, the modulation factor remaining substantially constant. The ratio of the sideband-wave amplitudes to the carrier amplitude remains constant, and the modulation envelope increases and decreases according to the variations of the modulating wave.

FLOATING-CARRIER MODULATOR. Modulator designed to vary the amplitude of both carrier and sideband waves in proportion to the instantaneous amplitude of the modulating wave. The proportionality is not exact, because, with no modulation, the carrier-wave amplitude is small but none the less finite. Fig. 35 shows a form of floating-carrier modulator. As the amplitude of the modulating wave increases, the inductor in the mains supply to the mains unit is more highly magnetized by the increased current taken by the modulating-wave amplifier. This decreases its impedance and raises the high-tension supply to the modulated amplifier, which, in turn, increases the carrier-wave amplitude. The sideband waves are similarly increased by the greater output from the modulating-wave amplifier. See AMPLITUDE MODULATION, FLOATING-CARRIER MODULATION, MAINS UNIT.

FLOATING SCREEN-GRID BIAS. Screen-grid bias supplied through a resistor from the high-tension supply. Fig. 36 distinguishes what is called floating screen-grid bias from the method in which a potential divider is used. In the latter circuit, variations in the screen-grid slope resistance or its impedance cause smaller changes in screen-grid voltage than when the floating-bias arrangement is used.

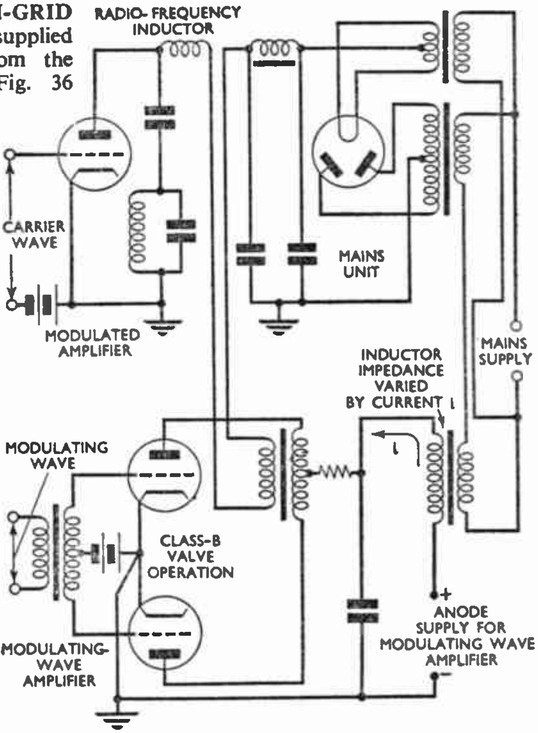


Fig. 35. Form of floating-carrier modulator. Increase in the modulating-wave amplitude reduces the impedance of an inductor in the mains-supply circuit to the mains unit; this is due to an increase in current *i*, corresponding to the reduced impedance, taken by the amplifier. As a result, the H.T. supply to the modulated amplifier is raised and the carrier-wave amplitude is increased.

Fig. 36c shows a circuit convenient when negative feedback is used. This circuit arrangement ensures that the variation of cathode potential due to

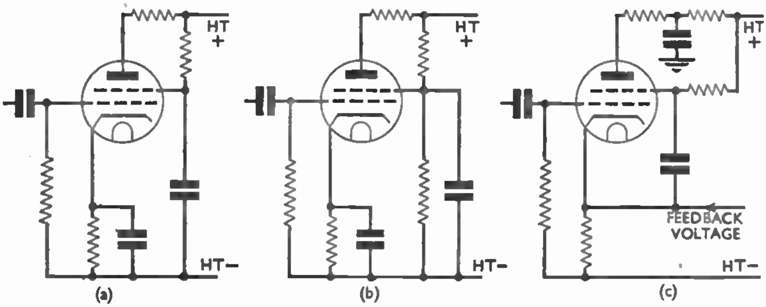


Fig. 36. Circuit arrangements in which (*a*) screen-grid bias may vary with variations in screen-grid slope resistance, and (*b*) bias is held more constant; (*c*) is a negative-feedback arrangement providing a floating screen-grid bias without introducing an alternating p.d. between screen grid and cathode.

feedback is communicated to the screen grid, so that the screen-grid/cathode potential remains constant. See AMPLIFIER, NEGATIVE FEEDBACK.

FLUCTUATION NOISE. See SET NOISE, SHOT EFFECT, THERMAL-AGITATION VOLTAGE.

FLUORESCENT SCREEN. Specially prepared surface of a cathode-ray tube which becomes luminescent when bombarded by an electron beam. See CATHODE-RAY TUBE.

FLY-BACK. In a cathode-ray tube, the return of the spot from the end of a trace to the starting point. This return is usually very rapid compared with the velocity of the forward trace. In television it is the rapid return of the spot from the end of one line or frame to the commencement of the next. See CATHODE-RAY TUBE.

FLYING-SPOT SYSTEM. Television system in which the scene to be sent out is rapidly scanned by a spot of light, the light reflected from successive parts of the scene being measured by a photocell.

FOCUSING. In a cathode-ray tube, the converging of the electron beam on a required area by electrostatic or magnetic means, or by the ionizing action of residual gas in the tube. See ELECTROSTATIC FOCUSING, GAS FOCUSING, MAGNETIC FOCUSING.

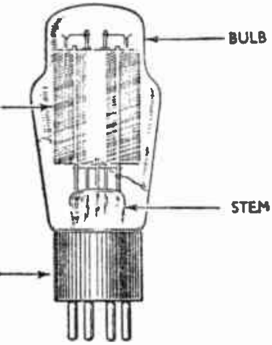


Fig. 37. Foot of a valve distinguished from the other three principal parts; the electrode structure in the example is that of a full-wave rectifier.

FOCUSING COIL. In a cathode-ray tube using magnetic focusing, the coil which focuses the beam by virtue of the magnetic field resulting from the direct current applied to the coil. See MAGNETIC FOCUSING.

FOCUSING ELECTRODE. In a cathode-ray tube or similar device, the electrode which controls the focus by virtue of the potential applied to the electrode. If this potential is variable, the focus is adjustable. See ELECTRON BEAM, ELECTROSTATIC FOCUSING.

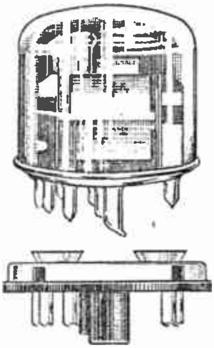


Fig. 38. An example of footless construction; a triode-hexode frequency-changer with electrode structure horizontally mounted on a glass disc.

FOOT. Part of a valve where the connexions to the electrodes are brought through to pins (Fig. 37). The pins fit into the valve holder. See FOOTLESS CONSTRUCTION.

FOOTLESS CONSTRUCTION. Term used to denote the method of bringing out the electrode connexions from a valve so that the capacitance between electrode connexions shall be less than when a foot is used (Fig. 38).

FOOT-POUND. British unit of work. It is the amount of work done when the point of application of a force of 1 lb. moves through a distance of 1 ft. in the direction of the force.

FORCED OSCILLATIONS. Oscillations which are maintained by a source of energy supply external to the oscillating circuit or system, and which have a frequency determined by this source of supply.

FORMER. Carrier or support, usually of insulating material, on which a coil of wire may be wound. For air-cored inductors it is usually circular in section, often a hollow tube. For resistors it may be circular or it may consist of a thin strip of rectangular section. A former with end-flanges or cheeks is called a spool. See FIXED INDUCTOR, FIXED RESISTOR, TRANSFORMER.

FORTUITOUS DISTORTION. Distortion due to irregularities in any part of a circuit or apparatus; in other words, distortion which cannot be classified. See DISTORTION.

FOUR-ELECTRODE VALVE. Synonym for TETRODE.

FOURIER ANALYSIS. Process of determining the number, amplitude, frequency and phase of the components in a given wave form. The French mathematician Fourier (1768–1830) showed that it was possible to synthesize any given repetitive wave form by adding together a number of sinusoidal wave forms, known as components or harmonics, of appropriate amplitude, frequency and phase. The components have frequencies which are simple multiples of the repetition frequency of the given wave form, which is known as the fundamental frequency.

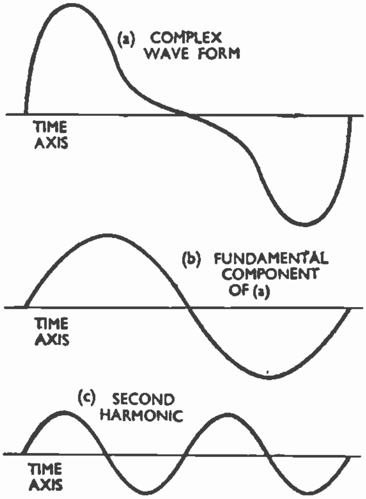


Fig. 39. Fourier analysis is a process of splitting up a complex wave form into a number of simple sine waves. In this diagram, for example, wave (*a*) is produced by mixing together the two waves (*b*) and (c).

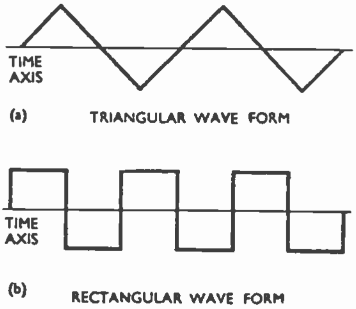


Fig. 40. It can be shown by Fourier analysis that an infinite number of harmonics is present in a wave such as (*a*) or (*b*); an approximation to a given wave form can be obtained, however, by adding the first 20 or so harmonics to the fundamental.

Wave forms without any abrupt changes in gradient have few components. For example, the wave form of Fig. 39a has only two components, and they are illustrated in Figs. 39b and c. The component in Fig. 39b has the same frequency as the original wave form and is a fundamental component, whereas the wave form of Fig. 39c has a frequency twice as great, and is known as a second harmonic.

It is possible for certain components (a fundamental even) to be missing from the results of a Fourier analysis; for example, only the even harmonics, 2nd, 4th, 6th, etc., may be present, the fundamental being absent. Something can be learnt of the harmonic composition of a wave by inspection of its shape. For instance, waves which are symmetrical about the time axis contain only odd harmonics, and those which are asymmetrical must contain some even harmonics, although odd ones may be present as well.

If a wave form has sharp changes in gradient, such as the triangular wave form (Fig. 40a), or the rectangular one of Fig. 40b, an infinite number of harmonics is present, but a good approximation to the given shape can be obtained by summation of the fundamental and, say, the first 20 harmonics. The greater the number of harmonics added, the more nearly does the result approximate to the triangular or rectangular shape.

Because of the large number of harmonics present, potentials of rectangular wave form are very useful for testing the linearity and frequency response of amplifiers. If the amplifier is good, its output wave form will be a good copy of the input wave form, having sharp corners; if the high-frequency response is poor, the upper harmonics are lost and the output wave form has rounded corners. But if the amplifier suffers from phase distortion at certain frequencies, the rectangular shape of the wave form is destroyed.

The human ear is able to make a Fourier analysis of complex sound waves to which it responds (see SPEECH AND HEARING), and it is able to appreciate the number and relative amplitudes of the components; but, in continuous sounds, it cannot detect any changes in the relative phases of the components. By changing these phases, it is possible to produce differing wave forms which sound the same to the ear.

FOUR-TERMINAL TRANSMISSION NETWORK. Synonym for QUADRIPOLE.

FOUR-WIRE CIRCUIT. Circuit used for two-way communication consisting of two pairs of wires, each pair of wires carrying a one-way communication in opposite directions. The arrangement overcomes difficulties that are experienced with a two-wire repeater designed to amplify speech in either direction equally, without instability. See TWO-WIRE CIRCUIT.

FRAME. In the cinematograph, one picture unit in the long sequence of units forming the film reel. To form a motion picture, the frames are projected on a screen in sequence and fast enough to give, through persistence of vision, the illusion of movement. In television, a frame is the picture or semi-picture resulting from one complete sequence of scanning. This scanning is repeated to form another frame, and about 50 frames a second are formed in high-definition television.

Between each frame, whether it be the cinema or television, the screen goes "dark" and no modulation of light is present. If the frequency of the frame repetition is not high enough, flicker results.

FRAME AERIAL. Synonym for LOOP-AERIAL.

FRAME DIRECTION-FINDER. Synonym for LOOP DIRECTION-FINDER.

FRAME-FREQUENCY. Frequency, in television, at which frames are repeated. In sequential scanning this must be not less than 16 per second, and is preferably 20 or over if flicker is to be avoided. In British high-definition television, which employs interlaced scanning, 50 frames per second are transmitted, although the picture-frequency is only 25 per second. See INTERLACED SCANNING, PICTURE-FREQUENCY, SEQUENTIAL SCANNING.

FRAME-SYNCHRONIZING SIGNAL. Series of impulses radiated by a television sender at the end of each frame. In a sequential-scanning system there is one such signal per picture, but in an interlaced system, such as that employed in the present B.B.C. high-definition service, there are two frame-synchronizing signals per picture.

The purpose of the frame-synchronizing signal is to ensure that the frame scanning in all receivers is precisely in step with that at the sender.

For satisfactory results, the receiver frame-frequency must be precisely equal to that of the sender; in addition, the two frequencies must be in phase. As the pictures in most modern television receivers are displayed on the screens of cathode-ray tubes, the need for frame-synchronizing impulses will here be explained in terms of such receivers.

The receiver frame-scanning generator is deliberately adjusted to operate at a frequency lower than the sender frame-frequency, and the frame-synchronizing signals are arranged to trip, or trigger, the receiver generator to cause the scanning spot to fly back to the top of the screen before it has completed its natural cycle. The spot then traverses the screen again, and is again returned to the top by the next frame-synchronizing impulse. In this way precise synchronism can be obtained.

There is usually a small range of receiver frame-generator frequency within which the frame-synchronizing signals are fully effective in securing synchronism.

The line-scanning generator is similarly "locked" at the correct frequency by line-synchronizing impulses radiated by the sender at the end of each line, and it is necessary that line scanning should continue normally throughout the duration of the frame-synchronizing impulse; if the line-scanning generator were to run free during the frame-synchronizing impulse, the generator would take an appreciable time to lock on the resumption of line-synchronizing signals, with the result that the first few lines of each frame would be distorted.

Thus the frame-synchronizing signal does not consist of a single broad pulse but is subdivided into a number of broad pulses in such a manner that there is a component at line frequency which can be used to trip the line-scanning generator to ensure continuity of line scanning during the frame-synchronizing signal. See BLOCKING OSCILLATOR, FRAMING, FRAMING OSCILLATOR.

FRAMING. Process of adjusting, in television, the frame synchronizing so that the picture falls properly on the vision screen. If the frame-frequency is out of synchronization with the sender frame-frequency, the picture may appear cut in two, with the lower portion at the top and the upper portion at the bottom of the screen, as indicated in Fig. 41.

Fig. 41. Example of the effect of incorrect framing on a received television picture.

This effect is caused by arrival of the frame-synchronizing impulse before the frame scan is complete. Under these conditions, the impulse will not trigger the oscillator and the frame time base will work on its own, the picture then drifting up or down the screen. Alteration of the scanning speed will allow the frames to drift until the time-base can be synchronized with the frame-synchronizing impulse.

FRAMING OSCILLATOR. Time-base circuit employing some form of saw-tooth generator providing the wave form necessary for deflecting the cathode ray in the vertical, or frame, direction. In modern television receivers a blocking oscillator or thyratron is almost universally employed.

At a predetermined instant, the length of scan being sufficient to have moved the spot right down the screen, the frame-synchronizing impulse is applied to the oscillator; this causes the cathode-ray beam to return rapidly to the original position. The process is repeated for every frame. See BLOCKING OSCILLATOR.

FRANKLIN AERIAL. Directive aerial employing multiple elements uniformly spaced along a line at right-angles to that of maximum radiation; it is thus a broadside array. The elements are vertical, several half-waves in length, radiation from alternate half-wave sections being suppressed (see HALF-WAVE SUPPRESSOR COIL). The array is characterized by giving maximum radiation in a horizontal direction.

FREE GRID BIAS. Term, now obsolete, describing any system for obtaining a grid bias without the use of a separate source of voltage such as a bias battery. The introduction of the indirectly heated cathode was of particular advantage to the circuit designer because it allowed him freedom to use a common heater source and yet supply different valves with different grid bias. See AUTOMATIC GRID-BIAS, CATHODE BIAS, GRID BIAS.

FREE OSCILLATIONS. Oscillations in a system containing capacitance, inductance and resistance, the values of which constants determine the frequency of the oscillations.

FREQUENCY. Measure of the rate at which a current or voltage alternates, or at which an electromagnetic radiation passes through one cycle. Unless a unit is specified, frequencies are assumed to be stated in cycles per second (c/s). The frequencies of low and medium rates of alternation, such as those of alternating currents used for power and sound reproduction, are conveniently stated in cycles per second, but as radio frequencies would involve clumsy figures in this unit they are stated in kilocycles per second and megacycles per second. A kilocycle is a thousand cycles, a megacycle is a million cycles.

Frequency is a fundamental characteristic of an alternating current, and has a direct bearing on the properties of the current and the methods used in handling it. The frequency is even more important in the case of high-frequency currents and the electromagnetic waves which they generate.

It is useful to have some mental picture of the whole spectrum of frequencies in common use. From about 25 c/s up to something of the order of 10,000–15,000 c/s, currents represent audible tones or harmonics and are described as audio-frequency.

Higher frequencies enter the radio-frequency range; the longest wavelengths which have been used are, in fact, equivalent to frequencies at the top of the audio-frequency scale. The medium-wave broadcasting waveband embraces frequencies ranging from about 550 to, perhaps, 1,600 kc/s.

Next is the range of short waves; the frequency corresponding to a wavelength of 100 metres is 3 Mc/s, and that corresponding to 10 metres is 30 Mc/s. In the microwave range, 10 cm. corresponds to a frequency of 3,000 Mc/s, and 1-cm. waves have a frequency of 30,000 Mc/s. Waves of millimetre wavelength may necessitate the use of a still bigger frequency unit; a wavelength of a millimetre corresponds to a frequency of 300,000 Mc/s.

A frequency of 300,000,000,000 c/s is certainly an impressive figure, but it is only part of the scale of the electromagnetic radiations which are known. At the wavelength of infra-red or heat rays, the frequency is of an order that calls for eight noughts even when expressed in megacycles, and visible light is of a still greater frequency; X-rays and gamma rays have frequencies thousands of times higher still. See ALTERNATING CURRENT, WAVELENGTH.

FREQUENCY BAND. Term expressed quantitively by specifying two frequencies which are the limits of the range of frequencies lying between them. The term is used a great deal in connexion with transmission theory and practice. Modulation of a carrier produces sideband waves of different frequencies and these can be said to lie within a frequency band. See CUT-OFF FREQUENCY, SIDEBAND WAVE.

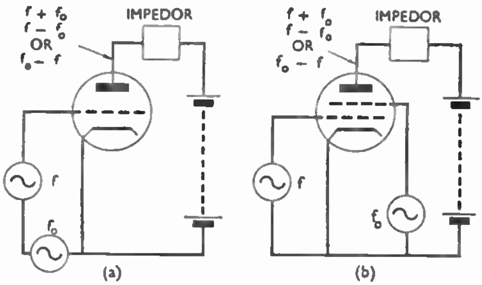


Fig. 42. Simplified diagrams which illustrate the operation of frequency-changer valves; (*a*) shows the circuit of non-linear and (*b*) that of linear modulation systems.

FREQUENCY-CHANGE OSCILLATOR. Synonym for BEAT OSCILLATOR.

FREQUENCY-CHANGER. Amplitude modulator of any kind, including any circuit which produces beating. See BEATING, FREQUENCY-CHANGER VALVE, MODULATOR.

FREQUENCY-CHANGER VALVE. Valve producing, at one electrode, waves which have a frequency that is different from those of waves applied to another electrode. Locally generated oscillations are essential to the process (see FREQUENCY-CHANGING). A distinction must be drawn between the circuits of a frequency-changer valve and those of, for instance, a multivibrator. Both circuits produce waves of changed frequency, but the multivibrator and similar devices are frequency multipliers, not frequency changers (see FREQUENCY MULTIPLICATION).

The frequency-changer, in using a local oscillator, is not limited to producing harmonic waves from a fundamental as is the multivibrator; given locally generated oscillators, the frequency-changer can produce from one wave a new wave of any frequency, within obvious circuit limitations (see LOCAL OSCILLATOR). Frequency-changers are of two types: those which are based on non-linear, or additive, modulation, and those that are based on linear, or multiplicative, modulation (see NON-LINEAR MODULATION).

Fig. 42 shows the distinction, and how, in non-linear modulation, the wave whose frequency is to be changed is connected in series with the local-oscillator wave. In contrast, the linear-modulator type of valve must have at least four electrodes so that the anode current may be modulated by the two waves of different frequency which are applied to different grids.

The frequency-changer valve is thus essentially a modulator, and frequency changing is a process of modulation (see MODULATION). In other words, if f is the frequency of the wave which is to be changed in frequency and f_o the frequency of the local oscillator, then the waves of changed frequency are sideband waves. These sideband waves are of frequencies $(f+f_o)$ and $(f-f_o)$ or (f_o-f), depending on whether f is greater or less than f_o (see SIDEBAND).

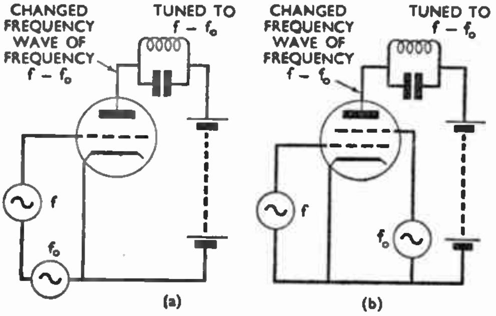


Fig. 43. Frequency-changing circuits in each of which a filter (shown as a tuned circuit) attenuates all but the chosen frequency-changed wave; (*a*) is for non-linear and (*b*) for linear modulation.

In all frequency-changers it is probable that besides the sideband waves, their harmonics and other modulation products, the local-oscillator wave and the input waves will also appear in the output. For this reason a filter (Fig. 43) must be used in the output circuit to attenuate all waves but that which is chosen as the frequency-changed wave. This is commonly a first-order sideband.

The non-linear modulator type of frequency-changer (Fig. 42a and Fig. 43a) is sometimes called an anode-detector frequency-changer (or plate detector in American textbooks). It has the advantage of causing less background noise, and the simple triode may be used. The non-linear type of frequency-changer has the disadvantage that the two oscillations, when close together in frequency, may, in some circumstances, come into synchronism (see COGGING). For this reason most superheterodyne receivers use the linear-modulator type of frequency-changer. The basic form of this valve is a tetrode (Fig. 42b and Fig. 43b).

The multiplication of electrodes to form hexodes, heptodes, octodes and triode-hexodes is necessary in order to isolate the signal-frequency and oscillator circuits from one another by minimizing inter-electrode capacitance (see INTER-ELECTRODE CAPACITANCE); and, secondly, to provide electrodes for the generation of oscillations in the valve itself, thus dispensing with the necessity for another valve to generate the (local) oscillations essential to frequency-changing. Thus Fig. 44 shows several possible variations of the frequency-changer valve in its different forms. It is essential to realize that all are based upon the principle of linear modulation, as shown in Fig. 43b.

In Fig. 44a the hexode is used with a local oscillator, the screen grids G_2 and G_4 shielding the control grid from the grid energized from the local oscillator. In Fig. 44b the heptode generates its own oscillations. In Fig. 44c the triode-hexode consists of a hexode used for frequency-changing and a separate triode for generating the local oscillations, all the electrodes being in one bulb and a common cathode sufficing for both oscillator and frequency-changer. Variations upon the basic schemes of Fig. 44 are used; for example, suppressor grids may be

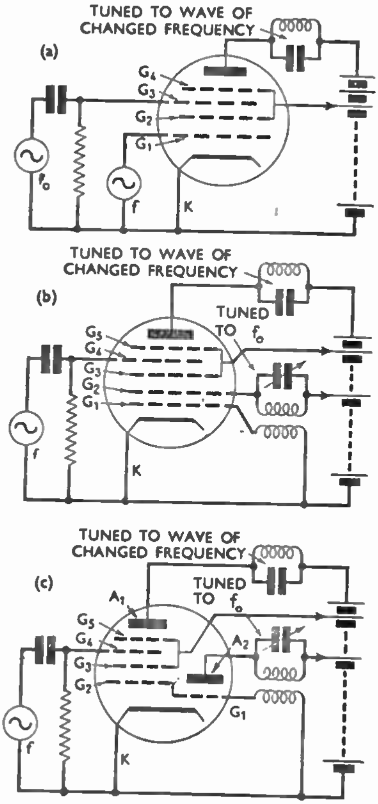


Fig. 44. Frequency-changer valves shown are: (*a*) a hexode using an external local oscillator f_o, (*b*) a heptode which illustrates how oscillations may be generated in the frequency-changer valve, and (*c*) a triode-hexode in which the triode generates oscillations by the use of a cathode common to the hexode.

used to give frequency-changers pentode characteristics.

Frequency-changer valves are designed as variable-mu valves. This is advantageous in certain cases. Thus, by using the grid-leak connexion of Fig. 44a, changes of oscillator voltage tend to alter the conversion conductance in a compensatory way, thus tending to keep constant the level of the wave of changed frequency. See BEATING, BEAT RECEPTION, CONVERSION CONDUCTANCE, VIRTUAL CATHODE.

FREQUENCY-CHANGING. Process in which a wave of one frequency has another frequency added to, or subtracted from, it to produce a wave of changed frequency. The process of modulation is essential to that of frequency-changing. Thus, if a wave of frequency f_1 is amplitude-modulated by a wave of frequency f_2, the modulated wave contains waves of frequencies $f_1 + f_2$ and $f_1 - f_2$ (or $f_2 - f_1$) as well as f_1. In suppressed-carrier modulation, the modulated wave contains waves of frequencies $f_1 + f_2$ and $f_1 - f_2$ (or $f_2 - f_1$). The waves of frequency $f_1 + f_2$ and $f_1 - f_2$ (or $f_2 - f_1$) are waves of changed frequency; in fact, they are sideband waves.

Thus, basic to all frequency-changing is a process of amplitude modulation (though any other form of modulation would suffice, amplitude modulation is generally used). In a superheterodyne receiver, the signal wave is a modulated wave containing frequencies $f_c + af_m$, $f_c - af_m$, $f_c + bf_m$, $f_c - bf_m$, and so on, where f_c is the carrier wave and af_m, bf_m the modulating-wave frequencies. The frequency-changing in the frequency-changer valve produces, among others, waves of frequency $f_c - f_o + af_m$, $f_c - f_o - af_m$, and so on, where f_o is the oscillator frequency. Taking $(f_c - f_o) = f_{1c}$, we see that a new carrier wave with a frequency of f_{1c} is produced; in other words, the modulated wave has its carrier frequency changed by subtracting a constant frequency from the signal carrier wave. The new modulated wave contains waves of frequency $f_{1c} + af_m$, $f_{1c} - af_m$, $f_{1c} + bf_m$, $f_{1c} - bf_m$ and so on. Many waves are produced in frequency-changing, but those wanted are selected by a filter.

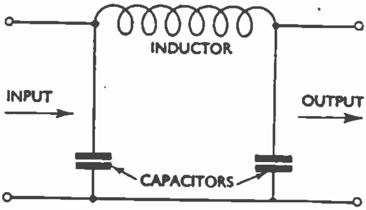


Fig. 45. Frequency-discriminating filter; the values of the capacitors and inductors are governed by the frequency of operation required, the inductor sometimes being iron-cored.

Beating constitutes frequency-changing and can be classified as a system of amplitude modulation (of a non-linear type). Circuits to produce non-linear modulation and beating are identical, except that the wave selected by the filter is different. Modulation is common to both. Thus frequency-changing, in all its aspects, is based on modulation. See AMPLITUDE MODULATION, BEATING, FREQUENCY-CHANGER, FREQUENCY-CHANGER VALVE, MODULATION, SIDEBAND.

FREQUENCY CONVERSION. Synonym for FREQUENCY-CHANGING.

FREQUENCY CONVERTER. Synonym for FREQUENCY-CHANGER.

FREQUENCY DEMULTIPLICATION. See FREQUENCY DIVISION.

FREQUENCY DEVIATION. Maximum value of the frequency swing of a frequency-modulated wave. Maximum value occurs when the modulating wave has its maximum amplitude. See FREQUENCY MODULATION.

FREQUENCY-DISCRIMINATING FILTER. Network containing reactances, and perhaps resistances, designed to pass a particular frequency or frequency band more easily than other frequencies. Fig. 45 illustrates a low-pass filter which allows low frequencies to pass with little attenuation but discriminates against high frequencies. See BAND-PASS FILTER, FILTER, HIGH-PASS FILTER, LOW-PASS FILTER.

FREQUENCY DISCRIMINATOR. Discriminator in which the output is substantially proportional to the variation of the frequency of a wave from a mean value. In many circuit applications, notably automatic tuning and frequency modulation, the frequency of the waves generated by an oscillator must be maintained substantially constant. A frequency discriminator does this, and one form of such a discriminator is shown in Fig. 50. The term is used to describe any device which converts a frequency-modulated wave into an amplitude-modulated wave. See AUTOMATIC TUNING-CONTROL, FREQUENCY MODULATOR.

FREQUENCY DISTORTION. Term commonly used for ATTENUATION DISTORTION.

FREQUENCY-DIVIDER. Device which produces, at its output terminals, a wave which has $1/n$ times the frequency of a wave applied to its input terminals, n being a whole number. The circuit of Fig. 46 illustrates one form of frequency-divider.

The gain of the amplifier must be sufficient to start the process, which is otherwise automatic. See FREQUENCY DIVISION.

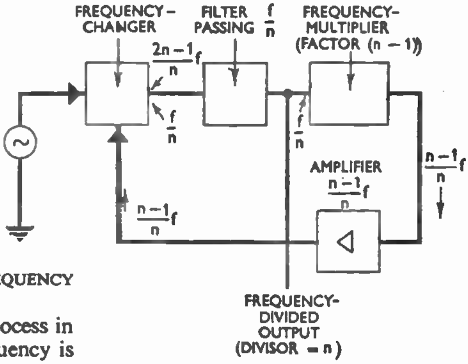


Fig. 46. Schematic diagram of one form of frequency-divider, where f is the frequency of the wave applied to the input terminals of the frequency-changer, and f/n is the frequency of the output, n being a whole number.

FREQUENCY DIVISION. Process in which a wave of a given frequency is made to produce a wave of lower frequency, the ratio of the lower to the higher frequency being a whole number. Thus, if the original wave has a frequency f, the frequency-divided wave has a frequency f/n, where n is a whole number. See FREQUENCY-DIVIDER.

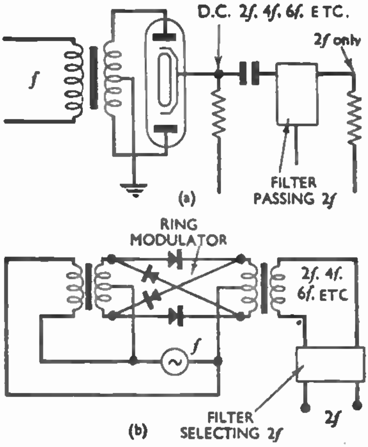


Fig. 47. Two ways in which a frequency-doubler may be set up: (a) by means of a full-wave rectifying valve, and (b) by a modulation process.

FREQUENCY-DOUBLER. Device which produces a wave at its output terminals that is exactly twice the frequency of a wave applied to its input terminals. Any device producing a strong second harmonic of a wave is a frequency-doubler. Any modulator, in which the modulating and carrier waves have the same frequency, is also a frequency-doubler. A filter is used to select the wave of doubled frequency (Fig. 47). See FREQUENCY-CHANGING.

FREQUENCY-DOUBLING. Process occurring in any device in which the output contains a strongly marked component having twice the frequency of the input signal. A full-wave rectifier gives frequency-doubling; so does an electromagnetic transducer (a power-transformer between electrical, mechanical or acoustic communication-system components) when the polarizing current is inadequate. Loudspeakers with straight-sided diaphragms are prone to frequency-doubling, and exponentially curved cones were introduced to minimize this effect. See FREQUENCY-DOUBLER.

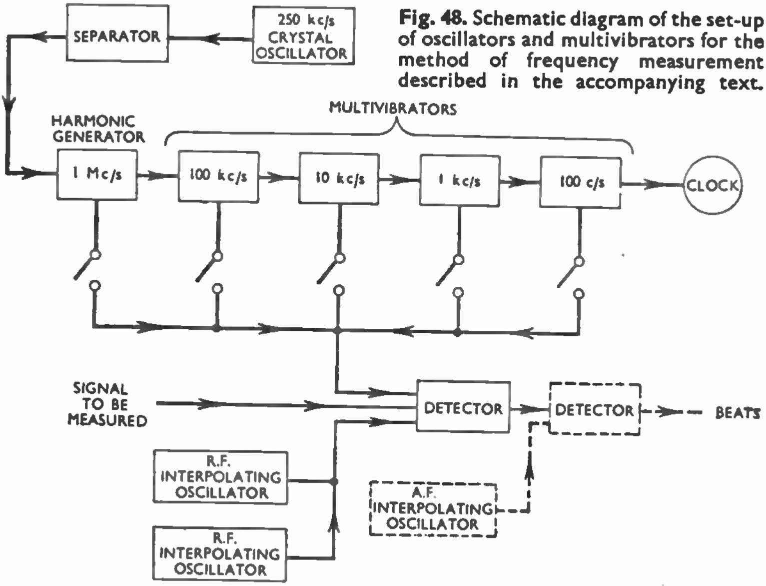


Fig. 48. Schematic diagram of the set-up of oscillators and multivibrators for the method of frequency measurement described in the accompanying text.

FREQUENCY MEASUREMENT. Term usually implying the act of measuring the frequency of electromagnetic waves radiated by a sender; but it may also be applied to audio frequencies. It is more usual to determine the frequency of an electromagnetic wave than its wavelength. Wavelength and frequency are related thus:

$$\text{frequency} = \frac{\text{velocity}}{\text{wavelength}}.$$

The velocity is fixed and equal to 3×10^{10} cm./sec. Hence it is easy to determine frequency if the wavelength is known, and vice versa. For example, the wavelength corresponding to 1,500 kc/s is given by $\frac{3 \times 10^{10}}{1{,}500 \times 10^{3}} = 2 \times 10^{4}$ cm. = 200 metres.

Frequency is rarely determined absolutely; it is usually obtained by comparison of the unknown frequency with a known one. The theory of one method of frequency measurement can be understood from Fig. 48. The accuracy of this method depends on the accuracy of the thermostatically controlled quartz-crystal oscillator, and this can give a frequency stability as high as a few parts in a million.

The quartz-crystal oscillator may operate at 250 kc/s, and feeds into a separator stage, the anode circuit of which contains an inductance-capacitance circuit tuned to 1 Mc/s, that is, the fourth harmonic of the crystal frequency. The next stage is a harmonic generator operating with an input of 1 Mc/s, and providing an output very rich in harmonics.

Part of the harmonic-generator output is fed to the input of a multivibrator, the constants of which are chosen so that the fundamental frequency of oscillation is approximately 100 kc/s. By this means the 1-Mc/s output "locks" the frequency of the multivibrator, and its output contains components spaced accurately at 100-kc/s intervals over a very wide frequency range.

Part of the output of the 100-kc/s multivibrator is used in a similar circuit arrangement to lock the frequency of a 10-kc/s multivibrator. This circuit arrangement is continued as far as a 100-c/s multivibrator, and part of the output of this is sometimes used to control an electric clock. The accuracy of time-keeping by the clock thus gives a check on the accuracy of the entire equipment.

The equipment also includes an oscillator with variable tuning known as an interpolating oscillator. Its tuning dial is calibrated in terms of frequency, and its output is fed into a detector stage together with the signal to be measured and the output of the various multivibrators, which may be selected as desired by means of keys.

The measurement is made as follows: it is assumed that the frequency of the signal to be measured is known roughly (from, say, its position on the tuning dial of a receiver). The signal is applied to the detector and the interpolating oscillator is tuned until audible beats between the two signals are obtained at the output of the detector. The interpolating oscillator must now be accurately calibrated at and near this setting by the use of the multivibrators.

First, the interpolating oscillator is accurately calibrated at the nearest multiple of 1 Mc/s by heterodyning it with the output of the 1-Mc/s harmonic generator. Next, the output of the 100-kc/s multivibrator is added and the interpolating oscillator is accurately calibrated at the multiple of 100 kc/s nearest the frequency of the unknown signal. Further multivibrators can be switched in, and the position of the signal to be measured on the dial of the interpolating oscillator can be determined as accurately as desired.

If the frequency of the signal to be measured does not fall within the range of the interpolating oscillator, beats may be obtained between the signal and one of the harmonics of the interpolating oscillator, and the frequency measurement may be carried out as previously described, the final frequency reading being multiplied by the order of the harmonic used.

To minimize this additional labour, two interpolating oscillators are often employed, one covering long and medium waves on fundamental or second harmonic and the other covering the greater part of the short-wave range in a similar manner.

When the frequency has been determined to the nearest kc/s, the measurement may be continued to a greater degree of accuracy with the aid of an accurately calibrated audio-frequency oscillator. To do this, the signal is heterodyned with the nearest multiple of 1 kc/s and the beat note resulting in the detector output is applied to a second detector together with the output of the audio-frequency oscillator, which is adjusted to produce zero beat at the output of the second detector.

The reading of the A.F. oscillator is then noted and is added to or subtracted from the frequency given in the early part of the measurement, depending whether the multiple of 1 kc/s is lower or higher than the frequency to be measured. By this means, frequency determinations that are accurate to within a few parts in a million can be made.

FREQUENCY METER. Synonym for WAVEMETER.

FREQUENCY MODULATION. System of modulation in which the frequency of the carrier wave is changed in accordance with the amplitude of the modulating wave, the amplitude of the frequency-modulated wave remaining unchanged. Fig. 49 shows a sinusoidal modulating wave and the resulting frequency-modulated wave. The important quantities relevant to frequency modulation are: (1) The difference between the carrier-wave frequency and instantaneous frequency of the modulated wave; this is the frequency swing. (2) The maximum value of the frequency swing; this occurs when the modulating wave has its maximum amplitude, and is called the frequency deviation. (3) The ratio of the frequency swing to the frequency of the modulating wave. This is called the modulation index.

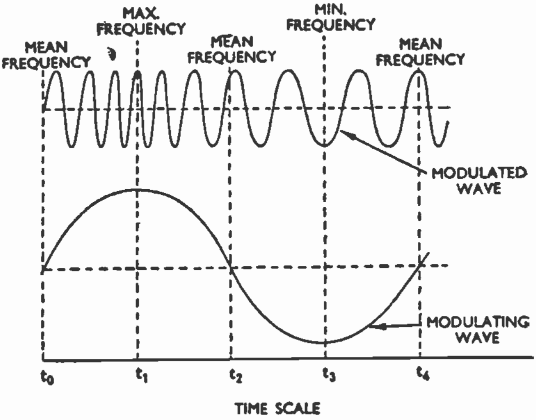


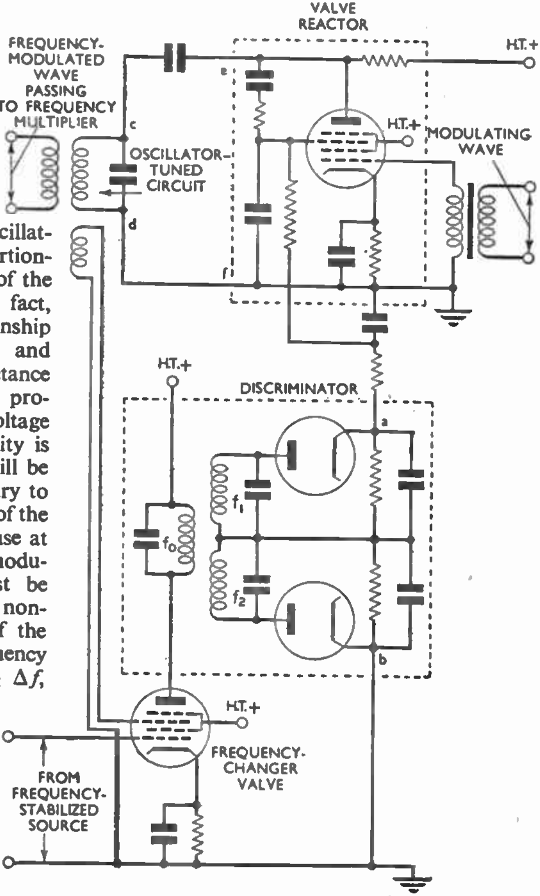
Fig. 49. Diagrams which illustrate the principle of frequency modulation by showing a frequency-modulated wave in relation to the (assumed) sinusoidal modulating wave. They are not, however, representative of quantities used in normal practice.

The sideband waves produced during frequency modulation have frequencies $f_c + f_m$, $f_c - f_m$, $f_c + 2f_m$, $f_c - 2f_m$, $f_c + 3f_m$, $f_c - 3f_m$, and so on to infinity. The amplitude and frequency of the sideband waves is determined by the value of the modulation index. Thus the band of frequencies taken up by a frequency-modulated wave is much greater than that taken up by an amplitude-modulated wave. There are notable advantages in using frequency modulation, in spite of the wider sidebands; for example, the signal-to-noise ratio is improved. See FREQUENCY MODULATOR, PHASE MODULATION, SIDEBAND WAVE.

FREQUENCY MODULATOR. Modulator which changes the frequency of a carrier wave in accordance with the amplitude of a modulating wave. The amplitude of the modulated wave remains substantially constant. Fig. 50 shows a form of frequency modulator using a valve reactor. The input impedance of its terminals *e* and *f* has the nature of an inductance and the value of this inductance is determined by the grid-cathode potential of the valve. Thus the tuned circuit of the oscillator (the valve itself is not shown) is in parallel with what is, in effect, a large inductance.

The value of this inductance is controlled by the voltage on the grid of the valve reactor. This voltage is varied by the modulating wave and so the effective inductance in parallel with the oscillator-tuned circuit changes in accordance with the voltage of the modulating wave. This implies that

Fig. 50. Frequency modulator using a valve reactor and incorporating arrangements to stabilize the frequency of the oscillator.



the frequency of the oscillating circuit varies proportionately with the voltage of the modulating wave. In fact, the non-linear relationship between grid voltage and effective inductive reactance of the valve reactor prohibits a large grid-voltage change if proportionality is to be maintained. It will be noted that it is necessary to multiply the frequency of the modulated wave, because at the output from the modulator the change must be small owing to the non-linear characteristics of the valve reactor. If a frequency changes from *f* to *f* ± Δ*f*, multiplying by *n* produces *nf* ± *n*Δ*f*.

Such a circuit, by itself, would not in the absence of modulation maintain a constant oscillator frequency. Thus, the slightest change in the constants of the valve reactor would alter the oscillator frequency and the carrier-wave frequency would drift. This is most undesirable, and the discriminator shown in Fig. 50 controls the oscillator frequency within fine limits. The frequency-changer valve produces an output frequency f_o determined by the difference between a stabilized-frequency source and the oscillator frequency.

The coupled circuits of the discriminator are tuned to frequencies slightly greater and slightly less than f_o. Thus the rectifiers produce potentials across *a* and *b* which are zero when f_o has the correct value. If f_o rises or falls in frequency due to the oscillator changing its frequency, these steady potentials are developed across *a* and *b* in one sense or the other. These potentials change the screen-cathode potential of the valve reactor so as to adjust the inductive impedance across *e* and *f* to a value to maintain f_o, and hence the oscillator frequency, at a constant value.

FREQUENCY MULTIPLICATION. Process whereby a wave is produced which is *n* times the frequency of the wave from which it is produced, *n* being a whole number. If a wave has a frequency *f*, it is possible to generate from it waves having frequencies 2*f*, 3*f*, 4*f* and so on. Any one of these waves is a frequency-multiplied wave and may be selected by a filter. See FREQUENCY-MULTIPLIER.

FREQUENCY-MULTIPLIER. Device which produces a wave of frequency *nf* at its output terminals when a wave of frequency *f* is applied to its input terminals, *n* being a whole number. A recognized form of frequency-multiplier consists of a rectifier which distorts the input wave and a filter which selects the desired harmonic of the distorted wave created (Fig. 51a). The rectification of a wave produces waves having frequencies 2*f*, 4*f*, 6*f* and so on; any one of these may be selected by a filter. Generally the greater the frequency of the harmonic, the less its amplitude (see FOURIER ANALYSIS). Any distorting device produces harmonics (Fig. 51b). The saw-toothed wave produces frequencies 2*f*, 3*f*, 4*f*, 5*f* and so on. The multivibrator can be used as a frequency multiplier. See FREQUENCY DIVIDER, FREQUENCY MULTIPLICATION, HARMONIC DISTORTION, MULTIVIBRATOR, RECTIFICATION.

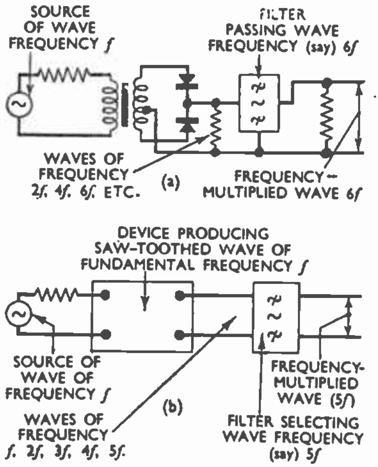


Fig. 51. Circuit of a recognized form of frequency-multiplier (*a*). Harmonics are produced by any distorting device as, for example, that shown at (*b*).

FREQUENCY OF INFINITE ATTENUATION. Frequency at which the attenuation of certain types of filter sections would be infinite if the elements composing the section had zero loss. A filter section of the so-called "m-derived" type is shown in Fig. 52, and this has a frequency of infinite attenuation associated with it. See FILTER.

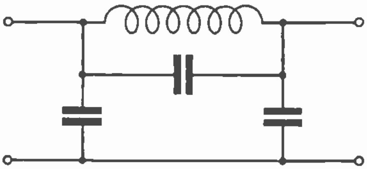


Fig. 52. Diagram of the "m-derived" filter, with which is associated a frequency of infinite attenuation.

FREQUENCY RESPONSE. Variation in gain or loss of a component or piece of apparatus as frequency is varied over its working range. If the gain or loss is not constant, the response characteristic of the component is usually exhibited as a curve obtained by plotting the output against frequency.

FREQUENCY STABILIZATION. Reduction to a minimum of the frequency drift of an oscillator. When oscillation is maintained in a circuit by means of a valve supplied with current from batteries or a mains rectifier, the frequency varies from the moment of switching on.

The magnitude of the frequency deviation, or drift, depends on a number of factors and may be as much as 2,000 parts in a million. An oscillator with a drift as great as this is said to have poor stability, whereas one in which the fluctuations amount to a few parts in a million is said to have great frequency stability, the process of reducing the drift being termed frequency stabilization.

In most practical cases, frequency drift is undesirable or inadmissible. In small laboratory oscillators it reduces the accuracy of calibration, and, in oscillators used as carrier sources in senders, it may cause interference with other radio senders.

For the purpose of listing the chief causes of frequency drift, the oscillator may be regarded as a frequency-determining network and a maintaining system, both of which may cause drift. That due to the maintaining system may be caused by changes of electrode voltages and variations with temperature of the valve characteristics, but it has been established that these factors rarely cause fluctuations in excess of 20 parts in a million.

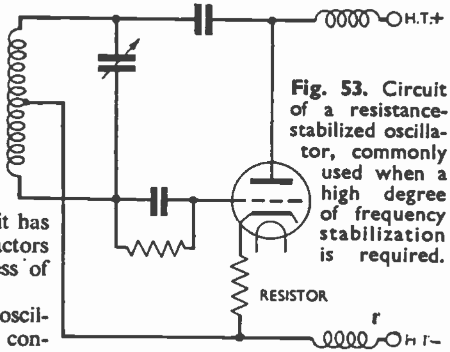


Fig. 53. Circuit of a resistance-stabilized oscillator, commonly used when a high degree of frequency stabilization is required.

The chief cause of drift is the oscillatory circuit itself. This usually consists of an inductor and a capacitor, and any changes in inductance or capacitance cause fluctuations in frequency. Changes in inductance or capacitance as great as 1,000 parts in a million may result from the following factors, given in the order of their relative importance:

- variation in atmospheric temperature;
- temperature variation in the conductor only;
- ageing of the constructional materials; and
- change of atmospheric pressure.

It is the purpose of stabilization to reduce the effects of these factors to a minimum.

The most obvious way of stabilizing inductance is to place the inductor in an oven the temperature of which is automatically kept constant. This method is used in master oscillators employed as carrier sources for senders.

If the temperature of an inductor changes, the resistance, the self-capacitance and the inductance all vary. Although each of these three changes affects the frequency of oscillation, it is the change in inductance which produces the major effect and the purpose of inductance stabilization is to render the inductance independent of temperature.

One method of stabilization is to maintain the dimensions of the inductor as constant as possible, either by applying constraint to conductors having normal expansion properties so as to keep the diameter and length as constant as possible, or by making the former from material having a low expansion coefficient, with special means of retaining adhesion between conductor and former. The logical development of the latter method is by coating the conductor with an electrolytic deposit or by spraying a former of very low temperature coefficient.

A second method of inductance stabilization is by using a design in which the inductance variation caused by a change in the diameter of the coil is corrected automatically by the change in length. This may be obtained by use of a formerless coil in which the conductor is stressed deliberately to give a particular ratio of radial/axial expansion, or by a coil wound on a former having such expansion coefficients in the radial and axial directions as to give compensation.

The capacitance of most commercial

capacitors changes at the rate of 160 parts in a million for a change in temperature of 1 deg. Centigrade. The types consisting of silver deposited on mica are better, and have a change of the order of 40 parts in a million per degree Centigrade. It is possible, however, to arrange for the variation of inductance to compensate for the variations in capacitance, and this is quite a satisfactory method of stabilization for an oscillator designed to work at one frequency only.

Capacitors with low temperature coefficients of capacitance can be designed by using iron-nickel alloy plates and frame to eliminate expansion effects, or by using a similar frame, with brass plates sliding in grooves, in order to maintain the area/air-gap ratio constant. Another method is to use a bimetallic expansion device to vary the air-gap so as to compensate for the increase in effective area of the plates.

A capacitor may be stabilized in the same way as an inductor by placing it in a thermostatically controlled oven.

Although the effects of the maintaining circuit on the frequency are not so important as the effect of temperature variation on the oscillatory circuit, it is necessary to adopt some means of stabilization where the highest degree of stability is required. The following are the chief methods of stabilization applied to the maintaining system:

1. The reduction of grid current to a very small value by the application of grid bias, preferably by automatic means.

2. Increasing the anode-circuit resistance either by the use of a valve of high r_a (anode A.C. resistance), or by the insertion of an additional series resistor. This is known as resistance-stabilization and the circuit of an oscillator employing this principle is illustrated in Fig. 53.

3. The use of a tuned circuit with a high C/L (capacitance-to-inductance) ratio. This tends to reduce the harmonic content of the oscillator output and to stabilize frequency.

4. Making the oscillatory circuit of low resistance.

5. Using a stabilizing reactance. An improvement in stability may be obtained by including in the circuit a reactance designed to neutralize the effect of the reactance of the maintaining system.

6. Using a very close coupling between anode and grid circuits.

7. Equalizing the resistance in the inductive and capacitive branches of the oscillatory circuit.

Possibly the best method of stabilizing an oscillator designed to operate at one frequency only is by the use of a quartz crystal to control the frequency. Certainly, this is the only method capable of ensuring stability of the order of a few parts in a million (see CRYSTAL OSCILLATOR).

Alternatively, a device may be designed in which any deviations of frequency from the desired value gives rise automatically to a restoring action which tends to eliminate the deviation. This involves the use of a stabilized oscillator as a frequency standard, and the correction may be applied by mechanical or electrical means. A system in which the inductance or capacitance is varied by mechanical means has the disadvantage of requiring appreciable time for its action, but the electrical system, in which the controlling agent is a potential applied to the grid of a valve, is superior in this respect.

FREQUENCY-STABILIZED OSCILLATOR. Oscillator in which special precautions have been taken to minimize frequency drift from the causes mentioned under the heading FREQUENCY STABILIZATION. For example, variations in inductance and capacitance with temperature can be minimized by special design of inductors and capacitors. See OSCILLATOR.

FREQUENCY SWING. In a frequency-modulated wave, the positive difference between the maximum or minimum frequencies of the frequency-modulated wave and the carrier wave. In general practice, the frequency swing is of the order of 150 kc/s and the carrier-wave frequency, 30–50 Mc/s. See CARRIER WAVE, FREQUENCY MODULATION, MODULATED WAVE, PHASE MODULATION.

FULL LOAD. Load resistance which equals the internal resistance of a source of power. In Fig. 54 the condition shown ensures that the maximum power is delivered to the load; thus the load is the full load of the generator. In another sense, full load might mean the maximum load which could be put across a generator without damage. Note that if the mains load "matched" the generator, the mains voltage would vary 2 : 1 between full and no load. See MATCHING.

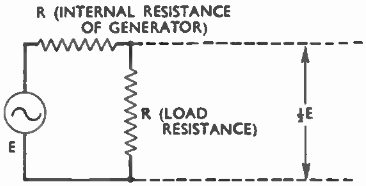


Fig. 54. The full load, considered in terms of power, of a generator is that which matches the internal resistance of the generator.

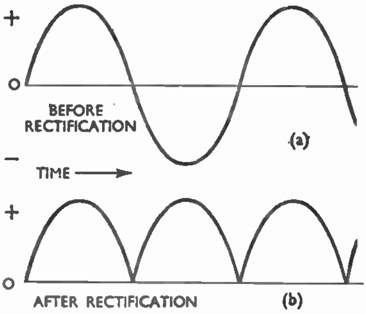


Fig. 55. In full-wave rectification, each half-cycle of the wave is used to produce a unidirectional current; if wave (*a*) is reversed every half-cycle, the wave shown at (*b*) is produced.

FULL-WAVE RECTIFICATION. Method of rectification in which unidirectional current is produced during each half-cycle of the wave rectified. The diagrams of Fig. 55 illustrate the result of full-wave rectification; they should be compared with that illustrating half-wave rectification elsewhere. It should be noted that the same wave form would be obtained if alternate half-cycles of the wave were reversed (see MECHANICAL RECTIFIER).

In full-wave rectification, the lowest

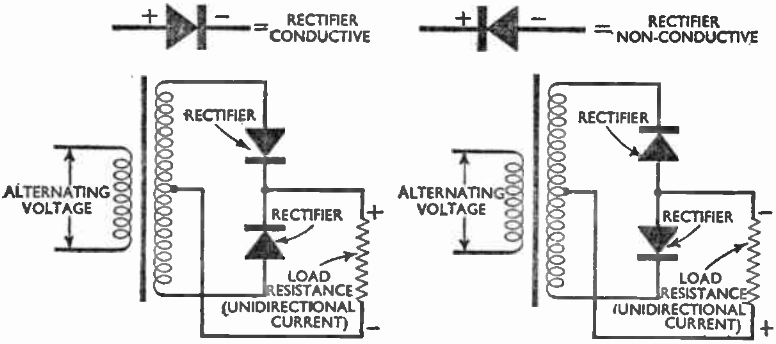


Fig. 56. Basic circuit for full-wave rectification. The rectifier elements are conductive alternately for each half-cycle of the voltage across the transformer secondary, thus the current in the load is always in the same direction.

frequency of the alternating components in the rectified current is twice the frequency of the wave which is rectified.

In half-wave rectification, the lowest frequency of the alternating components in the rectified current is equal to the frequency of the wave which is rectified. See HALF-WAVE RECTIFICATION.

FULL-WAVE RECTIFIER CIRCUIT. Rectifier circuit arranged so that unidirectional current is produced during each half-cycle of the wave rectified. The accompanying diagrams show typical circuits for producing full-wave rectification. In Figs.. 56 and 57, as the voltage across one rectifier acts in one direction, it acts in the opposite direction across the other so that only one rectifier is conductive at a time. Each rectifier, however, conducts in the same direction, so that unidirectional current results.

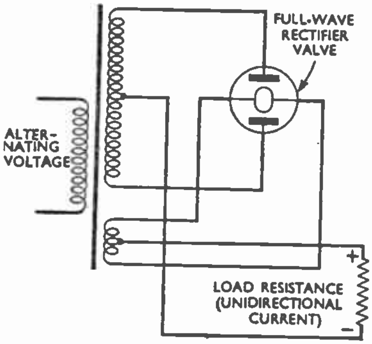


Fig. 57. Connexions of a full-wave rectifier valve. The circuit is fundamentally similar to that of Fig. 56.

The circuit can be looked upon as one in which the two rectifiers act automatically to reverse the circuit path which terminates in the load resistance. It can be compared with the circuit (Fig. 58) of a mechanical rectifier for commutator modulation to show an exact resemblance when modulating and modulated waves have the same frequency. Note that no direct current flows in the secondary of the transformer; this is advantageous because it ensures that the core of the transformer is not permanently magnetized in one or another sense. Bridge connexion of rectifiers is shown in Fig. 59.

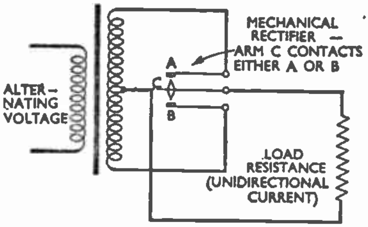
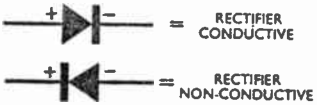


Fig. 58. Circuit of a full-wave mechanical rectifier. Contact *C* closes with *A* or *B* at the instant the alternating voltage is zero, and a unidirectional current flows in the load and in one half or the other of the secondary winding, depending upon which pair of contacts is then closed.

The voltage-doubler is a full-wave rectifier. See FULL-WAVE RECTIFICATION, HALF-WAVE RECTIFICATION, RECTIFICATION, SMOOTHING CIRCUIT.

FULTOGRAPH. System of fascimile transmission and reception. The mod-



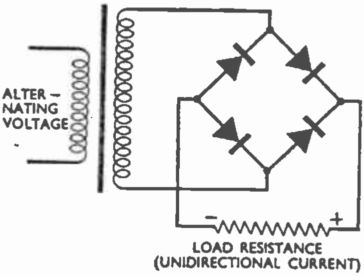


Fig. 59. Bridge connexion of rectifiers which provides full-wave rectification without making use of a transformer with a centre-tapped secondary.

ulation of the transmitted carrier is provided by light variations on a photocell from a spot of light tracing a path over a photograph or drawing. During reception the modulating waves are passed through a damp piece of paper impregnated with an iodine salt. Iodine, released by electrolysis, causes discoloration of the paper, the degree of discoloration being proportional to the intensity of the current; that is to say, it is proportional to depth of modulation of the carrier.

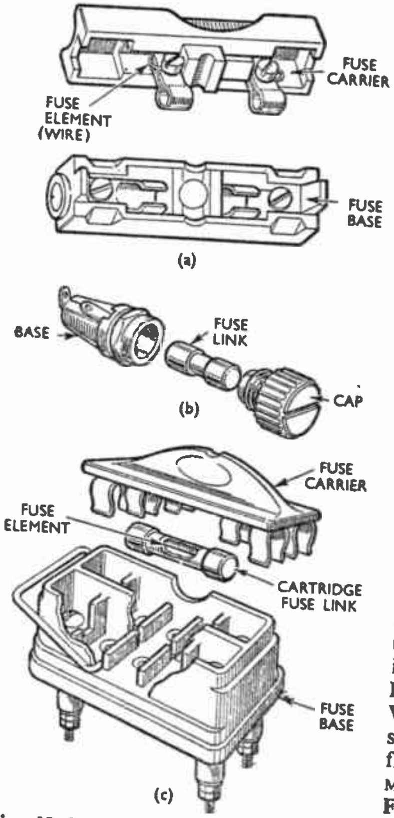


Fig. 60. Three examples of fuses used in radio engineering: (*a*) single-way, rewirable type of fuse; (*b*) single-way, light-duty fuse unit for panel mounting, and (*c*) two-way fuse unit with a cartridge-type fuse link.

The picture at the sender is mounted on a cylinder which slowly rotates while a spot of light travels along on a track in front of the cylinder. In so doing, it scans the whole picture once in about five minutes. Light reflected from the picture is focused on a photocell and the resultant emission is made to modulate the sender.

At every revolution of the cylinder, a synchronizing impulse is sent out while the rotating mechanism is stopped for a second or so. At the receiver, a stylus is made to trace a path on the impregnated paper, which is wrapped round a similar cylinder. Special electromagnetic relays hold up and release the rotating mechanism at each revolution, in synchronism with the synchronizing impulse.

Thus, the stylus produces a series of lines running round the cylinder, the lines being modulated in accordance with the light and shade of the original picture.

FUNDAMENTAL FREQUENCY. Rate of repetition of a complex wave form. When such a wave form is analysed, it is found to consist of a number of components of which the frequencies are exact multiples of a certain frequency; this frequency is the fundamental frequency. The term may be used also to distinguish the real resonant frequency of a tuned circuit from its harmonics. See FOURIER ANALYSIS, HARMONIC.

FUNDAMENTAL UNITS. Basic units from which a set of derived units is obtained. See DERIVED UNITS.

FUNDAMENTAL WAVELENGTH. Wavelength on which, for example, a sender may be working, in distinction from harmonics thereof. See FUNDAMENTAL FREQUENCY.

FUSE. Protective device for opening a circuit under fault conditions by means of a fuse element which melts when an excessive current flows. The component parts of typical radio types of fuse are shown in Fig. 60. Tinned copper wire is the usual material for the fuse element. For continuous current ratings of 1 amp. or less, the delicate wire is mounted in a ceramic or glass tube fitted at the ends with contact ferrules. This is called a replaceable cartridge-type fuse link. For these low ratings, the fuse element is designed to be melted in less than one second by a current of about 1·7 times the rated value.

For rated currents greater than 1 amp., either cartridge-type fuse links or rewirable fuse carriers may be used. At these ratings, the fuse element melts in less than one second when the current reaches a value of about three times the rated value. Suitable wire-gauges are, for tinned copper wire, (S.W.G.) 38, 35, 29, 25, 23, 22; continuous-current rating (amp.), 3, 5, 10, 15, 20, 25. The other parts of a fuse must be fire-resistant and are usually made of ceramic, asbestos, or mouldings of synthetic resin with an inert mineral filler mixed in. The common types of fuse are suitable for use at voltages up to 250. For higher voltages a longer element is necessary.

FUSE BASE. That part of a fuse to which the fuse carrier is fitted. See FUSE.

FUSE CARRIER. Removable holder which carries one or more fuse links and which may be fitted with contacts for this purpose. See FUSE.

FUSE ELEMENT. Part of a fuse designed to melt and open the circuit when an excessive current flows. See FUSE.

FUSE LINK. That part of a fuse which consists of a fuse element in a cartridge or other container fitted with contacts or capable of being attached to contacts. See FUSE.

G

GAIN. Increase of power or voltage in one part of an electrical system compared with another. Sometimes gain is increase of voltage irrespective of power. The gain (often referred to as the amplification) of an amplifier may be expressed as a number of decibels of voltage or power gain (see DECIBEL). The term "gain control" is preferable to "volume control" in discussing audio output, because the volume of reproduction varies from instant to instant but the mean power can be varied by a gain control. See AMPLIFICATION FACTOR, AUTOMATIC GAIN-CONTROL, STAGE GAIN.

GAIN CONTROL. Process of adjusting the amount of gain given by an amplifier or complete radio receiver, or the device for achieving that end. The need for a means of varying gain is sufficiently obvious when it is remembered that the signal received from a high-power local broadcast sender may be thousands of times stronger than one which has travelled some hundreds of miles to the receiver.

The general problem of adjusting gain to meet the needs of the moment is not an entirely simple one. Consider the design of a superheterodyne receiver with one stage of radio-frequency amplification, frequency changer, two intermediate-frequency amplifying stages, triode detector, and transformer-coupled pentode output valve. Such a receiver as this would overload the final valve severely on many transmissions, and it might seem that the proper place to attenuate the over-strong signal would be between the detector and the output stage.

If this were done, however, signs of overloading might still be heard on any very strong signal, and investigation would show that an excessive input was reaching the detector, or even the second intermediate-frequency amplifying valve (see OVERLOAD). The designer might then turn to the other end of the circuit and provide a means of varying the aerial coupling, thus enabling the input to the first valve to be so controlled as to keep the signal within bounds.

Such a gain control would certainly tend to prevent overloading at any point in the receiver, but still falls short of the ideal. In particular, it is

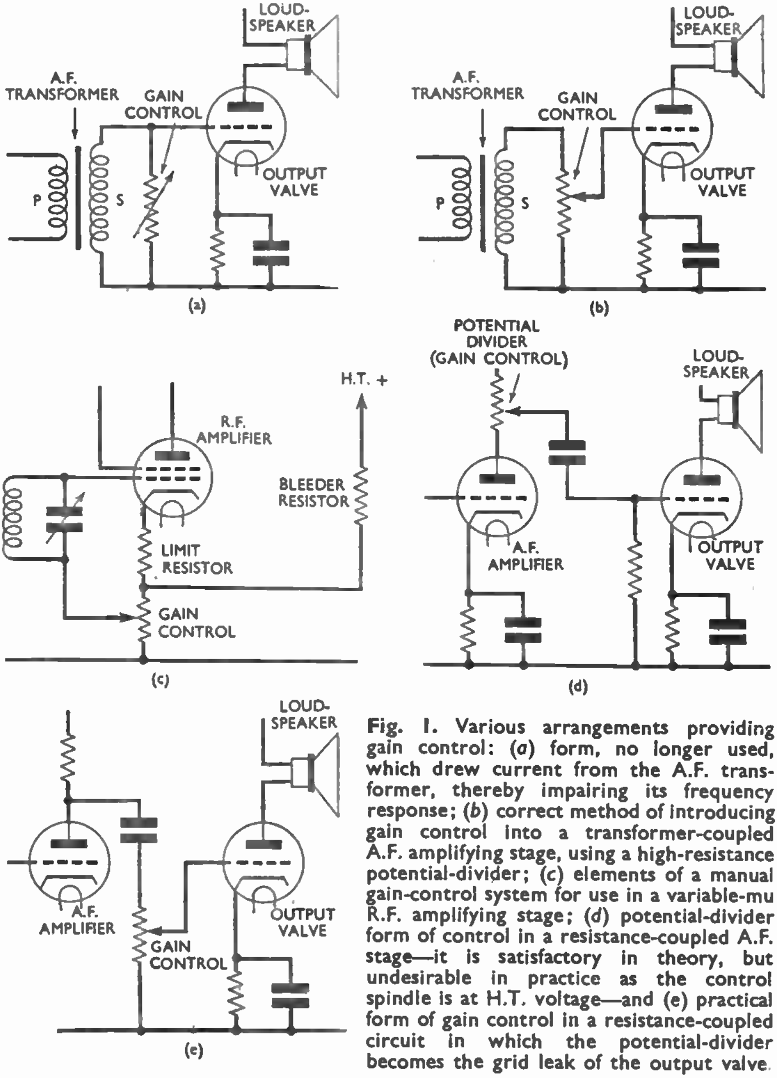


Fig. 1. Various arrangements providing gain control: (*a*) form, no longer used, which drew current from the A.F. transformer, thereby impairing its frequency response; (*b*) correct method of introducing gain control into a transformer-coupled A.F. amplifying stage, using a high-resistance potential-divider; (*c*) elements of a manual gain-control system for use in a variable-mu R.F. amplifying stage; (*d*) potential-divider form of control in a resistance-coupled A.F. stage—it is satisfactory in theory, but undesirable in practice as the control spindle is at H.T. voltage—and (*e*) practical form of gain control in a resistance-coupled circuit in which the potential-divider becomes the grid leak of the output valve.

objectionable in leaving the actual gain of the amplifying stages at maximum, since it acts merely by reducing the input to them when an over-strong signal is received. Consequently, valve noise, mains noise or circuit noise will still be at maximum (see RANDOM NOISE).

To obtain as quiet a background as possible, it is evidently desirable to reduce the actual gain of the amplifying stages on strong signals. Moreover, the attenuation must be so applied and so combined with correct design of the inherent gain of each amplifying stage that no valve tends to overload much ahead of the rest.

Thus, if the output valve overloads when its grid is swung more than 25 volts, and the preceding stage gives a gain of 10, then the latter valve must itself be capable of accepting an input of at least 2·5 volts (25 divided by the stage gain) if it is not to overload before the output valve does so.

In general, it is good design to see that each valve will accept a little more than is necessary to ensure that the *succeeding* valve is fully loaded. In a receiver thus designed, it is safe to insert the gain-control device at an early point in the circuit, since one can be sure that no other stage will overload if the signal strength is kept within the limits that the output valve can accept.

However, a little further consideration will show that, in a superheterodyne receiver such as that described, the first amplifying stage is not, in fact, the best place to control the overall gain. It happens that random noise is more apt to originate in the intermediate-frequency amplifying stages than in the radio-frequency stage, and it pays to reduce the I.F. gain when a strong signal permits.

Mains hum, on the other hand, is more likely to originate in the low-frequency amplifying circuits; there is, therefore, a case for applying at least some part of the gain-control process at this point.

The designer is indeed led to wonder whether he should not provide a simultaneous gain-control effect in both intermediate and low-frequency amplifying circuits. At one time this was done in some elaborate broadcast receivers, but the general adoption of automatic gain-control has involved some revision of ideas.

The basic method now largely used is to depend on the automatic gain-control to prevent overloading on even the strongest signals, and to provide, in addition, means of adjusting the receiver output to the level desired by the listener (see AUTOMATIC GAIN-CONTROL). This manual gain control frequently operates on the low-frequency amplifying stage, but may also take the form of an over-riding control on the A.G.C. system.

In a receiver designed on these principles, matters will usually be so adjusted that, while the A.G.C. prevents overloading, it does permit the output valve to be fully loaded on all the stronger transmissions. The receiver thus tends to give its maximum output at all times unless the manual gain control is operated.

In T.R.F., or "straight," receiver circuits it is scarcely possible to provide automatic gain-control that is sufficiently effective to prevent overloading on any possible signal. Hence, even if A.G.C. is included, the manual control must usually receive a fair amount of manipulation. Thus, in the "straight" combination of radio-frequency amplifying stage, detector and low-frequency stage, it is usual to control gain by varying the amplification of the R.F. stage.

Turning to the details of gain-control methods, it is found that they fall into two main classes. In the first, some device is used which enables an adjustable fraction of the output of one valve to be passed on to the succeeding one. In the second, the actual magnifying power of the valve itself is varied.

The former of the two general methods is mostly used in low-frequency amplifying circuits, while the second applies principally to radio-frequency amplifiers in which variable-mu valves are largely employed. Briefly, these valves, in giving an amount of amplification that can be varied by an alteration of grid-bias voltage, provide a simple method of gain control, either automatic or manual.

In low-frequency amplifying circuits, on the other hand, it is usual to fit some form of potential divider to control the amount of signal voltage passed from one valve to the next. A more detailed conception of these devices may be obtained from a study of Fig. 1. See AMPLIFICATION, SUPERHETERODYNE RECEIVER.

GAIN LIMITER. Device or circuit arranged to fix an upper limit of predetermined value to the gain given by an amplifier. It may be used to minimize the effects of strongly peaked interfering impulses, such as atmospherics, so that they shall not greatly exceed some desired signal in final amplitude. See LIMITER.

GALENA DETECTOR. See CRYSTAL DETECTOR.

GALVANOMETER. Instrument for the detection of small electric currents. The scale of the instrument is usually calibrated in arbitrary units.

GAMMA RAYS. Paths followed by short wave forms of highly penetrating character and emitted by radio-active substances during disintegration. Gamma rays are in the X-ray band.

GANGED CAPACITOR. Assembly of two or more variable capacitors on a common spindle, a single control knob then serving to adjust all the capacitors simultaneously (see VARIABLE CAPACITOR).

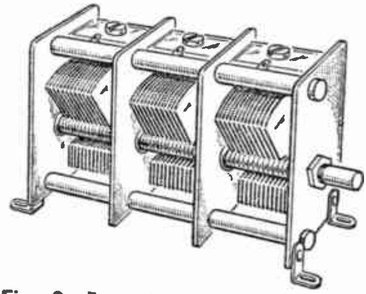


Fig. 2. Example of a three-section ganged capacitor with trimmers.

Since the various sections of such multiple capacitors may be in successive stages of a receiver circuit, they are constructed with careful screening between them, as shown in Fig. 2, and, of course, are accurately matched in capacitance. Combined with each variable section, there is usually incorporated a small trimmer for use in balancing differences in stray capacitances in the ganged circuits.

GANGED CIRCUITS. Two or more circuits arranged for tuning by means of a ganged capacitor or other device for simultaneous adjustment of all circuits from a single control. See GANGING.

GANGED CONDENSER. Synonym for GANGED CAPACITOR.

GANGED SWITCH. Multi-pole (and often multi-way) switch, usually of the rotary type. See SWITCH.

GANGING. Arrangement of two or more circuits for simultaneous tuning by capacitors linked on a common spindle or other device permitting adjustment of the whole system from a single tuning knob.

Such tuning is considered essential in broadcast receivers; hence their circuits must be ganged, and considerable research has been devoted to the numerous and interesting problems of maintaining "alignment" (exact identity of tuning on all wavelengths) between the separate circuits of such a system.

The first essential is that all circuits must contain the same amount of inductance if they are to tune similarly. The inductors for a chain of ganged circuits must, therefore, be matched in value within close limits.

There are many ways of producing them in matched sets; perhaps the simplest is to wind the units to a fixed specification with all reasonable care, then measure the inductance of each, and group them together in batches according to their divergence from the standard figure.

In this way, the inductors in each group can be used to make up matched sets of units, since those within each group will be of sufficiently equal inductance, though the groups will differ slightly from each other, and from the nominal standard value for the particular receiver design. With careful manufacture to a rigid specification, the variations will be slight; but, if they are allowed to exceed a certain small value, they cause difficulties in fitting a standard wavelength-calibrated dial to the finished receiver.

To ensure the highest accuracy of calibration in the completed receiver, the inductor units must obviously conform to a standard value. To achieve this, a proportion of the output of the winding shops will require a slight final adjustment of inductance. This can be done in a variety of ways, such as a small alteration in the spacing of a few turns in the winding, a change in the position of an iron-dust core or in the extent of a gap therein, or a bodily movement of the inductor unit nearer to or farther from some part of its screening case.

Given a set of closely matched inductors, the problem of ganging is half solved—but only half. There still remain sundry minor but awkward questions, such as the variation in stray capacitance between one circuit and another, the different effect on the tuning of a circuit which results from connecting different types of valves across it, the problem of coupling the aerial to the first circuit without altering its tuning characteristics unduly, and the design of the ganged capacitor itself.

Fortunately, most of the small tuning discrepancies between circuits containing matched inductors can be regarded as due to differences in a certain fixed value of stray capacitance, as though there were a small fixed capacitor across each circuit in addition to the tuning capacitor, these fixed capacitors differing slightly from each other in value.

The total stray capacitance in each circuit must obviously be equalized before a ganged capacitor can be expected to tune a row of circuits accurately, and, for this purpose, small adjustable capacitors called trimmers are used. A trimmer is usually built into each variable section of a ganged capacitor and, in the initial adjustment of a new receiver, these are carefully set to equalize conditions in the ganged circuits.

The aerial connexion to a ganged receiver is chiefly a matter of seeing that it is not coupled too closely to the first tuned circuit. Were it connected directly, for example, the effect would be much as though a fixed capacitor of considerable value had been shunted across the circuit, a capacitor of value so large, in fact, that the trimmers would no longer be able to correct the tuning.

It is usual, therefore, in ganged receivers, to provide either a small untuned coupling inductor for the aerial, with magnetic coupling to the first tuned circuit, or else to connect the aerial to a tapping point on the first inductor so that once again the coupling is comparatively weak. (This arrangement is favoured for selectivity reasons, in addition to the one just given.)

So far as the ganged tuning circuits are concerned, the requirements in the associated multiple capacitor are simple: it must provide the same capacitance in each circuit at any given point in the tuning range, and it must not introduce stray coupling effects between the circuits. To these ends it must be rigidly built, must have good bearings for the rotary spindle, and the sections must be screened from each other.

To enable the individual sections of a ganged capacitor to be matched to the capacitance of their neighbours at all points in the range of adjustment, a number of methods is available. A common and effective one employs a special vane, or plate, on the end of the moving portion of each section. This vane is cut radially so that a number of small segments results as shown in Fig. 3. Each of these segments can be bent to increase or decrease the air-gap between the special moving vane and its opposite number among the fixed ones. The capacitance of the section can thus be adjusted over each small range of travel of the moving vanes.

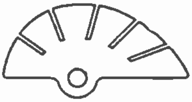


Fig. 3. End moving vane of a ganged capacitor cut into segments for capacitance matching.

Superheterodyne receivers afford an interesting problem in ganging. Here, the requirement is not merely to arrange that a series of circuits shall be tuned simultaneously to the same frequency, but that in the case of one of them a fixed frequency-difference from the rest shall be maintained. This, of course, is the oscillator circuit, which must be kept at the appropriate beat-frequency difference from the signal-frequency circuits.

One method of achieving and maintaining this fixed frequency-difference is by the use of a different value of inductor and specially shaped vanes in one section of the ganged capacitor, possibly combined with a slight off-setting in angular location on the spindle.

In order that the proper frequency-difference, or tracking, shall be preserved when switching from one wave band to another, what are called padding capacitors are used. These are adjustable, rather than variable, capacitors. These are connected in series with the tuning capacitor and may be regarded as reducing the maximum capacitance in the circuit. One padding capacitor is used for each wave band, and they are adjusted to give correct alignment of the oscillator circuit with the others. See STRAY CAPACITANCE, SUPERHETERODYNE RECEPTION, VARIABLE CAPACITOR.

GANGING OSCILLATOR. Oscillator specially designed for testing ganged circuits. It has constant output, but its frequency can be rapidly varied.

GAS AMPLIFICATION. Increase in sensitivity of a gas-filled photocell compared with a similar cell in which there is a high vacuum. The increase is due to ionization of the gas by electrons released from the photo-sensitive cathode and the consequent multiplication of the number of electrons present. See GAS-AMPLIFICATION FACTOR.

GAS-AMPLIFICATION FACTOR. Increase, expressed as a number, in the sensitivity of a gas-filled photocell due to ionization of the gas. See GAS AMPLIFICATION.

GAS CURRENT. Current flowing through an ionized gas; it is carried by positively charged ions. See IONIZATION, IONIZATION CURRENT, IONIZATION POTENTIAL.

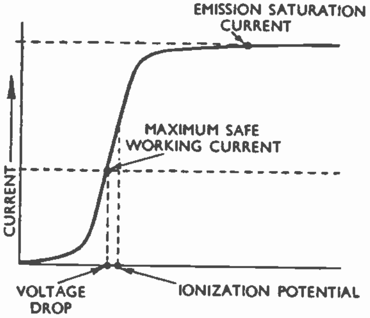


Fig. 4. Graph relating the various quantities associated with a gas-filled diode. The ionization potential is the minimum potential sufficient to set up the process of ionization; the voltage drop is the voltage acting between anode and cathode when the valve is taking its full rated current.

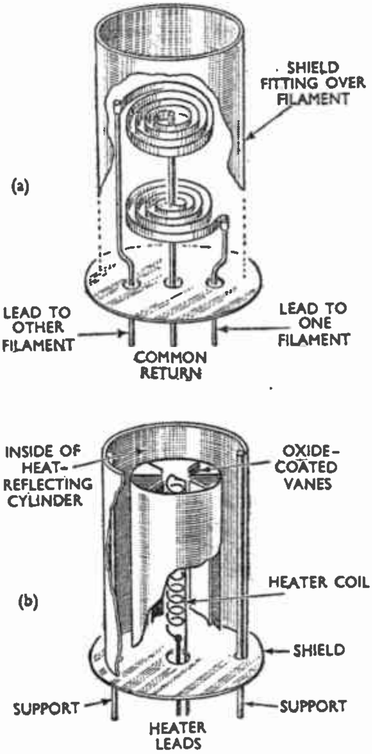


Fig. 5. Owing to annulment of the space charge, the cathode of a gas-filled diode is very different in construction from that of a hard-vacuum valve: (*a*) is a filament type of cathode, and (*b*) is an indirectly heated cathode.

GAS-DISCHARGE TUBE. Synonym for GLOW-TUBE.

GAS-DISCHARGE VALVE. Synonym for GAS-FILLED VALVE.

GAS-FILLED DIODE. Diode in which the amount of gas is sufficient to determine entirely the electrical characteristics of the valve. A gas-filled diode is also termed a gas-filled rectifier (see MERCURY-VAPOUR RECTIFIER). The gas-filled diode differs from the hard-vacuum diode in that, when the gas is ionized, the anode current suddenly changes to a high value which cannot be substantially increased by increasing the anode voltage (see DIODE, EMISSION LIMITATION). Fig. 4 shows the anode-volts/anode-current characteristic of a gas-filled diode.

The anode to cathode potential sufficient to produce ionization is called the ionization potential. The voltage acting between anode and cathode when ionization has taken place is called the voltage drop. Although the anode current can reach its emission-limitation value, it is unsafe to allow it to exceed about a third of this value (Fig. 4). An excessive current causes the cathode to be bombarded by positive ions which destroy it. With mercury-vapour gas, and a typical cathode structure using a separate heater, the voltage drop must not exceed about 22 volts, otherwise the cathode is destroyed.

The anode current of a gas-filled diode is not limited by space charge, and cathodes can be designed to produce the maximum possible emission for a given heating power. The cathode structures (Fig. 5) are quite different from those used in hard-vacuum valves.

The distribution of potential through the gas is shown in Fig. 6. It is seen to be non-uniform. In most of the space between anode and cathode there

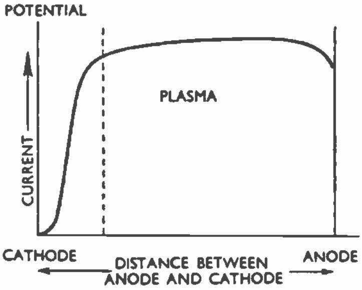


Fig. 6. Distribution of potential in a gas-filled diode. The region of plasma, in which there is an excess of positive ions, is at a higher positive potential than is the anode.

is a surplus of positive ions. This region is called plasma. Electrons strike the edge of the plasma, cause ionization, and then drift through the plasma to the anode. Note that the plasma potential is slightly higher than the anode because of the excess of positive ions.

Mercury vapour, in equilibrium with liquid mercury, is commonly used in gas-filled diodes (see MERCURY-VAPOUR RECTIFIER). Temperature has a considerable effect upon the performance of the valve, and precautions must be taken to maintain the correct temperature.

See CATHODE, DIODE, EMISSION LIMITATION, GAS-FILLED TRIODE, IONIZATION.

GAS-FILLED RECTIFIER. Gas-filled valve used as a rectifier. The fact that the space charge is virtually eliminated in a gas-filled rectifier makes it efficient. The advantage of the low internal resistance of the gas-filled rectifier is not, however, given without attendant disadvantages, notably a liability to damage by misuse.

Where conditions of operation can be stabilized, where short-circuits are not liable to occur in the load circuit and when power-efficiency is a prime requirement, the gas-filled rectifier has a wide range of practical uses. For ordinary mains units, as employed in radio receivers and for small amplifiers, the vacuum-valve rectifier is almost always used (see VACUUM-VALVE RECTIFIER).

Mercury vapour is most often used as the gas in the gas-filled rectifier and, while glow-tubes contain other forms of gas and can be used as rectifiers, they are not generally employed as such. The practical applications of the mercury-vapour gas-filled rectifier are as numerous as the nomenclature distinguishing the variations of a basic principle is confusing.

We must, however, distinguish between the mercury-arc rectifier and the mercury-vapour (hot-cathode) rectifier because there is a basic point of difference, namely, that in the former almost any amount of current may be drawn from the device for a short period, while, in the latter, irreparable damage would be caused by short-circuit or overload. There is a further distinction between these gas-filled rectifiers, inasmuch as some may be designed with electrodes to control the flow of current and others without any electrodes other than anode and cathode. The action of the grid in a gas-filled rectifier is to alter the anode voltage at which the gas becomes suddenly conductive. See IGNITRON, MERCURY-ARC RECTIFIER, MERCURY-VAPOUR (HOT-CATHODE) RECTIFIER.

GAS-FILLED RELAY. See GAS-FILLED TRIODE, GAS-FILLED VALVE.

GAS-FILLED TETRODE. Tetrode in which the amount of gas is sufficient to determine entirely the electrical characteristics of the valve when ionization takes place. The gas-filled triode has the disadvantage, for certain circuit applications, that the control-grid current is large and therefore the control-grid slope-resistance small.

The addition of another electrode between control grid and anode reduces the control-grid current to a very small amount. Thus a gas-filled tetrode can be made to "trigger," or suddenly pass, a large current, by the application of a few microvolts to the grid. Such delicacy of action would be impossible using a gas-filled triode. Fig. 7 compares the electrode structure of gas-filled triodes and tetrodes. See GAS-FILLED TRIODE.

GAS-FILLED TRIODE. Triode in which the amount of gas is sufficient to determine entirely the electrical characteristics of the valve when ionization takes place. A gas-filled diode becomes conductive directly the anode voltage equals the ionization potential. In a gas-filled triode the control-grid potential determines the anode voltage at which ionization takes place; thus the more negative the control grid with respect to cathode, the higher must be the anode voltage, before ionization takes place (see CONTROL RATIO). As in a hard valve, it is the grid potential which determines the potential gradient at the cathode and it is, therefore, in a gas-filled valve, the grid potential which determines the ionization potential.

Once ionization takes place, the control-grid potential makes no difference to the anode current. Thus, before the valve can again become non-conductive, the anode voltage must be reduced well below the ionization potential and maintained at this low value for a fraction of a second (see DE-IONIZATION TIME). Once ionization has ceased, the anode potential may again be raised and the control of ionization potential by grid potential is restored.

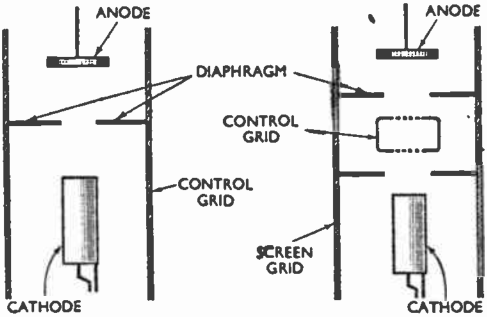


Fig. 7. Diagrammatic representation of the electrode structures of (*left*) a gas-filled triode and (*right*) a gas-filled tetrode. The cathode in each is similar to that employed in a gas-filled diode.

The control-grid current in a gas-filled valve may flow in either direction; thus positive ions forced from anode towards cathode may cause the control grid to become positive, or a collection of electrons may cause it to become negative.

The electrode structure of a gas-filled triode or tetrode is very different from that of a hard-vacuum valve; this is shown in Fig. 7. See GAS-FILLED DIODE, GAS-FILLED TETRODE, GRID CURRENT, IONIZATION, IONIZATION CURRENT, IONIZATION POTENTIAL.

GAS-FILLED TUBE. See GAS-FILLED VALVE, GLOW-TUBE.

GAS-FILLED VALVE. Valve in which the amount of gas is sufficient to determine entirely the electrical characteristics of the valve when ionization takes place. The gas-filled valve differs from the glow-tube because the valve has a hot cathode which emits electrons; the cathode of a glow-tube is cold and does not emit primary electrons (see GLOW-TUBE). Thus the ionization potential of a gas-filled valve is lower than that of a glow-tube (see IONIZATION POTENTIAL).

The basic characteristic of a gas-filled valve is that it has only two electrical conditions: one when it is relatively non-conductive, the other when it is fully conductive. The conduction between anode and cathode is through an ionized gas. Once the gas is ionized, the current that it carries is substantially independent of the voltage acting across it; thus, once the anode-to-cathode potential of a gas-filled diode exceeds a certain value, the anode current leaps up to a high value, and it stays at that value even though the anode voltage be considerably increased.

In a gas-filled triode or tetrode it is the control-grid potential that determines the ionization potential at which ionization takes place, but once the valve becomes conductive, the grid has no more control over the anode current.

The hard-vacuum valve is distinguished by its property of giving a nearly linear relationship between, for instance, anode volts and anode current (when this is not limited by space charge or emission limitation) and a linear relationship over parts of its characteristic between control-grid volts and anode current (see ANODE-VOLTS/ANODE-CURRENT CHARACTERISTIC, GRID-VOLTS/ANODE-CURRENT CHARACTERISTIC).

On the other hand, the gas-filled valve, like a relay, has two conditions, conductive or non-conductive. It is sometimes called a trigger valve, thermionic relay or valve relay because of this property. It has many applications, notably as an efficient rectifier, and in applications similar to those in which electromechanical relays might be used. The fact that the electrons and ions take a definite time to recombine limits the frequency of operation of a gas-filled valve to about 50 kc/s. See DE-IONIZATION TIME, DIODE, GAS-FILLED DIODE, GAS-FILLED TETRODE, GAS-FILLED TRIODE, GLOW-TUBE, IONIZATION, MERCURY-VAPOUR RECTIFIER.

GAS FOCUSING. In a cathode-ray tube, the focusing of the electron beam by means of the ionization of residual gas in the tube. Positive ions are formed by the collision of electrons with the small quantities of gas in the tube, giving rise to a core of positive ions in the beam and thus providing the necessary focusing field.

GAS VALVE. Synonym for GAS-FILLED VALVE.

GAUSS. Unit of magnetic-field density in the centimetre-gramme-second system; it is equal to one magnetic line per square centimetre.

GEE. See NAVIGATIONAL AID.

GENERATOR. See A.C. GENERATOR, D.C. GENERATOR, SYNCHRONOUS GENERATOR.

GETTER. Substance used in the process of degassing a hard-vacuum valve. It is placed in the bulb and made to burn to absorb residual gas. In degassing it is important to remove all gas that may be occluded in the metal of the electrodes or in the glass; degassing is helped by heating these parts while pumping goes on. The getter is an added process; it consists in the quick volatilizing or burning of a substance within the valve.

This necessarily uses up any oxygen present. Magnesium, barium and phosphorus are used as getters. Mixtures may also be used, but the object is always to absorb oxygen by a burning process. It is possible that the explosion caused by the sudden burning of a getter may also trap gases which are not absorbed in the burning process, so that the gases are combined with the hot substances and cannot escape when these cool. See DEGASSING, KEEPER.

GILBERT. Measure of magnetomotive force in the centimetre-gramme-second system. It is equal to 0·4π ampere-turns.

GLOW DISCHARGE. Current passing through a gas at low pressure, and accompanied by the emission of light. An example of glow discharge is sometimes seen in a vacuum valve when high anode voltages are used and the valve is soft, i.e. the vacuum has deteriorated.

GLOW-TUBE. Tube in which the bulb contains gas at a low pressure. Anode current flows through the gas when this is ionized. The glow-tube differs from the gas-filled valve in having a cold cathode; there is thus no source of electrons to start the process of ionization, which is brought about solely by the potential gradient acting on the gas between anode and cathode. The tube will conduct whichever way round the voltage is applied.

In practice, the electrodes may be of different construction; for instance, the cathode may be coiled or sputtered with material of low work-function. For working conditions, one electrode is made positive and called the anode, the other being the (negative) cathode. The voltage at which ionization takes place is the ionization potential, but is also referred to as the striking voltage.

Fig. 8 shows the anode-volts/anode-current characteristic of a glow-tube.

It will be noted that the striking voltage is greater than the voltage drop. The voltage drop in a glow-tube is higher and the current density lower than in a gas-filled valve. The table below shows some characteristics of typical glow-tubes.

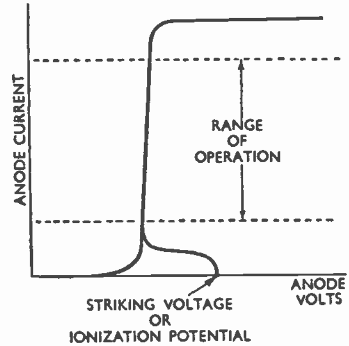


Fig .8. Graph of the anode-volts/anode-current characteristic of a glow-tube. This may readily be compared with that applicable to a gas-filled diode by reference to Fig. 4.

Max. Current (mA)	*Operating Voltage*	*Striking Voltage*
2	48–87	87
30	75	105
50	90	125
60	50–60	85

The last entry refers to a 3-watt neon glow-tube.

Glow-tubes are chiefly used to stabilize the output voltage from mains units. This is because the voltage drop is largely independent of the current. The gas, typically neon or argon, is usually at a pressure of 0·1 mm. of mercury. See DIODE, GAS-FILLED DIODE, IONIZATION, IONIZATION POTENTIAL, VOLTAGE DROP.

GLOW-TUBE RECTIFIER. Glow-tube used as a rectifier. The glow-tube can conduct electricity either from cathode to anode or from anode to cathode, and is not inherently a rectifier. Nevertheless, by making the electrodes of different areas, asymmetrical conduction can be produced. The property of the glow-tube, namely, that its voltage-drop is largely independent of the current flowing through it, gives it a wide application as a voltage regulator, but it is seldom, in fact, used as a rectifier. See GLOW-TUBE, NEON GLOW-TUBE.

"GO" CHANNEL. Term distinguishing one conductor of a transmission line from another, or a channel used for one-way communication.

GOLDSCHMIDT ALTERNATOR. Synchronous generator for the production of currents at radio frequencies. See SYNCHRONOUS GENERATOR.

GONIOMETER. Synonym for RADIO-GONIOMETER.

GRAMOPHONE. Machine for rotating a gramophone record, or disc, and reproducing it by means of a sound-box (acoustic) or a pick-up (electrical). The term was invented to distinguish between the phonograph system, which used cylinders, and a machine for playing flat discs. In America, however, the terms phonograph and gramophone are synonymous. See ELECTRICAL RECORDING, GRAMOPHONE PICK-UP, SCRATCH FILTER.

GRAMOPHONE PICK-UP. Reproducing head used for the electrical reproduction of gramophone records or direct-recorded discs. It is usually mounted on an arm pivoted at one corner of the turn-table plate. The pick-up and arm are driven in an arc across a radius of the disc by the pull exerted on the needle in the spiral groove as the turn-table revolves.

The needle traces the wave form of the grooves, setting up e.m.f.s at the terminals of the pick-up. These are amplified and equalized to produce, from the loudspeaker, sound waves corresponding to those applied to the microphone during the recording process.

The *moving-iron* type of pick-up

(Fig. 9) is preferred for general use because of its robustness and simplicity. It works on the principle of electromagnetic induction. A soft-iron armature, situated in a stationary coil, is pivoted at some point so that, as the needle is displaced about its mean position when tracking a groove, the armature oscillates about its pivot. When the armature is in its upright equilibrium position, as in Fig. 9, no lines of force pass along its length; instead the lines cross from each of the two north pole-pieces to the opposite south pole-piece.

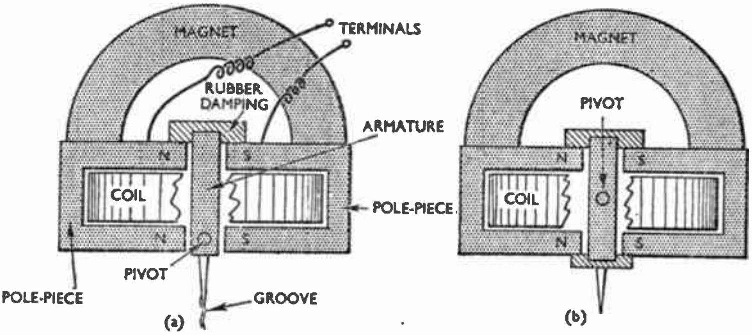


Fig. 9. Diagrams showing operating principles of two forms of gramophone pick-up: (*a*) the unbalanced-armature or half-rocker type, and (*b*) the balanced-armature type, in which the armature is pivoted at or near its centre of gravity.

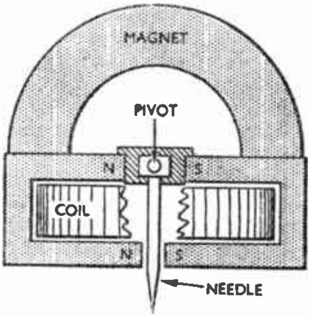


Fig. 10. Needle-armature pick-up. The needle forms the greater part of the armature and is therefore of iron or steel; it may be pivoted for either balanced or unbalanced working.

If, however, the armature rocks in a clockwise direction about its pivot, it provides a low-reluctance path between the lower north and the upper south pole-pieces. Some lines of force leave their original horizontal path to travel upwards along the armature and, in moving, they cut the numerous turns of the coil and generate an e.m.f. at its ends. This e.m.f. is generated only *during the movement* of the armature; there is no output when the armature is stationary.

If the armature oscillates in an anti-clockwise direction, it provides a low-reluctance path between the upper north pole-piece and the lower south pole-piece, and lines of force move to take up this path. The lines now move *down* the armature and, in cutting the coil, generate an e.m.f. of opposite polarity to that produced before. Thus an oscillatory movement of the armature gives rise to an alternating e.m.f. at the pick-up terminals, this e.m.f. being directly proportional to the speed of the movement and the number of turns in the coil.

In Fig. 9a the armature is pivoted at one end and is called an unbalanced armature or half-rocker. If pivoted at the centre (Fig. 9b) it is called a balanced armature or full-rocker. If, as in Fig. 10, the needle forms the armature, the pick-up is said to be of the needle-armature type. The working principles of all three types are similar.

The disadvantage of the original moving-iron pick-ups was their inherent resonance. One resonance occurred at the natural mode of armature vibration, the resonant frequency being between 3,000 and 5,000 c/s. At and near this frequency, the e.m.f.s are not proportional to, but considerably greater than, the speed of needle-point movement. A second resonance was prevalent at a lower frequency (50–150 c/s), due to the mass of the head and arm swinging about the pivot of the arm whilst the needle traced the groove. Another fault was the harmonic distortion of the output e.m.f. particularly noticeable at large stylus-displacements. The relationship between armature velocity and output e.m.f. is, in a good design, reasonably linear for small angular displacements of the armature, but departs from linearity if the armature moves very close to the pole-pieces.

In modern moving-iron pick-ups, the treble resonance is minimized by reducing the armature mass, thus tending to raise the resonant frequency to a point beyond the normal audio-frequency range. The effect of bass resonance is reduced by decreasing the stiffness of needle suspension which tends to lower the resonant frequency. Harmonic distortion is decreased by using a wider pole-piece gap.

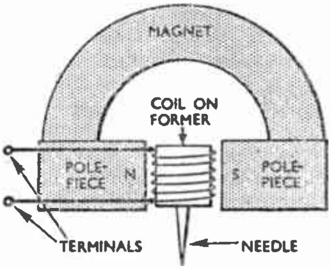


Fig. 11. Theoretical drawing of a moving-coil type of gramophone pick-up. As the needle traces the groove, the coil moves bodily in the gap between the pole-pieces, causing e.m.f.s to be induced in the coil at the frequency of the recorded signal.

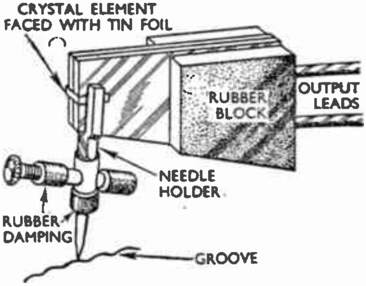


Fig. 12. As the needle of a crystal pick-up traces a groove, the crystal plates are subjected to alternating mechanical stresses; these stresses cause e.m.f.s. to be set up between the two adjacent faces of the element.

In the *moving-coil* type of pick-up (Fig. 11), the needle is attached to a former which carries the coil, the latter oscillating at the frequency of needle vibration. The magnetic field is provided by a permanent magnet and e.m.f.s are generated at the terminals of the coil by virtue of electromagnetic induction.

This type is less prone to resonance than the moving-iron type, but is less sensitive. It requires an intense magnetic field which, in earlier types, necessitated a large magnet. High-density magnets are now employed, reducing the mass of the pick-up and improving its sensitivity. Harmonic distortion is low, largely owing to the absence of iron, at high needle-displacement amplitudes.

The *piezo-electric*, or *crystal*, pick-up works on principles entirely different from those of the moving-iron and moving-coil. If certain crystals are subjected to mechanical stress, e.m.f.s are set up between the facets at which the stress is applied. If two crystal plates are cut from Rochelle salt (sodium-potassium tartrate) they can be so arranged that an applied stress will cause one to expand and the other to contract and electric potentials will be set up between the plates.

In the crystal pick-up (Fig. 12) two such plates are used. A needle-holder is attached to the assembly and, as the needle vibrates, varying pressures are exerted on the crystal plates, setting up alternating e.m.f.s between conducting electrodes touching the crystals. The amplitude of the e.m.f.s is proportional to the amplitude of the groove formation. The crystal pick-up has high sensitivity, is somewhat fragile in construction and subject to mechanical resonance.

The maximum e.m.f.s generated at the terminals of any pick-up rarely exceed 1 volt r.m.s. Excepting the crystal types, modern pick-ups sacrifice sensitivity to achieve a level frequency response. With all types, an amplifier is necessary to produce sufficient energy to operate a loudspeaker.

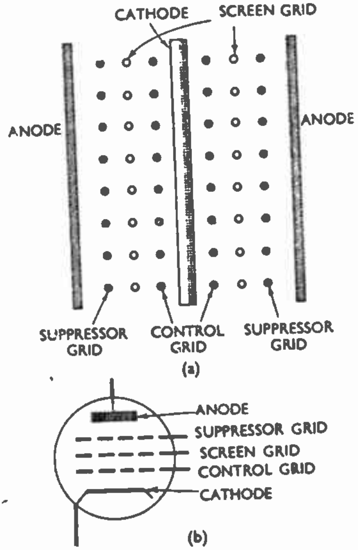


Fig. 13. Diagrams distinguishing grids from the other electrodes of a valve: (*a*) section through, and (*b*) conventional symbol for, a pentode.

The moving-iron and moving-coil types are constant-velocity devices; that is to say, the e.m.f.s produced are proportional to groove velocity. This velocity in r.m.s. values is equal to $4{\cdot}44\,fa$ cm/sec, where f is the frequency in cycles per second and a the amplitude of displacement, in centimetres, of the wave form.

For reference purposes, a standard velocity of 1 cm/sec at 1,000 c/s is generally adopted. If the velocity of a recording system is 2 cm/sec at 1,000 c/s, then it can be given in decibel form as $+6$ db. with reference to the standard velocity.

Over most of the frequency range, gramophone records and discs are recorded at approximately constant velocity; hence a constant-velocity pick-up will have generated at its terminals e.m.f.s, the wave form of which will correspond to that of the recorded sounds. Below 250 c/s, however, the groove amplitude is attenuated during recording to avoid groove overlap, and the pick-up must be equalized to restore the level. With some pick-ups, the natural resonance of the mass of pick-up and arm automatically corrects this attenuation. With others, electrical equalization of the amplifier is necessary.

The crystal pick-up is a constant-amplitude device. Thus the e.m.f.s generated at its terminals are proportional to groove amplitude. Since, with constant-velocity recordings, the amplitudes of needle displacement are inversely proportional to frequency, this pick-up has a falling characteristic; that is, the higher notes are attenuated. This can be corrected by incorporating an equalizer in the amplifier. See ELECTRICAL RECORDING, ELECTRICAL REPRODUCTION, PIEZO-ELECTRIC CRYSTAL.

GRAPH. Line drawn with respect to rectangular co-ordinates to illustrate the relationship between two variable quantities. In many cases, the term "characteristic" is used instead of "graph" (see, for example, VALVE CHARACTERISTIC). The word "curve" is also used instead of graph, but is illogical when the graph shows a linear relationship between two quantities and is therefore a straight line. See SINE GRAPH, VALVE CHARACTERISTIC.

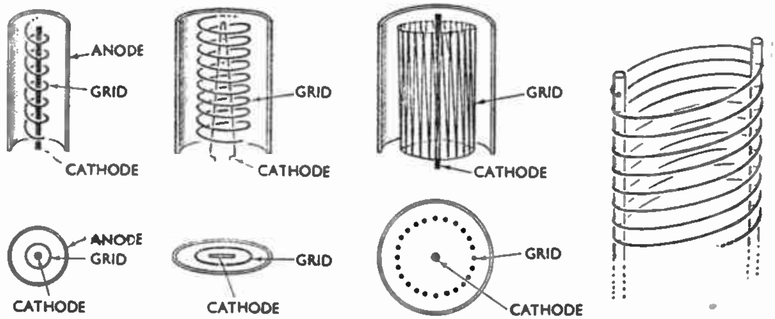


Fig. 14. Various forms of electrode structure, shown in elevation and plan, the control grid being indicated in each case. Also shown (*right*) is the method of mounting the grid; the pillars have notches to take the turns of the coil.

GRAPHICAL SYMBOLS. See SYMBOLS.

GRATZ RECTIFIER. Full-wave rectifying circuit in which four valve rectifiers or four metal rectifiers are connected in the form of a bridge. See BRIDGE NETWORK.

GRID. Electrode of a valve constructed so that some electrons and ions may travel through it and some be collected by it. Electrons and ions accelerated by the potentials acting between electrodes may pass between the coils of a helical electrode, and some may hit the wires forming the helix and so cause current to flow to and from the grid electrode. Grid-type electrodes are used to control the flow of electrons according to their potential, and are also used as shields to reduce the capacitance between electrodes. Grid electrodes are shown in Figs. 13 and 14.

The grid-type electrodes are classified as *control* grids, *screen* grids and *suppressor* grids. The control grid is located nearest to the cathode and is normally a helix embracing, but not touching, the cathode; the control-grid potential has the greatest effect in determining the potential gradient at the cathode and hence the space current (see VALVE). The control grid is usually negatively biased with respect to cathode and so reduces the space current; or, in a gas-filled valve, determines the ionization potential.

The function of the screen grid is to act as a shield between control grid and anode, and so reduce the control grid to anode capacitance. It is arranged to embrace the control grid and thus act as a shield. It is biased at a positive potential with respect to cathode. This potential is of the same order as the anode potential. The screen grid necessarily collects some electrons (though most travel to the anode) and so causes a current to flow between the source of screen-grid potential and the screen grid, and so to the cathode (see SCREEN-GRID CURRENT).

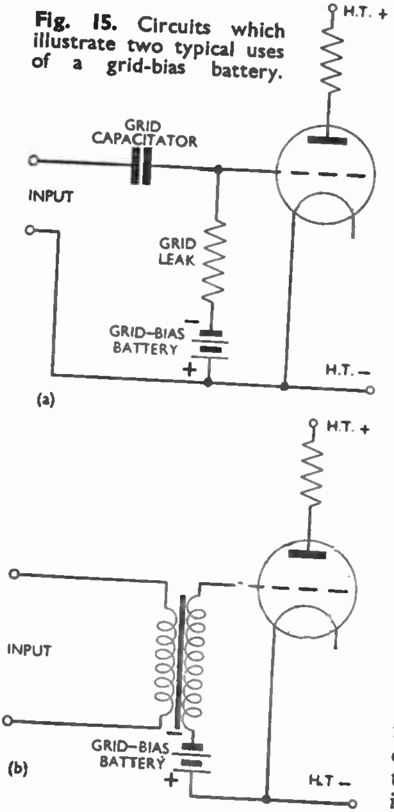
The suppressor grid is placed between anode and screen grid, and is usually, though not invariably, connected to the cathode. Its function is to prevent secondary electrons emitted by the anode from passing to the screen grid (see SECONDARY EMISSION). The great majority of electrons coming from the cathode cannot pass the suppressor grid, since it is at a low (namely, cathode) potential. In frequency-changer valves, other grids are added to form screens between the operative electrodes.

Grids are generally made from a wire helix; but they may be in the form of hollow cylinders, with holes or with plates, mounted parallel to the electron stream. See CONTROL GRID, GRID CURRENT, PENTODE, SCREEN GRID, SCREEN-GRID CURRENT, SUPPRESSOR GRID, TETRODE, TRIODE.

GRID BASE. Synonym for CUT-OFF BIAS.

GRID BIAS. Component of the grid potential which has a steady value. The term generally refers to the control-grid bias; where the screen grid is concerned, the term screen-grid bias is used. See AUTOMATIC GRID-BIAS, BIAS, CATHODE BIAS, GRID-BIAS BATTERY.

Fig. 15. Circuits which illustrate two typical uses of a grid-bias battery.



GRID-BIAS BATTERY. Battery, commonly of dry Leclanché cells, used to maintain a steady difference in potential between the grid and filament of a valve. Two circuits containing a grid-bias battery are shown: Fig. 15a shows a resistance-capacitance-coupled amplifier in which the grid-bias battery is connected to a grid leak; Fig. 15b shows a transformer-coupled amplifier in which the battery is connected to the secondary winding of the transformer. See GRID LEAK.

GRID-BIAS MODULATION. Synonym for GRID MODULATION.

GRID-BIAS RESISTOR. See CATHODE-BIAS RESISTOR, GRID LEAK.

GRID-BIAS VOLTAGE. Synonym for GRID POTENTIAL.

GRID CAPACITOR. Capacitor connected between the control grid of a valve and the associated circuit. The capacitor has an infinite resistance to D.C., but offers only a low impedance to audio- or radio-frequency currents. A GRID LEAK (q.v.) is generally used in conjunction with the capacitor to permit of the grid being supplied with D.C. bias.

GRID CIRCUIT. Any circuit associated with the control grid (not screen grid) of a valve. See CONTROL GRID, GRID.

GRID CONDENSER. Synonym for GRID CAPACITOR.

GRID CONDUCTANCE. Synonym for GRID SLOPE-CONDUCTANCE.

GRID CONTROL. Synonym for GRID MODULATION.

GRID CURRENT. Current flowing to and from the control-grid electrode. If, in a hard-vacuum valve, the grid is made positive with respect to cathode, it collects electrons and grid current flows between control grid and cathode. In a gas-filled triode or tetrode the grid may, depending upon its potential, collect either electrons or positive ions. Thus, in a gas-filled triode, grid current can flow in either direction. The effect can also take place to a lesser degree in a hard-vacuum valve (see GAS-FILLED TRIODE, REVERSE GRID CURRENT).

With small differences of potential between grid and cathode, the grid current is very small, but it increases rapidly as the grid becomes more positive. The anode potential affects grid current; if it is large, it draws electrons away from the space charge and these pass the grid; if it is small, the grid collects more electrons. It is helpful to realize that, when the control grid is positive with respect to cathode, then grid and cathode form a diode; while the anode–cathode structure forms an amplifier of the potentials, due to the current rectified between grid and cathode.

The production of grid current in a hard-vacuum valve, when the grid is positive with respect to cathode, is an important factor in many circuit applications; notably, grid-leak detection, the use of the grid-leak in oscillators, and as the driver stage preceding a class-B valve amplifier. See AMPLIFICATION, DIODE, GRID-CURRENT CHARACTERISTIC, GRID SLOPE-RESISTANCE.

GRID-CURRENT CHARACTERISTIC. Graph plotting grid current against grid volts. In a hard-vacuum valve, the grid-current characteristic resembles that of the anode-volts/anode-current characteristic of a hard-vacuum diode, but is modified by the anode potential. See GRID CURRENT, REVERSED GRID CURRENT.

GRID-CURRENT MODULATION. Synonym for GRID MODULATION.

GRID DETECTION. Process wherein detection is performed by the grid and cathode of a triode or multi-electrode valve. A typical circuit is shown in Fig. 16. In the absence of any signals, the grid will take up a potential such that a very small grid current flows. On the application of a positive signal, the grid will momentarily become positive and grid current will flow. It will flow into the capacitor, which will thus become negatively charged. As a result, the anode current of the valve will be decreased.

The action is similar to that of the diode detector, the circuit, in fact, being equivalent to that of Fig. 18, on page 162, under DIODE DETECTOR. The grid and cathode act as the diode and the same conditions regarding the time constant of the resistance-capacitance combination apply. The grid capacitance cannot be made too small because the voltage actually applied between grid and cathode is not the full input voltage, but only a portion thereof, and is determined by the ratio of the input impedance of the valve and the reactance of the capacitor.

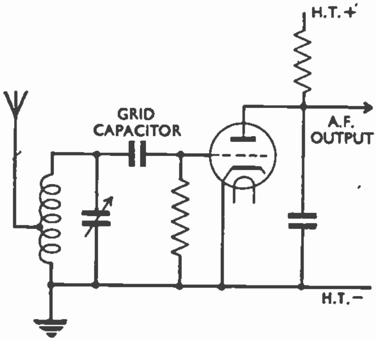


Fig. 16. Circuit for grid detection by the use of a triode; the detection process is explained in the text.

The desirable condition, of course, is that the reactance of the grid capacitor should be small compared with the valve impedance, so that nearly all the input voltage reaches the valve. If the grid capacitor is made too small its reactance becomes high and an appreciable fraction of the voltage is lost.

Given proper conditions, however, the grid potential will vary in accordance with the modulation changes and, consequently, the anode current will also vary. The arrangement thus combines the action of detector and amplifier in one valve. The valve will also tend to amplify the radio-frequency carrier—which we do not require.

To avoid this, and also to by-pass the carrier as quickly as possible after this has been finished with, it is customary to connect from anode to cathode a capacitor of such a value that it does not seriously reduce the amplification of the valve at the upper audio frequencies of the modulation, but acts as a low-impedance by-pass to the very much higher carrier frequency.

For weak signals, the valve operates with a small negative grid voltage. Under these conditions, the slope of the anode-current/grid-voltage characteristic is high, and good amplification is obtained. The valve will, in fact, always work just above the point at which grid current commences, which is the condition for maximum amplification. As the strength of signal increases, however, the increasing negative charge on the grid capacitor moves the working point on the valve characteristic towards the bottom, where it is becoming increasingly more curved, so that the amplification falls off, and distortion occurs.

If the operating point reaches the bottom bend of the curve, anode-bend rectification will commence. But, with anode rectification, the anode current increases when the signal arrives, which is just the opposite of the conditions with grid rectification. Hence the two effects are in opposition and the detector efficiency falls rapidly and may even become zero. The grid detector is thus most suitable for weak signals. It can be used with strong signals if a high anode voltage is used (see POWER DETECTION) but, in any case, the signal which the circuit can accept is always limited.

GRID DISSIPATION. Heat dissipated in a grid electrode. Although, in the majority of circumstances, the anode has to dissipate the greatest heat, a screen grid may also become very hot when drawing considerable current. As its structure does not lend itself so readily to heat dissipation, the question of overheating of the screen-grid electrode, or the control grid of a gas-filled triode, is one that must be considered when considerable power is handled. See ANODE DISSIPATION, COOLED VALVE, ELECTRODE DISSIPATION.

GRID EMISSION. Emission of secondary electrons from a grid electrode. See SECONDARY EMISSION.

GRID GLOW-TUBE. Glow-tube in which a grid regulates initiation of the discharge.

GRID IMPEDANCE. Impedance of the control-grid electrode. See ELECTRODE IMPEDANCE.

GRID KEYING. In radio telegraphy, the keying of the sender by changing the grid bias on one of its valves.

GRID LEAK. High-value resistor connected between the grid of a valve and a point of steady potential, such as an earth connexion or a GRID-BIAS BATTERY (q.v.), when there is a capacitor in the grid circuit. Without a grid leak or some other conducting path from the grid, electrons would accumulate on the grid, causing the anode current to fall to zero and the valve to become inoperative. This is prevented by the grid leak, which provides a path, that is, a leak for the electrons on the grid.

GRID MODULATION. Modulation in which the grid potential of a valve is varied by both the carrier and modulating waves. The term is used to distinguish grid from anode modulation; the former being a non-linear and the latter a linear form of modulation. See NON-LINEAR MODULATION, GRID MODULATOR.

GRID MODULATOR. Non-linear modulator in which the sources of the carrier and modulating waves are connected in series in the grid-cathode circuit of a valve. A filter in the anode circuit of the valve selects the modulated wave. Fig. 17 shows the schematic of a grid modulator, and the resulting wave forms. The valve is operated at a bias greater than cut-off and, when the modulating wave has its maximum positive amplitude, class-B operation is obtained. For all other values of the amplitude of the modulating wave, the valve operates under class-C conditions. If some degree of modulation distortion is tolerable, the grid may be allowed to become more positive than the cathode, thus increasing efficiency. See GRID MODULATION, MODULATION DISTORTION, NON-LINEAR MODULATION.

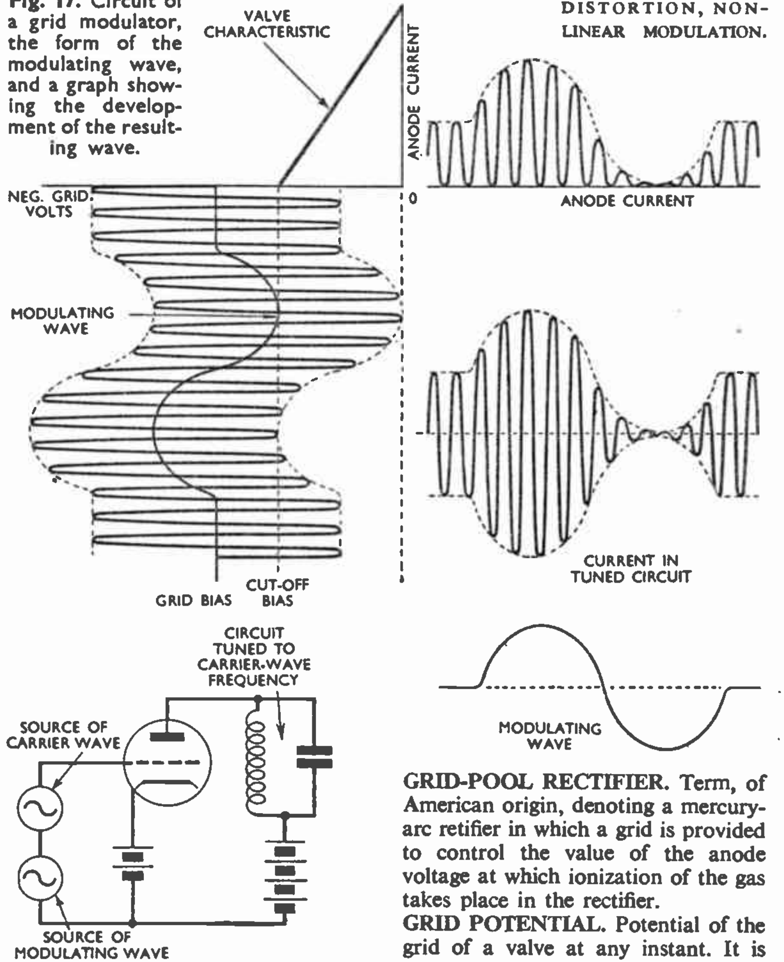


Fig. 17. Circuit of a grid modulator, the form of the modulating wave, and a graph showing the development of the resulting wave.

GRID-POOL RECTIFIER. Term, of American origin, denoting a mercury-arc retifier in which a grid is provided to control the value of the anode voltage at which ionization of the gas takes place in the rectifier.

GRID POTENTIAL. Potential of the grid of a valve at any instant. It is usually given with respect to the cathode. See GRID BIAS.

GRID RECTIFICATION. See GRID DETECTION.

GRID RESISTANCE. Deprecated synonym for GRID SLOPE-RESISTANCE.

GRID SLOPE-CONDUCTANCE. Inverse of GRID SLOPE-RESISTANCE.

GRID SLOPE-RESISTANCE. Slope resistance of the control grid. This is finite only when grid current flows. See CONTROL GRID, GRID CURRENT, SLOPE RESISTANCE.

GRID-STOPPER. Synonym for PARASITIC STOPPER.

GRID SWEEP. Difference between the extreme limits of the grid potential of a valve used as an amplifier (Fig. 18). It is obvious that, if the excursions of grid potential either reduce the grid potential below the cut-off value, or make it positive with respect to cathode, distortion of the output wave is liable to occur. The term "available grid sweep" is used to mean the total excursion of grid volts over which the grid-volts/anode-current dynamic characteristic of the valve is substantially linear. See AMPLIFIER, CLASS-A, CLASS-B AND CLASS-C VALVE OPERATION.

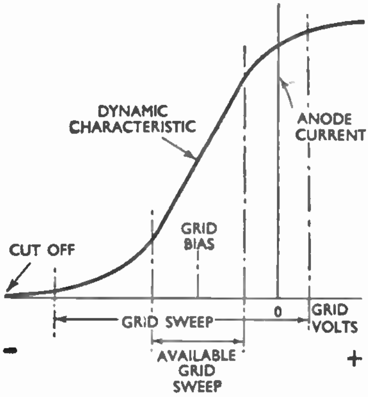


Fig. 18. Diagram showing that the grid sweep is the total excursion of grid volts; the available grid sweep is that portion of it over which the grid-volts/anode-current characteristic of the valve is substantially linear.

GRID SWING. Synonym for GRID SWEEP.

GRID VOLTAGE. Term commonly used for GRID POTENTIAL.

GRID-VOLTS/ANODE-CURRENT CHARACTERISTIC. Graph of the voltage of the control grid plotted against the resulting anode current. Fig. 19 shows the typical grid-volts/anode-current characteristics of a triode. For any one curve the anode voltage is constant; and its value determines the position of the curve. The slope of the curve at any point gives the mutual conductance of the valve at that point. Mutual conductance should be defined with respect to grid and anode volts. When a tetrode or pentode characteristic is shown, the value of the screen-grid bias is also given because the position of the curve is also affected by this. See ANODE-VOLTS/ANODE-CURRENT CHARACTERISTIC, GRID SWEEP, MUTUAL CONDUCTANCE.

GROUND. Synonym used in America for EARTH.

GROUNDED-GRID AMPLIFIER. Triode amplifier of radio-frequency waves in which the control grid is earthed and the input wave is applied between cathode and earth and thus

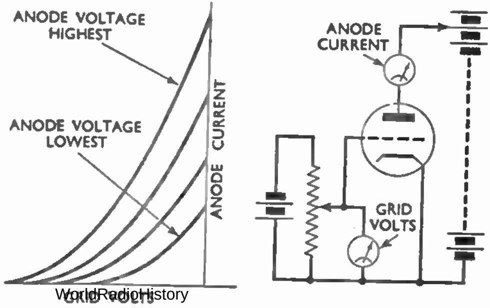


Fig. 19. Grid-volts/anode-current characteristics of a valve at four fixed values of anode voltage. The circuit diagram indicates how the values are taken, the anode voltage being kept constant for plotting each graph.

varies the potential of the cathode. The circuit, shown in Fig. 20, has the advantage over the more conventional arrangement that little, if any, neutralization is necessary. A conventional triode amplifier cannot be used for amplification of waves whose frequency is greater than about 100 kc/s because the anode-control grid capacitance causes positive feedback and consequent oscillation. This can be overcome by neutralization, or by the adoption of the grounded-grid amplifier arrangement. In the latter, the grid acts as a screen between anode and cathode and helps to prevent feedback via anode-cathode capacitance. The grounded-grid amplifier is also known as the inverted amplifier.

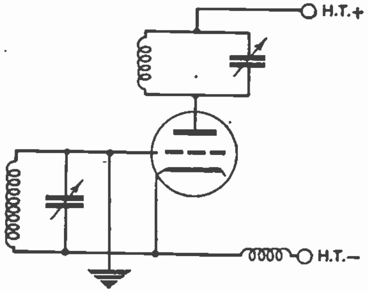


Fig. 20. Grounded-grid amplifier, sometimes known as an inverted amplifier; the input is applied between the cathode and earth.

GROUND-PATH ERROR. That component of the total error of a direction-finding system which is due to lateral deviation of waves that travel over the surface of the earth, in distinction from errors due to lateral or other deviation of those which come by reflection from the ionosphere.

GROUND RAY. Radio ray which travels to the receiver over the surface of the earth and is not reflected by the ionosphere. At low frequencies, it is usual to speak of the ground wave, but at the higher frequencies, where the wavelength is small compared with the distance travelled, it is permissible to think of radio rays as if they were optical rays; but it must be remembered that the rays have no separate existence and are simply representative of an indefinite number of possible paths.

As the distance from the sender increases, the ground ray gets weaker, the actual strength depending upon the frequency in use and the nature of the intervening terrain. For example, a station having a ground range of, say, 1,000 miles over sea water would have a range of only about 100 miles over desert sand.

Moreover, the lower the frequency in use, the greater is the ground range. This is because diffraction effects in the lower atmosphere cause a tilting of the wave front downwards, a process which tends to make the wave follow the surface of the earth. The tilting increases with the frequency, which accounts for the rapid disappearance of the ground ray at high frequencies. With low and medium frequencies, the range of the ground ray may be increased by increasing the power radiated, but, because of diffraction effects at high frequencies, an increased ground-ray range is not evident.

Ground rays of all frequencies suffer absorption due to earth currents; these absorption losses are proportional to frequency and become very great at high frequencies. See ABSORPTION, DIFFRACTION, SPACE WAVE, SURFACE WAVE.

GROUND WAVE. Radio-wave which travels to the receiver over the surface of the earth and is not reflected by the ionosphere. See GROUND RAY.

GROUP DELAY. Time taken for a wave to travel between two points. It is given by the distance travelled by the wave between the two points, divided by the group velocity. See GROUP VELOCITY.

GROUP FREQUENCY. Frequency of trains of oscillations or waves expressed in terms of the number of trains per unit time. In a spark system, the group frequency is equal to the spark frequency.

GROUP MODULATION. Process in which the same frequency is added to or subtracted from the frequency of a number of waves of different frequency, such waves representing several different messages sent by carrier transmission.

Group modulation is employed typically in carrier transmission over cables and open-wire circuits. A group of messages is transmitted by modulating carrier waves of different frequencies. This transmission occupies a given frequency band, within which there are a number of (single) sidebands in frequency juxtaposition. It may be convenient to transpose all the waves in the band to lie between higher or lower frequency limits. The process involved is called group modulation.

Group modulators are usually ring modulators. The complete band to be group-modulated is taken to the modulating-wave terminals of the modulator, and a local oscillator supplies the carrier wave. Thus the same carrier-wave frequency is added to, or subtracted from, all the waves comprising the several different transmissions. Filters must be used to separate the desired frequency bands at the output. See FREQUENCY-CHANGING, RING MODULATOR.

GROUP MODULATOR. See GROUP MODULATION.

GROUP VELOCITY. Velocity of a group of sinusoidal waves. It is the velocity of a characteristic feature of the wave envelope; the amplitude, for example. The group velocity is the velocity of the energy associated with the waves. It takes a certain time for a wave to travel between sender and receiver. The group velocity of a radio signal is the velocity of light, which is 186,000 miles per second. All waves transmitted through space travel at the same velocity, which is that of light waves. In transmitting waves through wires, the velocity of propagation is less than that of light. Waves of different frequency may travel at different velocities. See DELAY DISTORTION, PHASE VELOCITY, WAVE.

GUARD BAND. Term used in connexion with frequency bands used in sending a number of modulated carrier waves through the same medium. Each message is transmitted on a separate channel characterized by a particular carrier-wave frequency (see CHANNEL). If the separation of carriers in a double-sideband system were exactly twice the highest modulation frequency, sidebands would not overlap. It would, however, be impossible to design filters with so sharp a cut-off as to ensure the full pass of one band and complete attenuation of waves outside this band. In consequence, a guard band is left between the sidebands of transmissions occupying adjacent channels. See CARRIER-WAVE TRANSMISSION, MODULATION, SIDEBAND, SIDEBAND WAVE.

GUIDED WAVE. Radio-wave travelling down, and controlled by, a hollow conducting tube known as a waveguide. Broadly speaking, waves travelling down ordinary transmission lines may be termed guided waves, but the term nowadays is usually reserved for wave-guide transmission. See WAVEGUIDE.

GUN. In a cathode-ray tube, the system of electrodes which produces and controls the electron beam.

GUN CURRENT. Total current produced by the electron stream emitted by the cathode of a cathode-ray tube.

H

H. Abbreviation for HENRY(S).

H_2S. See NAVIGATIONAL AID, RADAR.

HALF-WAVE AERIAL. Aerial which is approximately half a wavelength in physical length. More precisely, an aerial which resonates at a particular frequency in such a manner that there is a voltage-maximum point at each end and a single voltage-minimum point in the middle.

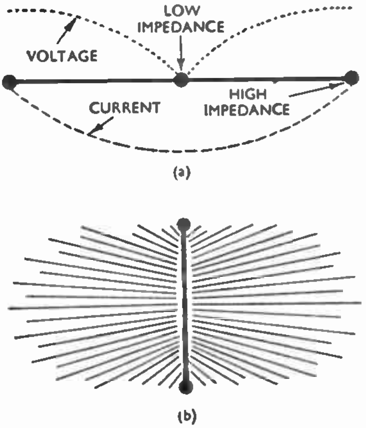


Fig. 1. Characteristics of a wire or rod behaving as a half-wave aerial. Diagrams show (*a*) impedance–voltage–current relationships, and (*b*) radiation, which is strongest perpendicularly from the axis of the aerial and nil in the end-on directions.

The half-wave section is a characteristic element common to most forms of aerial; the majority of aerial types can be built up from such sections. The quarter-wave aerial, for instance, is simply half a half-wave element, with the earth or a counterpoise system representing the missing half. A long aerial responding to some harmonic of its fundamental frequency does so in such a way that there is a series of half-wave patterns of voltage maxima and minima along the wire. Even a slot aerial possesses some of the properties of a half-wave element.

The half-wave mode of response is, in fact, the natural one for any isolated and elongated conductor exposed to a stimulus of appropriate frequency. An understanding of the general properties of the half-wave aerial is, therefore, a desirable preliminary to any study of aerials.

The voltage and current distribution along a wire resonating in half-wave fashion is shown in Fig. 1, which indicates that the current is large at the centre and zero at the ends, where there is, of course, nowhere for it to go. The voltage, on the other hand, is high at the ends and progressively lower towards the middle, the distribution being similar to that in a closed oscillatory circuit containing lumped inductance and capacitance (the differences between a resonating rod or straight wire and a closed circuit with lumped constants are mainly in details arising from the fact that the inductance and capacitance of the rod are spread uniformly along its length).

If connexion is made to a half-wave aerial at various points for the purpose

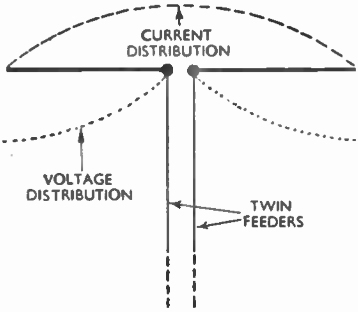


Fig. 2. In a half-wave aerial, current is highest at the centre and zero at the ends, while the voltage is low at the centre and high at the ends. The aerial shown is centre- (or current-) fed.

of injecting energy into it (for instance, by linking it to a sender through a twin-feeder line) its impedance seems to vary according to the position of the point of connexion. If the wire is cut in the middle and feeders are joined to the two halves (Fig. 2), the impedance of the aerial will appear low—about 80 ohms. At either of the two outer ends, on the other hand, the impedance is high—several thousand ohms.

These points of connexion are often useful in devising feed systems to suit various purposes; and further adjustments can be made by connecting feeders, not to an opening in the centre of the aerial, but across a length of the aerial chosen to give the desired impedance.

A half-wave aerial suspended vertically, and fed with energy from a sender, radiates uniformly in all horizontal directions, behaving as an omnidirectional aerial. There is practically no radiation from the ends of such an aerial, and no energy is directed upward or downward.

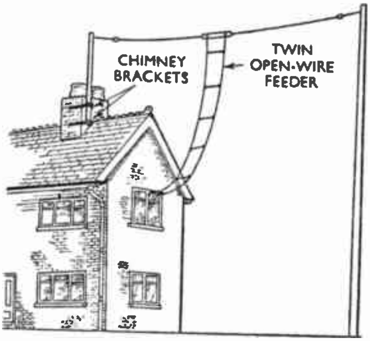


Fig. 3. Centre-fed horizontal half-wave dipole with slung open-wire feeder, the wires of which are spaced a few inches apart by rod insulators.

A half-wave aerial slung horizontally gives a figure-of-eight horizontal polar diagram. This is similar to the polar diagram of a loop-aerial, because of the absence of radiation from the two ends. If several half-wave elements are grouped side by side in an array and energized appropriately, the figure-of-eight becomes more and more elongated the greater the number of half-wave units; this is the basis of the broadside array. (If the half-wave elements are grouped vertically, a figure-of-eight polar diagram results, this replacing the circular polar-diagram characteristic of the single vertical aerial.)

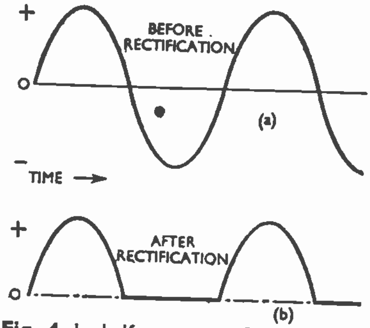


Fig. 4. In half-wave rectification, only one half of the wave is used to produce unidirectional current. If alternate half-cycles of wave (*a*) are suppressed, wave (*b*) is the result.

In practical applications, it is probably more often desired to produce a beam strengthened in one particular direction than a two-direction figure-of-eight diagram. This can be done with half-wave elements by using a broadside array backed at a suitable distance by a second array of passive aerials to act as reflectors When excited by the radiation from the active aerials, these in their turn emit waves which reinforce those in a forward direction and tend to cancel out with those going back behind the array (see PASSIVE AERIAL).

The practicability of the half-wave aerial in its basic form is a matter of wavelength. Above rather indefinite limits this aerial becomes unwieldy, and below another limit it again ceases to be practicable because of unexpectedly acute difficulties in adjusting it accurately to wavelength. The upper and lower wavelength limits are in the region of 40 metres and 10 centimetres; but horizontal half-wave aerials of much greater length are sometimes used, and shorter ones have been common in connexion with laboratory work for a long time. See AERIAL, AERIAL-ARRAY, BROADSIDE ARRAY, HALF-WAVE DIPOLE, OMNI-AERIAL, PASSIVE AERIAL, TIER.

HALF-WAVE DIPOLE. Length of wire, rod or tube, usually straight, approximately one half-wave in length, in which the current and voltage distribution is symmetrical about the centre point. This type of aerial is of considerable importance at the higher frequencies. It is used, normally without earth connexion, both for sending and receiving, commonly with a twin feeder connected to the centre (Fig. 3) where the two halves of the dipole are separated for the purpose (see CURRENT-FED AERIAL, VOLTAGE-FED AERIAL).

When maximum efficiency at a fixed wavelength is required, the half-wave dipole is made approximately 0·97 of the actual half wavelength, allowance thus being made for the effect of insulating supports and the like. A half-wave dipole aerial may be erected horizontally or vertically, according to the direction of polarization of the waves to be radiated or received. See HALF-WAVE AERIAL.

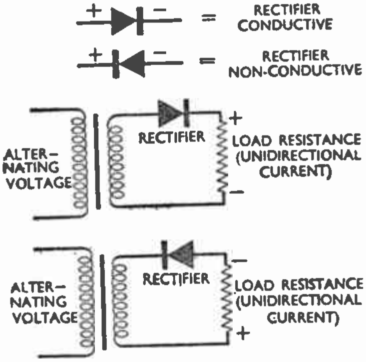


Fig. 5. Basic circuit of a half-wave rectifier; the element is conductive only during alternate half-cycles of the voltage induced in the secondary winding of the transformer.

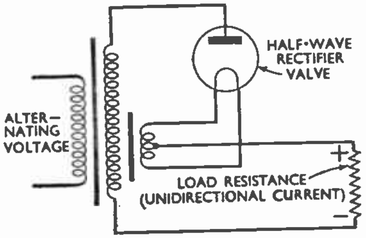


Fig. 6. Basic circuit for a diode used as a half-wave rectifier.

HALF-WAVE RECTIFICATION. Method of rectification in which unidirectional current is produced during one or another half-cycle of the wave being rectified. The results of half-wave rectification are shown in Fig. 4; it should be compared with that elsewhere illustrating FULL-WAVE RECTIFICATION. See also HALF-WAVE RECTIFIER CIRCUIT.

HALF-WAVE RECTIFIER CIRCUIT. Rectifier circuit in which a single rectifier unit is connected between a source of A.C. and the load to be supplied with D.C. Typical circuits for producing half-wave rectification are shown in Figs. 5 and 6.

Obviously it is not so efficient as full-wave rectification and has the disadvantage that the unidirectional current flows in the transformer secondary, thus magnetizing the transformer core. The circuit has practical use for detection. A circuit employing a mechanical rectifier is shown at Fig. 7. See FULL-WAVE RECTIFICATION, HALF-WAVE RECTIFICATION.

HALF-WAVE SUPPRESSOR COIL. Inductor placed at half-wave intervals along an aerial in which it is desired to suppress radiation in reverse phase from alternate half-wave sections. The arrangement is applicable only to aerials, such as the Franklin, with a

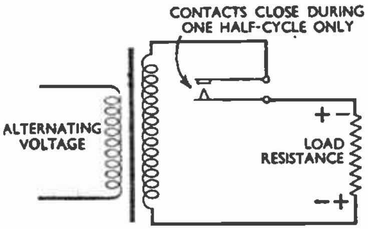


Fig. 7. Mechanical half-wave rectifier; the contacts close at the instant the alternating voltage is zero and open when the value is again zero, remaining so for the next half-cycle, and so on. The current in the load resistance is thus unidirectional.

length large compared with the half wavelength. See FRANKLIN AERIAL.

HAM. Term applied to amateur who operates a radio station.

HARD-VACUUM VALVE. Valve in which the amount of gas is so small that it has substantially no effect upon the operating characteristics of the valve. The space current is carried by electrons, not by ions. The hard-vacuum valve is one in which a proportionality exists between electrode voltages and electrode currents over large portions of the characteristic. It can thus be used as an amplifier, detector and oscillator. The GAS-FILLED VALVE (q.v.) is one in which the valve has virtually two conditions, conductive or non-conductive. See GLOW-TUBE, SOFT-VACUUM VALVE, VALVE.

HARD VALVE. Synonym for HARD-VACUUM VALVE.

HARMONIC. Sinusoidal oscillation, the frequency of which is an integral multiple of some basic frequency, the latter being called the fundamental in this connexion. Thus, an alternating current with a frequency of 50 c/s might have a third harmonic of 150 c/s, a fourth harmonic of 200 c/s, and so on. Harmonics are sometimes expressed in terms of wavelength. Thus, the third harmonic of a wave of 600 metres is a

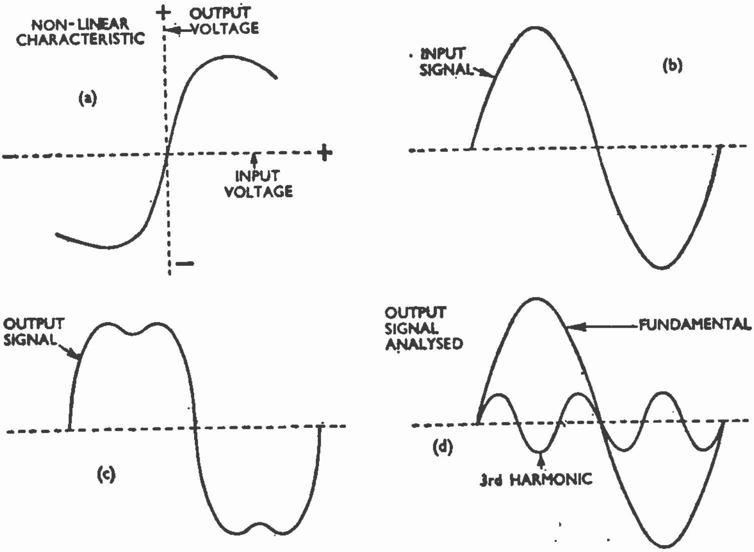


Fig. 8. Wave forms which illustrate the principles of harmonic distortion. If a pure sine wave (*b*) is applied to a non-linear device having, for example, an operational characteristic (*a*), the output is distorted (c). This output wave consists of a fundamental with the addition of one or more harmonics (*d*).

wavelength of 200 metres. Harmonics play an important part in sound reproduction; in complex sounds, such as those of speech and music, it is the relative amplitude of the harmonics to the fundamental which imparts the characteristic quality to a note.

HARMONIC AERIAL. Aerial designed to work on a frequency which is a harmonic, or multiple, of its natural frequency, and operating in standing-wave fashion. See NATURAL FREQUENCY, STANDING-WAVE AERIAL.

HARMONIC ANALYSER. See WAVE ANALYSER.

HARMONIC DISTORTION. Distortion of the wave form occurring when a signal of sine-wave form is applied to an amplifier or other system which is non-linear. As indicated in Fig. 8, the distorted output can be analysed into a fundamental sine wave having the same frequency as the input, together with harmonic waves (see FOURIER ANALYSIS, HARMONIC).

The harmonic distortion may be expressed quantitatively by stating the voltages of all the separate harmonics as percentages of the fundamental, or by giving the vector sum of all the harmonics present (total harmonic distortion; see DISTORTION FACTOR).

Triodes operating normally as amplifiers give mainly second harmonic; in tetrodes and pentodes the third harmonic is also liable to be prominent. Higher harmonics are relatively small unless the input/output graph has sharp bends.

In sound reproduction, the objectionableness of introduced harmonics increases very rapidly with the order of the harmonic. The ear can tolerate a considerable percentage of second harmonic, rather less third harmonic, and very little indeed of eleventh, thirteenth, etc. Total harmonic distortion is, therefore, not a satisfactory measure of distortion unless the proportions of harmonics present are approximately known or can be assumed.

In any case, the unpleasantness of non-linear distortion is due more to intermodulation than to harmonics, but the harmonic distortion being easier to measure is more often used as a measure of non-linearity. See INTERMODULATION DISTORTION, NON-LINEAR DISTORTION.

HARMONIC EXCITATION. Excitation of an aerial at a frequency which is an integral multiple of its natural frequency; or excitation of a transmitter at a frequency which is an integral multiple of that of the master oscillator.

HARMONIC GENERATOR. Any device delivering output power at a frequency which is an integral multiple of that of the input signal. For example, output of a frequency-doubler is twice the frequency of the input signal.

Harmonic generators may consist of a saturated iron-cored inductor or a valve operating on a non-linear portion of a characteristic, the desired output frequency being selected by means of a tuned circuit.

HARMONIC SUPPRESSOR. Network or filter which gives a large attenuation to an harmonic wave or waves, but transmits the fundamental component. See HARMONIC.

HARTLEY OSCILLATOR. Oscillator containing a parallel-tuned circuit connected between the anode and grid of a valve, a tapping point on the inductor being connected to the cathode or to the H.T. supply. Whether

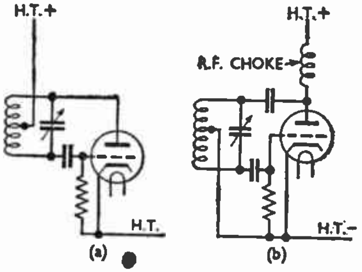


Fig. 9. Two forms of Hartley-oscillator circuit: (*a*) series feed; (*b*) shunt feed, including an R.F. choke.

the tapping point is connected to the cathode or to the H.T. supply, it is at zero alternating potential, and the mutual inductance between the two parts of the inductor provides the positive feedback between anode and grid circuits, which is necessary to maintain oscillation.

Two possible circuits for a Hartley oscillator are given in Fig. 9. In (a) the anode current of the valve passes through part of the inductor; thus all parts of the inductor and capacitor are at a steady H.T. potential with respect to earth. This disadvantage is often serious, but can be overcome by using the shunt-fed Hartley circuit shown in Fig. 9b.

In this the anode current passes through an R.F. choke, and the inductor is coupled to the anode circuit through a fixed capacitor, which is a barrier to D.C. but has low reactance to the A.C. generated. With this circuit arrangement the tapping point can be earthed.

HAY BRIDGE. A.C. bridge of the form shown in Fig. 10, generally used for determining the value of an inductor by comparison with a standard capacitor. When the bridge is balanced, minimum sound is heard in the headphones, and the following equations, where ω represents 2π times the frequency, apply:

$$L=\frac{R_3R_4C}{1+R_2{}^2\omega^2C^2};\ R_1=\frac{R_2R_3R_4\omega^2C^2}{1+R_2{}^2\omega^2C^2}.$$

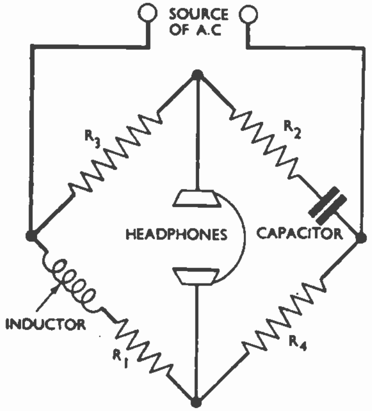


Fig. 10. Hay bridge as used to determine the value of an inductor by comparison with a standard capacitor.

HEADPHONE. Telephone receiver, with head-band attached. It usually consists of a circular iron diaphragm, placed over an electromagnet, the whole assembly being housed in a casing, with an insulated ear-piece to cover the diaphragm.

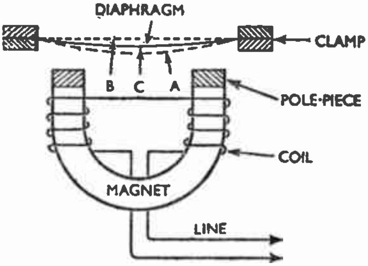


Fig. 11. Simplified diagram which shows how audio-frequency currents in the coil of a headphone, producing a varying magnetic field at the pole-pieces, cause alternate attraction and repulsion of the diaphragm, which thus vibrates at the frequency of the currents in the coil.

The principle of operation is as follows: A magnetic field is produced as shown in Fig. 11. The diaphragm is clamped around its periphery, its centre being drawn toward the magnet pole-pieces (position *C*). A current passed in one direction through the coil will increase the magnetic field and hence the pull on the diaphragm (position *A*). A current in the opposite direction decreases the field, causing the diaphragm to move away from the pole-pieces (position *B*). If the current is alternating, the diaphragm will be moved first in one direction and then in the other as the polarity of the current changes.

In practice, audio-frequency currents are applied to the coil, the diaphragm vibrating at the frequency of the applied signals. A pair of headphones is normally used for purposes of radio reception or programme monitoring in order to maintain aural balance.

HEAD TELEPHONE. Synonym for HEADPHONE.

HEARING. Subjective appreciation of sounds applied to the ear from an external source. See SPEECH AND HEARING.

HEARTSHAPE RECEPTION. Synonym for CARDIOID RECEPTION.

HEATER. Abbreviation for HEATER COIL.

HEATER COIL. That part of an indirectly heated cathode which raises the temperature of the emitting substance, thus causing it to emit electrons. The heater element is usually a coil of wire of considerable resistance. When a current passes through the heater it becomes red hot. The heater is placed inside, but insulated from, the cylindrical cathode. Fig. 12 shows typical heater-coil structures. See INDIRECTLY HEATED CATHODE.

HEATER CURRENT. Current flowing in the heater coil of an indirectly heated cathode. See INDIRECTLY HEATED CATHODE.

HEATER EFFICIENCY. See CATHODE EFFICIENCY.

HEATER SATURATION. See EMISSION LIMITATION.

HEATER VOLTAGE. Voltage applied to the heater coil of an indirectly heated cathode.

HEAVISIDE LAYER. See E-LAYER, IONOSPHERE, KENNELLY-HEAVISIDE LAYER.

HECTOMETRIC WAVE. Radiowave between the wavelength limits of 100 and 1,000 metres, that is, within a frequency range of 3 Mc/s–300 kc/s. See MEDIUM-FREQUENCY WAVE.

HEDGEHOG TRANSFORMER. Transformer whose core is formed by iron wires the ends of which are bent over to form a partially closed iron circuit. The transformer is not much used nowadays. So much progress has been made in suiting laminations to particular requirements as to render other types of core, except iron-dust cores, obsolescent. See CORE, TRANSFORMER.

HEISING MODULATOR. Synonym for ANODE MODULATOR.

HELIX. Term used to describe an obsolete type of inductor of air-spaced copper strip, wound in the form of a clock spring.

HENRY. Practical unit (abbreviated H) of inductance, of convenient magnitude for the rating of inductors with iron cores. For smaller values, such as those found in inductors without cores used for tuning and other purposes in radio-frequency work, the millihenry (abbreviated mH) and the microhenry (μH) are used; these represent a thousandth and millionth part of a henry respectively. The henry is defined as the amount of inductance required to set up a back-e.m.f. of one volt when the current through it is changing at the rate of one ampere per second.

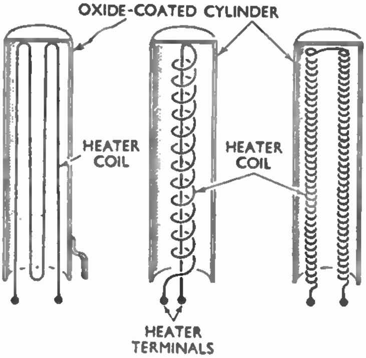


Fig. 12. Three typical forms of heater coil used to raise the temperature of cathodes of indirectly heated valves. The wire which forms the heater is invariably of tungsten.

HEPTODE. Valve with seven electrodes, used for frequency-changing; it is also known as a pentagrid. See FREQUENCY-CHANGER VALVE.

HERTZIAN OSCILLATOR. See OSCILLATOR.

HERTZIAN RADIATOR. Synonym for HALF-WAVE DIPOLE.

HERTZIAN WAVE. Synonym for ELECTROMAGNETIC WAVES.

HETERODYNE. Term used to denote what is now properly known as BEATING.

HETERODYNE DETECTOR. Device for detecting continuous waves. The rectification of a C.W. signal provides a direct current of constant amplitude, which will produce no response in a pair of telephones except for a click at the beginning and end of the signal; moreover, the detector output cannot be amplified at A.F. For C.W. reception, it is usual, therefore, to modulate the signal at the receiving end. This is done by mixing the received signal with a locally generated signal of slightly different frequency.

Beats are produced between the two frequencies, the strength of the combined current being a maximum when the two currents are oscillating in phase. A short while afterwards, however, due to the difference in frequency between the signals, one oscillation begins to lag behind the other, and later an instant is reached at which they are oscillating in exactly opposite phase.

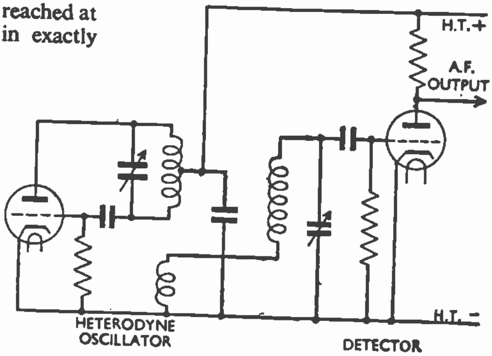


Fig. 13. Circuit of a simple heterodyne detector. A voltage from the local oscillator is induced into the signal-frequency circuit, and the combined signal is then rectified by the grid detector.

In this condition, the combined signal will be a minimum, and the strength of the combined signal will thus vary between a maximum and a minimum periodically. It can be shown that the frequency of this beat is equal to the difference in frequency between the local oscillation and the incoming signal.

A simple heterodyne detector is shown in Fig. 13. It is still necessary to rectify the resultant signal, because this is still at a radio frequency although it is now modulated in amplitude at the beat frequency. Hence a voltage from a local oscillator is induced into the signal-frequency circuit, and the combined signal is rectified by a grid detector.

Theoretically, a heterodyne detector should obey a square law so that the output is proportional to the square of the input signal. Only under such conditions is the output free from distortion.

Since C.W. signals, however, are usually telegraph signals, distortion is of minor consequence. On the other hand, a square-law detector provides an output which is proportional to the product of *both* signals, so that, by using a strong local oscillation, substantial amplification can be obtained during the detection process.

Heterodyning, however, is usually performed nowadays by an electronic mixer such as is used in superheterodyne receivers (Fig. 14). Such a valve provides an output proportional to the product of the incoming and local signals in the same way as does a square-law detector. See BEAT, BEATING, FREQUENCY-CHANGER, FREQUENCY-CHANGER VALVE.

HETERODYNE FREQUENCY METER. Stable radio-frequency oscillator, accurately calibrated, which can produce an audible beat with another oscillation, or with a signal, the frequency of which is to be measured. The meter is adjusted to zero beat, when the calibration reading indicates the frequency of the oscillation being investigated.

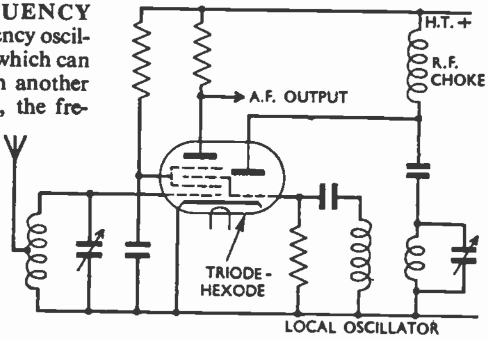


Fig. 14. Normal practice is to use a triode-hexode as a heterodyne detector; its output is proportional to the product of both the incoming and local signals.

HETERODYNE OSCILLATOR. Synonym for BEAT OSCILLATOR.

HETERODYNE RECEPTION. Synonym for BEAT RECEPTION.

HETERODYNE WHISTLE. See INTERFERENCE.

HEXODE. Valve with six electrodes. See FREQUENCY-CHANGER VALVE.

HIGH-DEFINITION TELEVISION. Name given to any system of television in which the scanning provides for more than 200 lines for each picture. Television commenced with low-definition systems, such as the 30-line mechanical method used originally by Baird.

Television is a highly complicated process, in which a scene, with all its details and light and shade, must be converted from a combination of reflected light rays into a series of electrical impulses which can be made to modulate a radio signal, and the process then reversed so that a replica of the original combination of light rays is produced. All this must be done in such a way that not only is movement transmitted, but that light and shade is retained in its original gradations.

A given source of light is caused to actuate a photocell. It is easy to vary the intensity of the light and by so doing vary the potential developed in the cell. With this single light source it is not difficult to go a step further and cause the variations in light, by means of the variations in potential in the cell, to modulate a radio sender so that the brighter the illumination, the greater the carrier amplitude obtained.

Moreover, the received signal can be made to modulate a lamp or a cathode-ray tube so that we obtain an increase in light on our screen as the original light increases in intensity, and a decrease as the light becomes less intense. That is the basis of television.

Now consider a scene. It is composed of myriads of points of light, of different and, as the picture moves, changing light intensity which may be of any degree between black and white. This scene cannot be transmitted as a whole. Even if we had myriads of photocells, one for each point of the picture, we could not transmit electrical impulses from all the cells at once.

The alternative is to transmit the impulses in sequence, each impulse corresponding in amplitude to the illumination of a point or element in the scene. Each element is dealt with in its proper order so that a "string" of signals is obtained. At the receiver, the string is laid out on the television screen in the right sequence and the picture is built up again.

The number of elements into which the field of view is divided determines the definition. The size of the elements also affects the detail seen on the receiver screen, since it is the light intensity from the whole of each element that affects the transmitter modulation and we cannot deal with any gradation of light within the area of one element.

Television, therefore, is based on a system which is similar to that used in printing, namely, the division of the picture into small units which, when laid down in their correct relative places, re-form the picture. The action of the retina of the eye works on a similar plan, being built up of small cells each of which plays its part by dealing with one element of the scene being viewed.

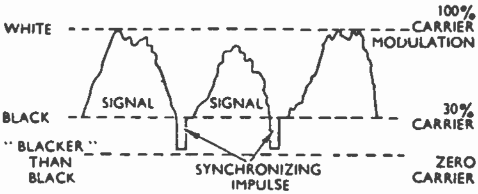


Fig. 15. Example of the transmitted wave form in high-definition television. As the synchronizing impulses are below the 30 per cent carrier-modulation level (at which the receiver screen shows no illumination), they are invisible.

For the method used to provide an orderly transmission of the picture, see SEQUENTIAL SCANNING. The camera employed is fully described elsewhere (see STORAGE CAMERA). We can, therefore, pass on to a more general consideration of the high-definition system, as used by the B.B.C. Other systems are similar in fundamentals, so that there is no need to describe them also.

The method of scanning used employs the principle of interlacing (see INTERLACED SCANNING). Thus, in a 405-line picture, the alternate lines 1, 3, 5, 7, 9 and so on are scanned up to 405, and then the scanning is repeated with lines 2, 4, 6, 8 and so on to line 404. The effect on the eye is to provide a continuous picture such as would be obtained by the scanning of successive lines throughout, but with the illusion that the picture is being scanned at twice the actual speed. A picture scanned *completely* 25 times in every second gives the impression, assessed by its lack of flicker, that it is being scanned 50 times a second.

This is more important than it seems, for, while the apparent picture-frequency has been raised to 50 per second, the actual picture-frequency is only 25. In practice, this has technical advantages. One is that certain types of motional distortion are reduced. Another is that large patches of equal light intensity, which would in sequential scanning produce low electrical frequencies, are made to provide frequencies of a higher order since the scanning spot is not on the object so long without change in intensity.

A great advantage in interlaced scanning is the reduction of the frequency band that the sender and receiver have to cover. This band width can be determined mathematically by a simple formula.

It can be assumed, without serious error, that the single impulse of potential produced as the scanning ray traverses each picture-element in the storage camera is similar to a sinusoidal half-wave form, and of amplitude proportional to the light intensity of the element in question. The scanning of the elements proceeds at a constant rate, so that the electrical impulses follow one another at a definite frequency, producing an electrical frequency equal to half the number of elements scanned per second. This frequency is the maximum frequency which the sending and receiving circuits will have to handle. Let us call that frequency f.

In a square picture, with N scanning lines each the width of an element, there will be N^2 elements. If the picture-frequency is F, the number of elements scanned per second will be N^2F. It can thus be stated that $f = \frac{N^2F}{2}$. With 405-line scanning and 25 pictures a second, the frequency is therefore $\frac{405 \times 405 \times 25}{2}$ where a square picture is concerned.

In the B.B.C. system, however, the picture ratio, sometimes referred to as the aspect ratio, is 4 : 3 (see PICTURE RATIO). So, instead of N^2 in the above formula, we use $N^2 \times P$, where P is the picture ratio, and the formula becomes $f = \frac{N^2 \times P \times F}{2}$. Substituting figures, we have $\frac{405 \times 405 \times 4 \times 25}{3 \times 2}$, which works out at just over 2,700,000 in round figures, or a frequency of 2¾ megacycles per second. That, then, is the modulation frequency that has to be dealt with, so that the sidebands will occupy a band width of 5½ Mc/s.

To accommodate such sidebands, it is obvious that a high-frequency carrier must be used. The British system employs a carrier of 45 Mc/s for the vision signal, and 41·5 Mc/s for sound. The high vision frequency (2¾ Mc/s) requires exceedingly well-designed radio-frequency circuits in sending and receiving amplifiers, and provides serious problems of attenuation and phase distortion, not only in the amplifying circuits, but particularly in any form of line transmission.

The mean brightness of the reproduced picture depends on the D.C. component of the vision signal, and an ideal vision-frequency amplifier must be able to amplify steady potentials in addition to the range of frequencies up to 2·7 Mc/s. The necessity for D.C. amplification does not present any serious problems in television-receiver design because most receivers have only a single stage of vision-frequency amplification, and it is comparatively easy to couple this directly to the diode detector preceding it and to the cathode-ray tube which follows it.

In television senders, however, and in multi-stage vision-frequency amplifiers generally, the design becomes very difficult if direct coupling is attempted throughout, and it is easier to use conventional resistance-capacitance coupling designed for a very low-frequency cut-off, and to use a stage of D.C. restoration at or near the final stage to supply the missing D.C. component.

As every frame is accompanied by a frame-synchronizing impulse, the lowest frequency with which the sender and receiver have to deal is the repetition frequency of this impulse. In the B.B.C. system it is 50 c/s, for, though only 25 pictures are transmitted in a second, the scanning lines have to be returned to the top of the picture 50 times a second, because of the interlacing in which the scan begins alternately at the first and the second line.

Both sender and receiver make use of the inertia-less cathode-ray tube. The camera uses it to scan a special photocell mosaic (see STORAGE CAMERA), and the receiver employs the cathode-ray tube as a means of building up the picture on a fluorescent screen.

It is easy to understand how the intensity of the light from the cathode-ray screen is made to vary by grid control of the number of electrons in the cathode-ray stream. It is not so easy, however, to see, at first, how the cathode-ray tube can be synchronized with the storage camera. The transmitted wave form of a high-definition television signal (Fig. 15) will help to make this point clear.

The carrier, unmodulated by the television signal, is set at a constant level corresponding to 30 per cent modulation. The signal is made to vary modulation *above* this figure. It never causes the modulation to drop beneath 30 per cent.

Therefore, if the receiver cathode-ray tube is so set that it is unmodulated (shows black) when the carrier is at 30 per cent, it will respond only to carrier variations between 30 and 100 per cent. It *cannot* be affected by any variation below 30 per cent. Any fall in the modulation below 30 per cent is known as "blacker" than black. It is in this range of modulation that the line- and frame-synchronizing impulses are sent, the carrier being reduced from 30 per cent to zero at each pulse.

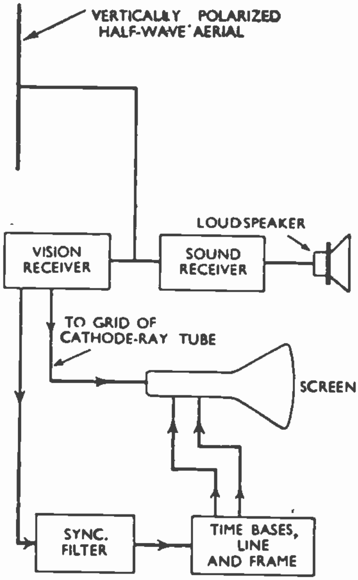


Fig. 16. Schematic diagram of a television receiving system. Synchronizing impulses are separated from the picture impulses by an amplitude filter in the vision receiver.

An amplitude filter in the vision-receiver circuit filters the synchronizing impulses from the vision-modulation (picture) signals, and special circuits (Fig. 16) are used to separate the line- from the frame-synchronizing impulses.

Each receiver cathode-ray line time base is so designed and set that, after each line, the electron beam flies back and waits for the synchronizing signal to trigger it off on the scan of the next line. Similarly, at the end of each frame (line 202 or 405), the electron beam is returned to the top of the screen by the frame impulse.

During the synchronizing impulses all vision signals are suppressed at the sender, and after each line-synchronizing impulse the carrier level is carefully restored to 30 per cent by special restoring circuits. It is essential for correct definition and picture reproduction that the carrier wave's basic modulation level of 30 per cent be accurately retained. It is re-set, therefore, before the commencement of each line.

Both T.R.F. and superheterodyne receivers are used, the former using about four R.F. stages tuned to 45 Mc/s, a band width of at least 4 Mc/s being essential in all receivers. Care must be taken that the number of stages of amplification after the R.F. detector is such that the picture modulation is positive. Phase-reversal takes place at each stage and, unless the correct phase is obtained at the output of the last stage, the picture will be reproduced in negative form.

HIGH FIDELITY. Qualitative term describing an amplifier or electro-mechanical device such as a loudspeaker or gramophone pick-up capable of giving reproduction which is remarkably faithful to the original. The term "high quality" is sometimes used in the same sense. See AMPLIFIER, BROADCAST RECEIVER, LOUDSPEAKER.

HIGH FREQUENCY. Relative term usually referring to high-frequency radio-waves of 3–30 Mc/s in frequency, that is, within a wave range of 10–100 metres. See HIGH-FREQUENCY WAVE.

HIGH-FREQUENCY ALTERNATOR. Synchronous generator for producing currents at very much higher frequency than is used for supply purposes. See SYNCHRONOUS GENERATOR.

HIGH-FREQUENCY AMPLIFICATION. Synonym for RADIO-FREQUENCY AMPLIFICATION.

HIGH-FREQUENCY CHOKE. Obsolescent term for RADIO-FREQUENCY CHOKE.

HIGH-FREQUENCY RESISTANCE. Resistance at radio frequency of a circuit, component or particular conductor. The resistance at high frequency is normally considerably in excess of the low-frequency figure because high-frequency currents tend to travel mostly on the surface of a conductor and do not make use of the inner area of the cross-section, and because they are subject to greater eddy-current and dielectric losses; both of these are included in the high-frequency resistance, in addition to the ordinary D.C. resistance of the particular section of the conductor which high-frequency currents occupy. See DIELECTRIC LOSS, EDDY CURRENT, SKIN EFFECT.

HIGH-FREQUENCY TRANSFORMER. Synonym for RADIO-FREQUENCY TRANSFORMER.

HIGH-FREQUENCY WAVE. Radio-wave between the frequency limits of 3 and 30 Mc/s, that is, within a wave range of 10–100 metres. Waves within this frequency band are commonly known as short waves. The longer wavelengths in this band are reflected by the E-layer, but no hard and fast dividing line can be laid down because the division depends upon the degree of ionization in the E-layer, which varies with the time of day and season of the year. The energy loss whilst the wave is in an ionized region is small, and short waves are reflected from the E-layer with relatively little loss, the attenuation being proportional to $1/f^2$, where f is the frequency. The least attenuation is therefore obtainable with the shorter wavelengths.

As the frequency is increased, a point is reached at which the bending in the E-layer is insufficient to return the wave to earth, and the wave continues on through space until it reaches the F-layer. At the F-layer the intensity of ionization is sufficient to reflect the wave and it ultimately returns to earth.

If the frequency of the wave is higher than the critical frequency of the F-layer, the wave passes right through the F-layer and disappears into outer space. For the normal waves used for broadcasting and commercial practice, most of the reflection takes place at the F-layer. See ABSORPTION, CRITICAL FREQUENCY, E-LAYER, F-LAYER, IONOSPHERE, IONOSPHERIC REFLECTION, MEDIUM-FREQUENCY WAVE.

HIGH-LEVEL MODULATION. Synonym for HIGH-POWER MODULATION.

HIGH-PASS FILTER. Filter which transmits waves having frequencies higher than the cut-off frequency with less attenuation than those having frequencies lower than the cut-off frequency. Fig. 17 shows the basic configurations of a high-pass filter; the shape of its attenuation-frequency characteristic is illustrated in Fig. 12 (page 227) under the heading FILTER. See also BAND-PASS FILTER, FILTER SECTION, LOW-PASS FILTER.

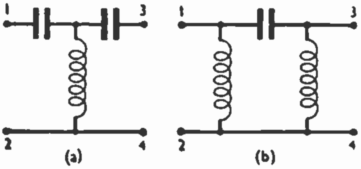


Fig. 17. Basic forms of high-pass filter: (*a*) T-section; (*b*) π-section.

HIGH-POWER MODULATION. Modulation in which the output from the modulated amplifier is passed directly to the transmission channel without further amplification. In order that intelligence may be transmitted, a carrier-wave sender, of any form, must contain a modulator (in telegraphy, the modulator is equivalent to the sending key). Modulation of the carrier wave may take place when this has its maximum power, or, on the contrary, may take place at such a relatively low power that the modulated wave must be amplified before being applied to the transmission channel. This is called low-power modulation (Fig. 18).

There are certain advantages and disadvantages in both systems; some broadcasting senders use high-power, some low-power modulation; neither is definitely better in all respects than the other. See LOW-POWER MODULATION.

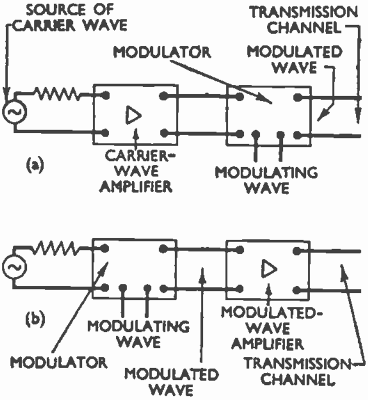


Fig. 18. Schematic diagrams which distinguish between (*a*) high-power and (*b*) low-power modulation.

HIGH-SPEED KEYING. See KEYING.

HIGH-STOP FILTER. Synonym for LOW-PASS FILTER.

HIGH TENSION. Term used in telecommunication practice to describe a source of anode voltage; the abbreviation is H.T. The direct voltage supplied to the anode circuits of valves is usually relatively greater than that used to heat valve cathodes or to establish any fixed grid potential; thus the use of the word "high" to distinguish it.

In installations using considerable power, the high-tension supply may come from direct-current generators or from mercury-arc rectifiers or mercury-vapour rectifiers energized from the mains power supply. In smaller installations, vacuum-valve rectifiers are commonly used to convert the alternating voltage of the mains to a direct voltage.

Batteries may be used for H.T. supply and have a lower internal resistance than that of ordinary mains units of similar capacity. They also eliminate all possibility of the hum which is prone to exist in mains units.

The virtues of any high-tension source are assessed in terms of low internal impedance (giving good regulation) and the diminution of a common coupling impedance which tends to produce instability in valve amplifiers (see MOTOR-BOATING). Low first cost and low maintenance cost, high power-efficiency, reliability and freedom from hum voltage are other important features.

A voltage-stabilized mains unit has many advantages, but has a low power-efficiency. Mercury-arc rectifiers meet the requirements demanded by big power installations, and the mains units using vacuum-valve rectifiers score in simplicity and reliability where only a small output is required. See HIGH-TENSION BATTERY, HUM, MAINS UNIT, VOLTAGE-STABILIZED MAINS UNIT.

HIGH-TENSION BATTERY. Battery of voltaic cells used to supply current to the anode circuit of a valve or valves. Dry-cell high-tension batteries are formed from a number of units having usually a nominal total voltage of 60, 90 or 120 volts maximum. Assuming 1·5 volt per cell, 60 cells are mounted in one unit to form a 90-volt battery (Fig. 19). Tappings are made at various voltages on some batteries; others have + and − connexions only.

Some manufacturers add one or two more cells in a group of 40 to maintain the full battery voltage when the voltage of each cell has fallen a little due to ageing.

A battery may deteriorate even though not used, partly because the container, particularly if damp, becomes conductive and causes the cells to discharge current through it. For this reason, among others, each unit of a battery has a limited maximum voltage. To build a 200-volt high-tension battery all in one unit would be to shorten what is known as its "shelf-life." Batteries have a very short life in the tropics unless special precautions are taken to keep them both cool and dry.

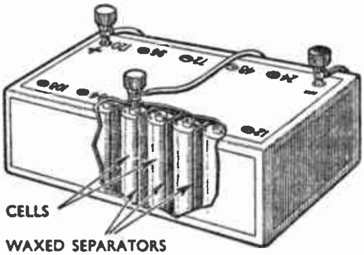


Fig. 19. A 120-volt high-tension battery with tappings. The case is shown partly cut away to reveal some of the cells and separators.

The average high-tension battery supplied for portable radio receivers gives about 5 mA during intermittent discharge periods for a few months. The rating is of the order one ampere-hour (see AMPERE-HOUR CAPACITY).

Small accumulator cells may be used as the units of a high-tension battery, but they require a good deal of attention, demanding constant charging, topping-up, and inspection for sulphating; they have, however, the advantage of a smaller internal resistance and a higher output current than have commonly used types of dry-cell battery.

In very large installations where many amplifiers may be energized from a common high-tension battery, the batteries may be formed from cells having even a 20-ampere-hour capacity. The very low internal impedance of such a battery is its chief recommendation; there is also the fact that it does not produce hum—as would a mains unit unless very special precautions were taken.

High-gain amplifiers, the input to which is at a very low power level, are sometimes energized from batteries in order to avoid any hum voltage. See ACCUMULATOR CELL, DRY CELL, VOLTAIC CELL.

HIGH-TENSION KEYING. In radio telegraphy, the keying of the sender by making-and-breaking the supply circuit to the anode of one or more of the valves.

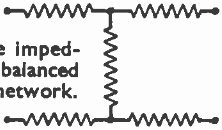
HIGH-TENSION POWER SUPPLY. Source of electrical energy which maintains the anodes of valves positive with respect to their cathodes. In portable receivers the high-tension power supply is generally a dry battery known as the high-tension (H.T.) battery; in A.C.-mains receivers the high-tension power supply is a rectifier and smoothing circuit. See HIGH TENSION, HIGH-TENSION BATTERY.

HIGH-VACUUM VALVE Synonym for HARD-VACUUM VALVE.

HILL-AND-DALE RECORDING. Recording system, particularly gramophone, in which the recording stylus moves up and down in a plane perpendicular to that of the surface of the material. A sound track thus produced varies in depth as the frequency and amplitude of the sound varies. See ELECTRICAL RECORDING.

H-NETWORK. Network composed of five impedances, as shown in Fig. 20.

Fig. 20. H-network of five impedances; it is the balanced form of the T-network.



The H-network is the balanced form of the T-network. See C-NETWORK, L-NETWORK, T-NETWORK.

HOMING SYSTEM. Method of using the direction-finding equipment carried by an aircraft for obtaining the position of a ground radio station. It enables the pilot to fly the plane directly towards the sender.

In early systems a simple loop aerial was used, and the output of the receiver was connected to a differential type of instrument with a centre zero; this gave a zero reading when no e.m.f. was induced in the loop and a reading to left or to right when a signal was received. This visual method is preferable to audible methods because of the very high noise level prevalent in an aircraft.

To use the equipment for "homing," the loop aerial is set at right-angles to the fore-and-aft line of the plane, which is steered so as to obtain a zero reading when the receiver is tuned to the chosen sender (which can be a broadcast sender). This simple system has two disadvantages: it is impossible to tell whether the plane is flying directly towards or away from the sender; and the sender may cease radiating without the pilot being aware of it.

To overcome these disadvantages, a different method was adopted: an instrument was developed having twin pointers which intersect on a centre line if the course being flown is correct, but intersect to the left or the right when the plane leaves the correct course. The height of the point of intersection depends on the received-signal strength, which varies during the flight and thus shows if the transmission ceases.

Between 1939 and 1945 various radar homing devices were developed, some of which give visual indication of the distance to the homing station in addition to information about the course. The most fully developed of these is known as "Rebecca-Eureka."

The distance reading is obtained by sending out pulses from the aircraft, which are received at a ground station and trigger a sender which also radiates pulses. These are received in the aircraft, and the time interval between the sending of each original pulse to the reception of each answering pulse is measured and exhibited on the screen of a cathode-ray tube, the time base of which is calibrated in terms of distance.

For course indication, two directional dipoles are used, mounted to either side of the forward part of the aircraft fuselage, and arranged to produce a cardioid diagram on either side of the line of flight. A switch driven by a high-speed motor alternately connects each aerial to the receiver, and the amplitude of the two signals is compared by observation of the size of two traces, arranged to either side of a vertical time base, on a cathode-ray tube.

For homing, the pilot steers until the traces are of equal amplitude. Frequencies of the order of 200 Mc/s are used, and the range of the system is about 90 miles at a height of 5,000 ft.

HOMODYNE RECEPTION. System in which a locally generated oscillation is adjusted to and reinforces an incoming type A3 signal (see TYPE A3 WAVE).

HONEYCOMB COIL. Special type of wave-wound coil. See WAVE-WINDING.

HONEYCOMB-WOUND INDUCTOR. Synonym for LATTICE-WOUND INDUCTOR.

HORIZONTAL AERIAL. Aerial in which the major part or the pick-up property is concentrated in a horizontally arranged member or members. A low and very long inverted-L aerial can be thus described. See INVERTED-L AERIAL.

HORIZONTALLY POLARIZED WAVE. Radio-wave in which the plane of polarization of the electric field is horizontal. On short wavelengths where half-wave dipoles are used extensively for transmission, horizontally polarized aerial-arrays are commonly used together with horizontal receiving arrays.

There is, however, very little to choose between horizontal and vertical arrays at high frequencies, because reception is by means of the ionospheric ray, whose plane of polarization is almost invariably rotating after reflection. Distant reception is equally good with any type of aerial, irrespective of the polarization of the sending array. In areas where automobile-ignition interference is evident, it is sometimes advantageous to employ a horizontal receiving aerial, because ignition interference is usually vertically polarized. See POLARIZATION.

HOT CATHODE. Cathode raised to high temperature so that electrons are emitted. Such electrons, notably in a hard-vacuum valve, conduct current across the vacuum separating electrodes. The term "hot-cathode valve" distinguishes a valve from a glow-tube. See COLD-CATHODE VALVE, GLOW-TUBE, VALVE.

HOT-WIRE DETECTOR. Early form of detector utilizing the fact that the passage of current through a fine wire raises its temperature, which, in turn, alters its resistance. The detector is therefore arranged in the form of a bridge network which is normally balanced, so that no current flows in the indicator, as shown in Fig. 21. The radio-frequency signals to be detected pass through the arm *AB* of the bridge, thereby increasing the temperature of this arm and consequently causing its resistance to increase. This throws the bridge out of balance and a current flows in the indicator.

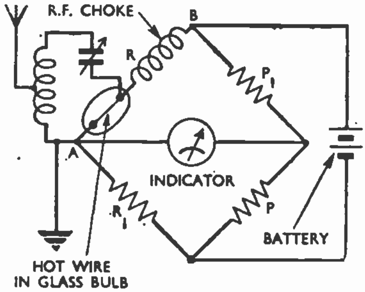


Fig. 21. Circuit of the hot-wire detector. The bridge is balanced, in the absence of a signal, by making $RP = R_1P_1$, R being the total normal resistance of arm AB, including choke.

Provided the change in resistance is small, the current in the indicator is directly proportional to the change of resistance; but the actual current in the indicator is many times greater than the radio-frequency current which gives rise to it. Hence the device not only performs the essential process of detection, but also provides some amplification.

HOT-WIRE MICROPHONE. Microphone depending for its action on the change of resistance of a conductor with change in temperature. In this instrument a wire is cooled by the passage over it of a sound wave, and the resulting resistance change is detected by telephones. The hot-wire microphone is now obsolete.

HOT-WIRE TELEPHONE. Instrument, now obsolete, working on the principles of the HOT-WIRE MICROPHONE (q.v.).

HOWLING. Audible note produced in a receiver in which excessive positive feedback is used, causing oscillation which beats with the received carrier wave. If the oscillation is radiated, the howling may be audible in neighbouring receivers also. See BEAT INTERFERENCE.

H.T. Abbreviation for HIGH TENSION.

H-TYPE ADCOCK DIRECTION-FINDER. Synonym for ELEVATED H-TYPE ADCOCK DIRECTION-FINDER.

HUM. Sound heard in telephones or loudspeakers due to low-frequency alternating currents. Hum voltages are most commonly produced by effects due to the alternating current of the mains supply. Where a mains unit is used, or the heaters of valves are energized from the mains, hum voltages are prone to be produced. Alternating fields, set up by low-frequency currents of large amplitude, may induce hum voltages in the first stages of high-gain amplifiers.

The principal causes of hum are:

1. Insufficient smoothing (or filtering) of the unidirectional currents

produced by the rectifiers in mains units.

2. The use of alternating current to heat the cathodes of valves.

3. Induction of alternating voltages in the amplifier circuits by stray fields set up by the alternating power-supply currents.

4. Insufficient smoothing of currents energizing the magnet systems of loudspeakers, when such devices are used.

There is, in nearly all cases, no reason why all audible hum should not be eliminated provided the cost of so doing is not prohibitive in relation to market and use. The root point is that, in many cases, a residual hum remains because the cost of the apparatus will not bear the extra money necessary to get rid of it.

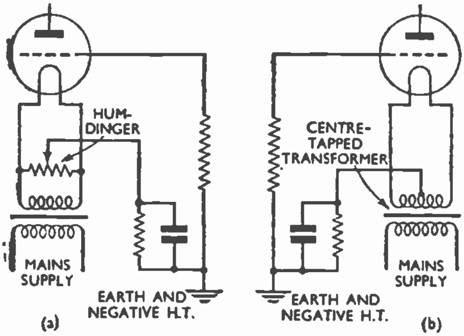


Fig. 22. Two methods of reducing hum in valves with filament-type cathodes: (*a*) by means of a hum-dinger, and (*b*) by the use of a centre-tapped filament transformer.

Hum arising from heating the cathode circuits of valves is partly, but not wholly, determined by the choice of circuit associated with heating the cathode. In valves with indirectly heated cathodes, hum voltages are produced due to the action of alternating electrostatic and electromagnetic fields, set up around the cathodes, which modulate the anode currents, just as superimposed grid voltages would.

In such valves, the fundamental frequency of the mains supply currents may be eliminated by biasing the heater positively in respect to the cathode to avoid electron emission from heater to cathode; this has no effect upon the second-harmonic component. The principal and most effective way to eliminate hum in indirectly heated valves is to provide efficient cathode screening in the design and construction of the valve. Valves with indirectly heated cathodes are available in which the inherent hum voltages are reduced below the level of thermal-agitation noise.

In filament-type valves, the design of the external circuit has a considerable effect in reducing hum. The hum-dinger, a potential divider arranged as in Fig. 22a, may be adjusted so that the mean alternating-current potential of the filament with respect to the anode is as near zero as possible. The use of the centre-tapped transformer is another way to reduce hum in filament-type valves (Fig. 22b). Both diagrams show how resistance in the cathode is used to bias the cathode positively with respect to earth potential.

Since the emission from a filament depends upon its temperature, and because the heating currents vary between a maximum and zero every half-cycle of alternation of the heating current, the anode current may, as a result, vary at twice the heating-current frequency. No external circuit (unless it be that which provides a direct-current heating source) will overcome this source of hum. The makers of the valves are to be trusted, however, to design the valve to reduce this type of hum to a minimum consistent with price and specified use.

Induction of hum in iron-cored inductors and transformers may be

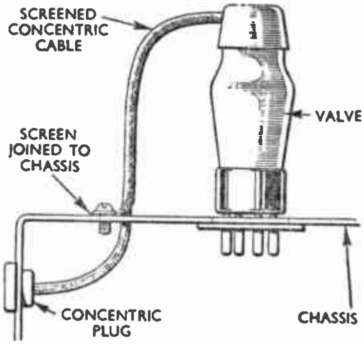


Fig. 23. Example of the use of a screened conductor to minimize electrostatic hum in the first stage of a high-gain audio-frequency amplifier.

reduced by placing these inside Mu-metal screens (an expensive method) or by the use of astatic windings for the transformers and inductors. Electrostatically introduced, hum can be eliminated by screening with copper or, in some cases, brass shields.

In a high-gain audio-frequency amplifier hum may be caused by electrostatic pick-up at high-impedance points (such as grid circuits). This can be minimized by screening and by use of screened wire (Fig. 23), provided that the capacitance introduced by such wire does not affect amplifier performance.

Hum may be caused also by magnetic pick-up in the wiring; this is most serious at low-impedance points in the circuit, and can be minimized by avoiding wiring loops, such as those caused by earthing screens at more than one chassis point.

A loudspeaker may be energized from a mains unit with insufficient smoothing and so set up hum; to eliminate this, a so-called hum-bucking coil may be employed. The improvement in the magnetic materials used for loudspeakers and the extra cost of using what is termed the energized type of magnet is, however, making this kind of loudspeaker obsolescent.

HUM-BUCKING COIL. Coil of a few turns close to, and in series with, the moving coil of an energized loudspeaker, used to reduce hum caused by inadequate smoothing of the D.C. supply.

HUM-DINGER. Tapped resistor that is used with an A.C.-heated valve in order to minimize hum. The resistor is connected in parallel with the filament of the valve, and the negative H.T. connexion is made to the tapping, this being situated in the electrical centre of the resistor (Fig. 22a).

HYBRID COIL. Transformer with four pairs of terminals, the windings being arranged in the form of a bridge circuit. A zero or small output appears at one pair of terminals when another pair is energized, provided that the third pair is connected to a suitable impedance. The hybrid coil has its chief use in telephone practice. It allows a two-way communication to be made on a single line without switching, and without the user being overwhelmed by too strong a reproduction of his own speech.

The diagram (Fig. 24) shows the circuit of a hybrid coil and the condi-

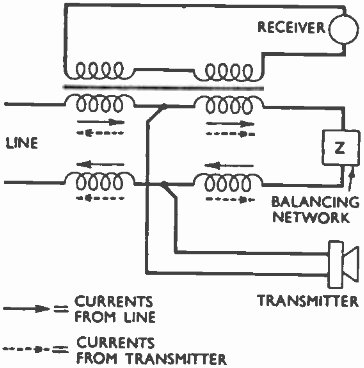


Fig. 24. Use of a hybrid coil in a telephone system. Signals from the line develop a voltage across the receiver, but, with a suitable balancing network, signals from the transmitter, although they are transmitted to the line, do not energize the receiver.

tions when a signal is received from the line or is transmitted to it. When currents are received from the line, the voltages developed across the two secondary coils are additive; but, provided the balancing impedance has the correct value, the secondary voltages connected to the receiver balance out when current is generated by the local transmitter. In practice, however, the balancing impedance is adjusted so that a small signal, known as a sidetone, is sent from the local transmitter to the local receiver. Note that the transmitter or microphone is connected to null points of a bridge circuit, and so does not absorb power from the line. There are many other uses of the hybrid coil, mostly concerned with measurement by bridge circuits. See BRIDGE NETWORK, LINE TRANSMISSION, TRANSMISSION LINE.

HYBRID TRANSFORMER. Synonym for HYBRID COIL.

HYDROMETER. Instrument used to measure the specific gravity of a liquid. The principle of the hydrometer (Fig. 25) is based on the fact that the upward force on a body in a liquid is equal to the weight of liquid displaced. The heavy shot in the bottom of the tube makes it float in a vertical position and the scale registers how deeply it floats; the scale is marked in values of specific gravity.

It is important to maintain the specific gravity of the acid in accumulators at a certain value, and a hydrometer is essential in the practice of accumulator maintenance. In larger cells which stand always in one place, the top (usually a glass plate) may be removed and the hydrometer dropped in to the liquid beside the lead plates.

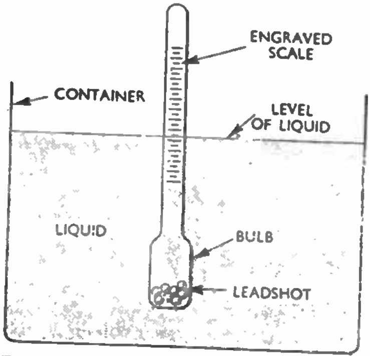


Fig. 25. Diagram illustrating the principle of the hydrometer. Graduations on the stem are in values of specific gravity, the reading being made from the scale at the level of the liquid.

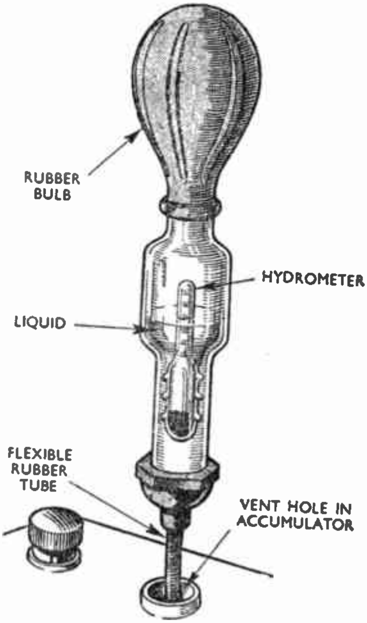


Fig. 26. Usual form of hydrometer for testing the specific gravity of acid in sealed accumulator cells.

In portable accumulators, however, which are sealed except for the vent holes, an arrangement such as that shown in Fig. 26 is used. Squeezing and releasing the rubber bulb sucks the liquid into the glass container and the hydrometer floats in the liquid.

The specific gravity of the acid varies with the charge in the accumulator. In certain makes of accumulator, a pointer, the position of which is determined by the specific gravity of the acid in the accumulator, registers the charge in the cell as "Full," "¾," "½," "¼," "0," the pointer and its mechanism constituting an hydrometer.

HYPERBOLIC NAVIGATION. System of navigation in which a craft's position is determined on a lattice of hyperbolic lines. These hyperbolae denote a constant difference of distance from two points which are synchronized, ground-based, sending stations. See NAVIGATIONAL AID.

HYPERFREQUENCY WAVE. Synonym for SUPER-FREQUENCY WAVE.

HYSTERESIS FACTOR. Proportion of the total loss in a capacitor which is due to hysteresis in the dielectric.

I

ICONOSCOPE. See STORAGE CAMERA.

I.C.W. Abbreviation for interrupted continuous wave, a synonym for TYPE A2 WAVE.

IDLE COMPONENT. Synonym for REACTIVE COMPONENT.

I.F. Abbreviation for INTERMEDIATE FREQUENCY.

IGNITION INTERFERENCE. Interference of an impulsive type caused by radiation from the ignition systems of petrol engines. It is generally most severe in the very-high-frequency wave band, and is the most widespread form of interference to which television is subject. The most effective cure is suppression at the source by means of screening the ignition leads and fitting suppressor resistors in series with the sparking plugs. The effects in receivers can be mitigated by limiter circuits.

IGNITRON. Mercury-arc rectifier in which an ignition electrode is used to maintain the flow of current every half-cycle of alternation of the wave that is applied. The term, of American origin, describes a mercury-arc rectifier which, like the mercury-vapour (hot-cathode) rectifier, possesses an automatic starting facility and yet has the heavy current capacity of an ordinary arc rectifier. In the ordinary mercury-arc rectifier, a considerable process has to be gone through before the arc is struck and the device, therefore, ready to function. In the Ignitron, however, rectification begins at once.

The Ignitron is a mercury-arc tube having a mercury pool in the bottom of an evacuated bulb and an anode above the pool. It also contains an igniting electrode which serves to strike the arc at a given period determined by the cycle of alternation of the applied current.

The igniting electrode is made of a suitable refractory material and makes contact with the mercury pool. A large current passes between this electrode and the mercury pool surface and this creates a small spark. This develops into an arc between anode and cathode if a suitable potential is applied to the anode at the time the spark is struck. Once the arc is established, the ignition circuit opens, so saving the power otherwise necessary to maintain the arc. See MERCURY-ARC RECTIFIER, MERCURY-VAPOUR (HOT-CATHODE) RECTIFIER.

IMAGE-ATTENUATION COEFFICIENT. Real part of the image-transfer constant of a network. This coefficient expresses the difference in level between the signals at the input and output terminals of a network terminated in its image impedance. See ATTENUATION COEFFICIENT, IMAGE IMPEDANCES, IMAGE-TRANSFER CONSTANT.

IMAGE DISSECTOR. Electron camera developed by Farnsworth. It uses a photo-electric cathode on which an image of the subject to be televised is focused. Each minute portion of the cathode emits electrons, the number being directly proportional to the amount of the light falling on it.

By a suitable electromagnetic field, the electrons from any point on the cathode can be made to focus at a point. This point is a hole in the anode which is kept at high potential with respect to the cathode. By means of deflector coils situated outside the tube, the electron image focused on the hole in the anode is made to move up and down and across the tube, so that the image is made to scan the hole. The effect is of scanning the cathode in a regular sequence of lines.

The electrons passing through the hole in the anode can then be collected and made to produce a potential difference which varies in accordance with the amount of light falling on various parts of the original image.

The scanning is accomplished by applying to one set of deflector coils (Fig. 1) a saw-tooth current wave having a frequency equal to the number of times per second the scene is to be scanned, that is, the frame frequency, and to the other coils a saw-tooth current wave having a frequency equal to the line frequency.

IMAGE-DISSECTOR MULTIPLIER. Device incorporated into the Farnsworth image dissector (see IMAGE DISSECTOR) which provides amplification by electron multiplication. The anode of the image dissector is replaced by a second cathode having a small hole in it, as shown in Fig. 2. Behind the second cathode is a cylindrical anode, and behind this is a third cathode coated with some electron-emitting material, such as caesium.

Electrons given off by the first cathode and accelerated by the anode fly through the hole in the second cathode as the scanning process is carried out. After passing the anode they strike the third cathode, where secondary electrons are given off. These are attracted by the anode and, since an alternating potential is applied between the third and second cathodes, the electrons fly past the anode and strike the back of the second cathode. Again secondary electrons are released, and they fly back to the third cathode, releasing still more secondaries.

Thus the few electrons escaping through the hole in the second cathode from the camera section give rise to a comparatively large stream of electrons bouncing back and forth between the second and third cathodes.

Two methods of stopping the process can be used. One is to make use of the drift of electrons to the anode, and to control the rate of drift by a guiding magnetic field set up by the solenoid

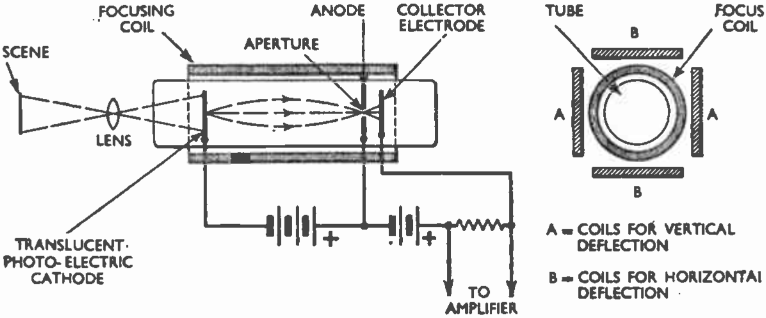
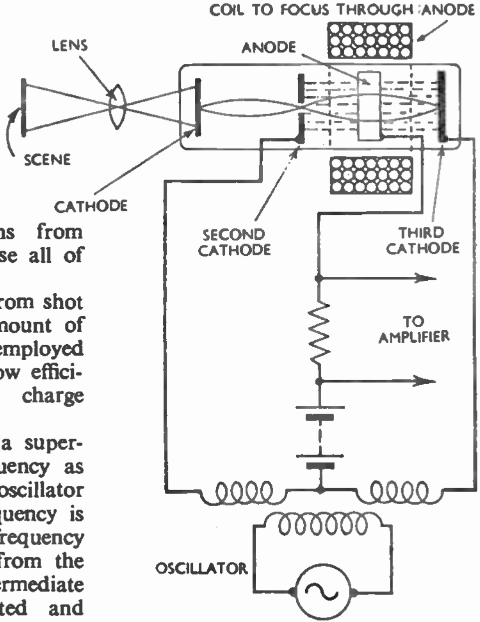


Fig. 1. Diagrammatic section and plan of the Farnsworth image-dissector tube, showing the coils used for magnetic scanning of the electron image.

Fig. 2. Simplified circuit arrangements of the image-dissector multiplier; the scanning and focusing coils of the dissector section have been omitted.



round the anode. The other is to apply a quenching frequency which will stop the oscillation of electrons from cathode to cathode and cause all of them to go to the anode.

Such a multiplier suffers from shot effect and this limits the amount of multiplication that can be employed in practice. The tube has low efficiency because there is no charge storage.

IMAGE FREQUENCY. In a superheterodyne receiver, a frequency as much above (or below) the oscillator frequency as the signal frequency is below (or above) it. Image-frequency signals produce an output from the frequency-changer at the intermediate frequency, and are accepted and amplified as well as the wanted signals by the I.F. amplifier, thus causing interference or whistles in reception.

For this reason, signal-frequency circuits are designed to reject image-frequency signals as far as possible. See INTERMEDIATE-FREQUENCY AMPLIFIER, SECOND-CHANNEL INTERFERENCE, SUPERHETERODYNE RECEPTION.

IMAGE IMPEDANCES. Two impedances such that when one of them is connected across the appropriate pair of terminals of a four-terminal network, the other is represented by the other pair of terminals of the network. Fig. 3 shows a network with four terminals, that is, a quadripole. The two image impedances are 1,000 and 100 ohms because, if the 1,000 ohms is connected across the terminals 1 and 2, terminals 3 and 4 have an impedance of 100 ohms; and when the 100 ohms is connected across terminals 3 and 4, terminals 1 and 2 have an impedance of 1,000 ohms.

If the two image impedances are equal, their value is the characteristic impedance of the network. To avoid losses in joining filter sections, the impedances of the two sections where they are joined must be the same, and must vary in the same way with frequency. In many cases, the filter sections have different impedances at either end, and they must be joined appropriately on an image-impedance basis. See CHARACTERISTIC IMPEDANCE, FILTER, FILTER SECTION, ITERATIVE IMPEDANCE, QUADRIPOLE.

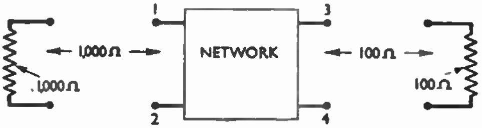


Fig. 3. Diagram of a quadripole which illustrates the example of image impedances described above.

IMAGE PHASE-CHANGE COEFFICIENT. Imaginary part of the image-transfer coefficient of a network. This coefficient expresses the difference in phase between the signals at the input and the output terminals of a network terminated in its image impedance. See IMAGE IMPEDANCES, IMAGE-TRANSFER COEFFICIENT, PHASE-CHANGE COEFFICIENT.

IMAGE RATIO. See SECOND-CHANNEL RATIO.

IMAGE-TRANSFER COEFFICIENT. Coefficient expressing the loss or gain in a network when it is terminated in its image impedance. Accurately expressed, it is one-half the natural logarithm of the vector ratio of the steady-state volt-amperes entering the network, to the volt-amperes leaving it. It is assumed that the network is terminated in its image impedance. See PROPAGATION COEFFICIENT.

IMAGE-TRANSFER CONSTANT. Synonym for IMAGE-TRANSFER COEFFICIENT.

IMPEDANCE. Measure of the total opposition to the flow of an alternating current round a circuit. Impedance comprises both reactance and resistance. But it is not simply the sum of the two quantities; it is the square root of the sum of their squares, thus, $Z = \sqrt{R^2 + X^2}$, where Z is the impedance, X the total reactance of the circuit, and R its resistance. The total reactance is, of course, the arithmetic difference of the inductive and capacitive reactances, thus, $Z = \sqrt{R^2 + (X_L - X_C)^2}$. It is at once apparent that there is here a special case in which $X_c = X_L$; the impedance then becomes simply the resistance. This is the case of the series resonant circuit (see TUNING).

Since both X_L and X_c are quantities into which frequency enters, it follows that it is meaningless to refer to the impedance of a circuit or component unless working frequency is specified.

Where alternating current is concerned it is the impedance which must be used in such calculations as finding the current in a given circuit; it will not suffice to apply Ohm's law to the voltage and resistance alone. Similarly, when determining the voltage drops across the individual components of a circuit carrying alternating current, it is their impedance which must be used, not simply their resistance as would be the case in a D.C. circuit. See REACTANCE, RESISTANCE.

IMPEDANCE COUPLING. See COMMON-IMPEDANCE COUPLING.

IMPULSE EXCITATION. Excitation of the grid of a valve in which flow of anode current is permitted for only a short part of each cycle.

IMPULSE FREQUENCY. Number of impulses per second in a train or group of regularly recurring impulses. See IMPULSE PERIOD, IMPULSE RATIO.

IMPULSE NOISE. Noise or interference having a relatively large peak value and short duration. If it cannot be prevented at the source, the most effective remedy is a limiter in conjunction with circuit design aimed at preserving the brevity of the wave form. See IGNITION INTERFERENCE.

IMPULSE PERIOD. Time period between the corresponding points of two successive impulses in a train or group of regularly recurring impulses. See IMPULSE FREQUENCY, IMPULSE RATIO.

IMPULSE RATIO. Ratio of the duration of an impulse to an impulse period. See IMPULSE FREQUENCY, IMPULSE PERIOD.

INCREMENTAL PERMEABILITY. Permeability of iron or other magnetic substance measured in terms of the additional flux produced by a small change in magnetizing force when the material is already magnetized by a steady polarizing current. The measurement is typically made by means of a small alternating current superimposed on a direct current already flowing in the magnetizing winding.

INDEPENDENT BEAT OSCILLATOR. Circuit used for beat reception in which a separate oscillator generates the waves to produce beating with the incoming signal. In some circuits, the valve which receives the signals also produces the beat oscillations to detect them, and this is called an autoheterodyne system. The term beat reception is preferred. See BEATING, BEAT RECEPTION.

INDEPENDENT DRIVE. Synonym for MASTER OSCILLATOR.

INDEPENDENT HETERODYNE. Synonym for INDEPENDENT BEAT OSCILLATOR.

INDIRECTLY HEATED CATHODE. Cathode, consisting of a cylinder coated externally with an oxide, which freely emits electrons when heated and embraces a coil which is heated by a current drawn from an external source. The oxide-coated cathode is insulated from the heater. The cylinder is made of thin sheet nickel and the emitting coating is spread over its surface. The heater coil, or wire, is of tungsten and is covered with some insulating material such as aluminium oxide. In general, it is inadvisable to let the cathode potential differ from the heater potential by more than 100 V, otherwise the insulation between cathode and heater may break down.

The indirectly heated cathode has several advantages; for instance, it is an equipotential cathode; the cathode potentials of a number of valves energized from the same heater supply may be different (see CATHODE BIAS); no elaborate arrangements are required to maintain mechanical rigidity between the hot and cold conditions as are necessary with the finer wire-filament types of cathode.

On the other hand, the emission surface is more sensitive to bombardment by positive ions than the fine tungsten filament, so that the greater emission efficiency and other advantages of the indirectly heated cathode cannot be used in high-power valves. See CATHODE, CATHODE BIAS, EMISSION, FILAMENT.

INDIRECTLY HEATED VALVE. Valve in which the cathode is indirectly heated. See INDIRECTLY HEATED CATHODE.

INDIRECT RAY. Synonym for IONOSPHERIC RAY.

INDUCTANCE. Property of a circuit which causes it to oppose any change in the current flowing therein. Inductance is a quality possessed by all current paths, since it arises from the self-induction effect of the magnetic field which surrounds a conductor carrying a current. It is thus a product of the process of electromagnetic induction acting back into the circuit in which the originating current flows. A change in the current (and hence in the surrounding magnetic field) will not merely induce an e.m.f. in a neighbouring circuit, but it will induce one in the original circuit. Further, the voltages induced back into a circuit when the current alters are in such a direction as to oppose the change; when the current is falling the voltages induced by the shrinking magnetic field are in a direction which tends to maintain the current (see LENZ'S LAW).

This effect may be regarded as analogous to inertia in the mechanical world; there is a flywheel effect in an inductor which delays the rise of a current when the driving voltage is first applied, and correspondingly delays its decay when the voltage begins to fall. Thus, in an alternating-current circuit, the current wave lags behind the voltage wave; the phase-angle by which the current lags is determined by the amount of inductance in the circuit if there is resistance also, or by the preponderance of inductive effect if there is capacitance also. Capacitance, of course, causes the current to rise to its maximum *ahead* of the voltage maximum (see LAGGING LOAD, PHASE ANGLE).

When the current rises during the beginning of a half-cycle, energy is stored in the growing magnetic field around the conductor. When the current falls, the magnetic field collapses and in doing so induces a voltage which tends to maintain the current; thus the stored energy is returned to the circuit.

There is a magnetic field of force round any conductor of current, but it is relatively weak round a straight one; i.e. straight wires have a low inductance. The strength of the magnetic field is manifestly a measure of the inductance of the current path, so a unit for evaluating inductance could be expressed in terms of the field produced by unit current. The practical unit is, however, defined in a somewhat more direct manner (see HENRY).

Strong magnetic fields of force are produced by coiling up the conductor to form a winding; practical inductors are nearly always wound in this manner. The term inductor is now generally used in preference to the older term "inductance," which sometimes led to confusion between the property itself and the device which possessed it.

One type of inductor is a single-layer winding of wire on a hollow tube, and such components are often used in radio work where space permits. A more compact winding, in some multilayer form, enables the same amount of wire to produce still more inductance and at the same time reduces the space required; inductors of this kind are also used.

Anything which increases the intensity of the magnetic field of force will, by definition, increase the inductance value. A core with a permeability higher than that of air will obviously do this, and for low-frequency purposes an iron core is generally used; it is usually necessary to laminate it to reduce eddy currents, and the laminated iron core is practically universal in all large-value inductors for low and audio frequencies (see EDDY CURRENT, PERMEABILITY).

At high frequencies, eddy-current losses become prohibitive and iron cores of the type commonly used at audio frequencies are not used at radio frequencies. High-permeability cores of a certain type are nevertheless used in many modern R.F. inductors; these cores consist of extremely finely divided iron in the form of dust, usually embedded for mechanical convenience (and to insulate the individual particles) in a solid medium of wax or plastic material.

Properly applied, the principle of the high-permeability core leads to a more efficient inductor even at quite high frequencies; it enables the desired amount of inductance to be obtained from a smaller number of turns in the winding; and the shorter length of wire used results, other things being equal, in a lower resistance. Dust-core inductors are therefore widely used in radio receivers; they have the secondary advantages that slight corrections of inductance value for matching purposes can be made by adjustment of the position of the core within the winding.

Inductance is required for many purposes in electrical and radio work. High-value inductors, colloquially known as "chokes," are used to provide a barrier against alternating or oscillating currents and to divert them from some part of a circuit where they are not wanted. For radio-frequency purposes, the inductances are usually less than a tenth of a henry; the inductors are somewhat similar in construction to the inductors used in tuned circuits.

Chokes for low-frequency purposes have inductance values of the order of, say, 5–100 H. They are usually wound on closed iron cores similar to those of transformers, except that a small air gap is usually left in the magnetic circuit; this air gap ensures greater constancy of inductance when the choke is required to carry varying amounts of direct current and, at the same time, to act as a barrier to alternating currents. A typical application is in a smoothing filter (see SMOOTHING CIRCUIT).

One of the most important uses of inductance is found in the tuned circuits of radio apparatus. Here, a precise value of inductance is needed in conjunction with a definite amount

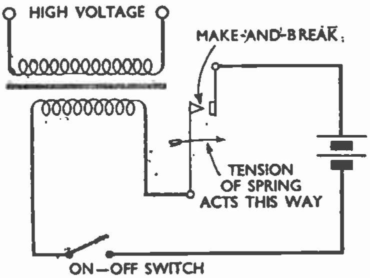


Fig. 4. Operating principle of the induction coil. When current flows in the primary circuit, the magnetized transformer core opens the make-and-break contacts; current thereupon ceases to flow in the primary, the points are closed by the spring, and so on. These sudden changes in primary current cause high voltages to be induced in the secondary winding.

of capacitance to tune to a given frequency; inductors for this purpose are, therefore, made to a particular standard when (as in all modern receivers) they are tuned by the various sections of a ganged tuning capacitor (see GANGING, MATCHING).

The amount of inductance required for each wave band in a receiver is that which will resonate at a wavelength just below the bottom limit of the band when placed in parallel with the minimum capacitance value of the variable capacitor, plus such stray capacitance as there may be in the circuit. This is a matter for empirical determination rather than calculation, but for approximate results the usual wavelength formula can be used to find the amount of inductance needed for resonance. See TUNING.

INDUCTANCE COIL. Synonym for FIXED INDUCTOR.

INDUCTANCE COUPLING. Synonym for INDUCTIVE COUPLING.

INDUCTION. Process of producing electrical or magnetic effects at a distance, without direct connexion between the electric current, electric charge or magnet which is producing the effect, and the circuit or body in which the effect is set up. See ELECTROMAGNETIC INDUCTION, ELECTROSTATICS.

INDUCTION COIL. Essentially a transformer having a make-and-break system, similar to that of an electric bell, in series with the primary. When a direct voltage is applied to the primary circuit (including the make-and-break and the primary coil of the transformer), high-voltage pulses are induced in the secondary coil.

In an induction coil the current is regularly interrupted by the make-and-break system. This produces a very large rate of change of flux in the secondary circuit and so a very high induced secondary voltage.

The differences between the induction coil and an ordinary transformer are:

1. In the transformer, the primary is energized by an alternating current, but the primary of the induction coil is fed with a suddenly interrupted current supplied from a direct voltage source.

2. The secondary voltage of an ordinary transformer used in a normal way is sinusoidal, but the secondary voltage of an induction coil is "peaky," and these peaks may have voltages of the order of a thousand, ten thousand, or even a hundred thousand volts, although the source of primary D.C. power has a low voltage.

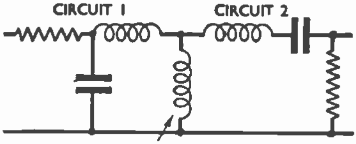
Fig. 4 illustrates the principle described. The induction coil was widely used in the early days of radio communication to produce the power for spark senders of moderate power (see SPARK SENDER, SPARK SENDING SYSTEM).

INDUCTIVE. Having the quality of inductance, whether distributed over a circuit or localized in a component part. See INDUCTANCE.

INDUCTIVE ATTENUATOR. Attenuator for use at radio frequencies consisting of inductive elements. See ATTENUATOR.

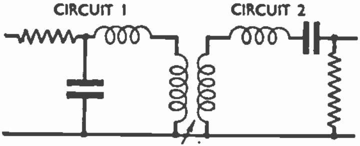
INDUCTIVE CAPACITY. Synonym for PERMITTIVITY.

INDUCTIVE COUPLING. Coupling of two circuits, either by a common impedance which is predominantly inductive, or by mutual inductance. Fig. 5 shows two circuits, one with common-impedance coupling by an inductive reactance, and the other coupled by mutual inductance. See COMMON-IMPEDANCE COUPLING, COUPLED CIRCUIT, COUPLING.



COUPLING BY AN INDUCTOR

(a)



COUPLING BY MUTUAL INDUCTANCE

(b)

Fig. 5. Two kinds of inductive coupling of circuits are shown: (*a*) by a common impedance in the form of an inductor, and (*b*) by mutual inductance.

INDUCTIVE FEEDBACK. Feedback of energy from one stage of a valve amplifier to another when they are coupled inductively. The coupling may be provided purposely to give feedback, or it may be caused by the close proximity or relative positions of certain components, producing unwanted positive feedback and, possibly, instability.

INDUCTIVE-FEEDBACK OSCILLATOR. Any valve oscillator in which the feedback of power from anode to grid circuits takes place only by an inductive path. An example is the Hartley oscillator.

INDUCTIVE LOAD. Synonym for LAGGING LOAD.

INDUCTIVE-OUTPUT VALVE. Valve in which an electrode is placed in the proximity of the electron stream, but which does not collect electrons. Changes of density of the electrons in the electron stream induce voltages on this electrode. The valve is designed to be used as an amplifier of waves of very high frequency (hundreds or thousands of megacycles per second). It has not found much practical application, being inferior in performance to special triodes, cavity magnetrons, Klystrons and so forth. See OSCILLATOR.

INDUCTIVE REACTION. Synonym for INDUCTIVE FEEDBACK.

INDUCTIVE RESISTOR. Wire-wound resistor having appreciable self-inductance, either by intent, or because of lack of care in design. See FIXED RESISTOR.

INDUCTIVE RETROACTION. Synonym for INDUCTIVE FEEDBACK.

INDUCTOR. Device capable of storing electromagnetic energy, and used primarily because of its property of inductance, or of inductive reactance when used in an alternating-current circuit. Its essential parts are a coil of one or more turns of insulated conductor wound on an insulating former or spool (which is usually hollow) and enclosing a core. The core may be of magnetic material, such as iron or an iron alloy, or it may be non-magnetic, such as is air or the insulating material of a solid former.

The inductance of such a coil is given by $L = \left(\frac{4\pi n^2}{S}\right) 10^{-9}$ henrys, where n is the number of turns of wire and S is the reluctance of the magnetic circuit.

In a high-permeability *iron-cored inductor*, in which the magnetic flux is confined to the core, the reluctance depends solely on the geometry of the core (not the coil) and on its permeability. It is given by the formula $S = \frac{l}{A\mu}$, where l is the mean length of the magnetic circuit (in cm.), A is the cross-sectional area (in sq. cm.) and μ is the magnetic permeability of the material.

If there is a small air-gap in the core (a normal method of reducing the iron losses, or the effect of too high a current, or of a superimposed direct current, upon the value of the inductance), then the total reluctance is the sum of the separate reluctances: $S = S_i + S_a$, where $S_i = \frac{l_i}{A\mu}$ and $S_a = \frac{l_a}{A}$. Here, l_i and l_a represent the mean length of the iron and air parts of the magnetic circuit respectively (the value of μ for air is 1). At the low values of flux density used in audio-frequency inductors, the effective permeability of silicon-iron laminations is about 500 and of nickel-iron laminations about 2,000.

The above formulae do not apply to dust-cored inductors because subdivision of the magnetic material lowers the effective permeability considerably.

In an *air-cored inductor*, except in the case of a toroidal-wound inductor, the magnetic flux is not confined to a core of known dimensions. For this reason it is not possible to state a general formula for inductance which is of an exact nature. Reliance has to be placed on formulae derived experimentally; although various formulae are sometimes given which depend upon the shape of the coil, the number of layers of wire and the method of winding.

The accompanying diagram (Fig. 6) gives a formula for the low-frequency inductance of a single-layer winding of circular wires on a cylindrical former, and which is approximately true for multi-ple-layer and wave-wound inductors. The effective inductance at radio frequencies is modified by the self-capacitance of the coil and to a small extent by its increased resistance. See FIXED INDUCTOR, VARIABLE INDUCTOR.

INDUCTOR LOUDSPEAKER. Moving-iron loudspeaker, the armature of which moves like a piston between two pairs of magnetic poles. This gives some freedom of movement to both armature and cone, giving good low-frequency response.

INDUCTOR MODULATION. System of non-linear modulation in which the sources of carrier and modulating wave are connected in series and applied to an inductor. The amplitude of the wave produced by adding the two waves varies, and the inductor offers an impedance which varies with the varying amplitude of the sum of the carrier and modulating waves. This resultant wave is, therefore, distorted, and contains the modulated wave, which is selected by a filter.

If the inductor has two windings, linear modulation is possible; the modulating wave is applied to one winding and the carrier wave to another. The variable magnetization of the core caused by the modulating wave causes the carrier wave to be modulated. Both methods are obsolescent. See LINEAR MODULATION, MAGNETIC MODULATION, NON-LINEAR MODULATION.

INERT CELL. Cell containing all the components and ingredients necessary

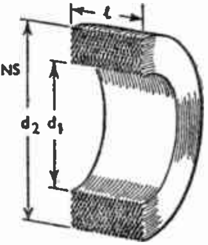
$L = k\,d\,n^2$ MICROHENRYS

WHERE n = TOTAL NUMBER OF TURNS

d = MEAN DIAMETER IN cm.

$= \frac{d_1 + d_2}{2}$

k = CONSTANT DEPENDENT UPON RATIO $\frac{d}{l}$ GIVEN BELOW



$\frac{d}{l}$	0·1	0·2	0·5	1·0	2·0	5·0	10·0
k	0·0009	0·0018	0·0040	0·0068	0·0104	0·0158	0·0200

Fig. 6. Formula for low-frequency inductance of a single-layer winding; it is approximately true for multi-layer and wave-wound inductors.

for the generation of an e.m.f. except the water required to actuate the electrolyte. It is similar in construction to a dry cell of the Leclanché type and, while inert, it can be stored indefinitely without deterioration. See VOLTAIC CELL.

INFINITE ATTENUATION. Property of a device which, when a voltage is applied to its input terminals, produces no output at all at the output terminals. A "null network" gives infinite attenuation. The term is used, in connexion with filters, to specify a frequency at which infinite attenuation would be produced if the inductors and capacitors forming the filter arms had zero loss. See FREQUENCY OF INFINITE ATTENUATION, NULL NETWORK.

INFINITE-IMPEDANCE DETECTION. Detection by an anode-bend detector with 100 per cent negative feedback. The circuit of an infinite-impedance detector is given in Fig. 7; it consists of a triode with the load connected in the cathode circuit, the output signal being developed between cathode and H.T. negative. Thus the cathode resistor acts as anode load and also provides grid bias, and best results are usually obtained with a value of the order of 50,000 ohms. This is quite a suitable value for an anode load, but is very high for a cathode-bias resistor; thus the valve operates with a very great negative bias and nearly at anode-current cut-off—correct conditions for an anode bend detector.

The capacitor in parallel with the cathode resistor is small, usually about 100 pF, and performs the same function as the capacitor in a diode detector. It is charged-up on positive peaks of the applied carrier and approximately trebles the output voltage.

The capacitor is too small to decouple the cathode resistor at audio frequencies, and the valve thus behaves as a cathode follower at these frequencies, giving less than unity gain. The circuit is, in fact, sometimes known as a cathode-follower detector. The components R_2C_2 are for R.F. filtering and perform no essential part in the detection process.

The input impedance of a cathode-follower detector is very high (hence the name infinite-impedance) and, under certain conditions, may even be negative; thus there is very little damping of the initial tuned circuit, and the Q-factor may possibly be improved. This low damping is the chief attraction of the infinite-impedance detector; in all other properties it is very similar to the diode detector.

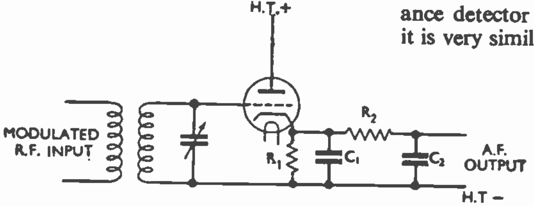


Fig. 7. Circuit of the infinite-impedance detector sometimes referred to as a cathode-follower detector.

INFINITE LINE. Uniform transmission line of infinite length, or of such a length that its sending-end impedance is substantially the same as if the line were of infinite length. If a line is short-circuited at a point near the sending end, the sending-end impedance is changed. If the line is infinitely long and its receiving end is short-circuited, there is no change in sending-end impedance because no voltage appears at the receiving end.

Thus a very long line gives so much attenuation that substantially no change in sending-end impedance would be noticed if the receiving end were short-circuited; the very long line, although of finite length, behaves as if it were an infinitely long line. The length of any line which behaves like an infinitely long line is determined by the electrical characteristics of the line. Thus, of any given line having a length greater than a specified value, it can be said that it is, in effect, an infinite line.

The characteristic impedance of a network or line is equal to the square root of the product of the sending-end impedances when the line is short-circuited and open-circuited respectively at its receiving end. Now the sending-end impedance of an infinite line is the same whether the receiving end is short-circuited or open-circuited. Thus the characteristic impedance of an infinite line is given by its actual impedance. See ARTIFICIAL LINE, CHARACTERISTIC IMPEDANCE, TRANSMISSION LINE.

INFRADYNE. Receiver employing the basic principle of the superheterodyne, but differing in that the intermediate frequency is *higher* than the signal frequency. Such a receiver does not possess the normal superheterodyne receiver's advantage of increased gain and stability in the I.F. amplifier stage, but it can be made to yield great selectivity. See SUPERHETERODYNE RECEPTION.

IN PHASE. Condition in which two currents or voltages, or a current and a voltage, alternate in perfect synchronism, passing through their maximum values at the same instant and their zero values at the same instant. That part of the current wave which is in step with the voltage, in an alternating circuit whose power factor is less than unity, is sometimes called the in-phase current.

IN-PHASE COMPONENT. Alternating current or voltage which is in perfect synchronism (i.e. in phase) with the reference component. See IN PHASE, PHASE-ANGLE, REACTIVE COMPONENT.

INPUT CAPACITANCE, IMPEDANCE, INDUCTANCE, RESISTANCE. Capacitance, impedance, inductance or resistance measured between the input terminals of a network, line, apparatus or any electrical device. See ELECTRODE IMPEDANCE, INTER-ELECTRODE CAPACITANCE.

INPUT CAPACITY. Term sometimes incorrectly used instead of INPUT CAPACITANCE.

INPUT IMPEDANCE. See INPUT CAPACITANCE (ETC.).

INPUT INDUCTANCE. See INPUT CAPACITANCE (ETC.).

INPUT RESISTANCE. See INPUT CAPACITANCE (ETC.).

INPUT TRANSFORMER. Transformer of which the secondary winding is connected across the input terminals of any network, line, apparatus or electrical device. The primary of the transformer is supplied with power which energizes the input terminals. See TRANSFORMER.

INPUT VALVE. Initial stage in any chain of valves in an amplifier or complete receiver; the valve, that is, to which the input is applied.

INPUT VOLTAGE. Voltage developed across the input terminals of any network, line, apparatus or electrical device.

INSERTION GAIN. Gain in voltage or current due to the connexion of a passive network between the output terminals of a generator and a load; or the gain in power due to the connexion of an amplifier between the output terminals of a generator and a load. The term is seldom used in connexion with amplifiers, the phrase "gain of an amplifier" being preferred. It should be noted that insertion gain in a passive network cannot represent a gain of power and so cannot be expressed in decibels.

In Fig. 8 it is assumed that the generator has an internal impedance made up of resistance and inductance (see INTERNAL IMPEDANCE). By connecting the generator to the load, a certain current in the load is produced. However, if a capacitor, having a reactance equal to the inductive reactance of the generator, is inserted between the output terminals of the

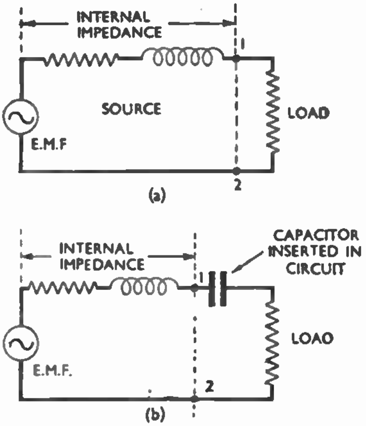


Fig. 8. A greater current flows in the load of circuit *(b)* than in that of *(a)*, and the gain in power due to the inclusion of a suitable capacitor is an example of insertion gain.

generator and the load, the load current increases. This is because the two reactances cancel as in a series-resonant circuit, leaving a purely resistive circuit. There is thus a gain of power due to the insertion of the capacitor. See CONJUGATE IMPEDANCE, INSERTION LOSS, MATCHING.

INSERTION LOSS. Loss of power due to the connexion of a passive network or other device between the output terminals of a generator and the load. There may be apparatus in the circuit between the point of insertion and the generator, and between the point of insertion and the load, but the insertion loss is the power lost between the input and output terminals of the device causing the loss. The loss of power is expressed in decibels.

If a filter section, transformer, or resistance pad is inserted between the output of a generator and a load (Fig. 9), less power appears at the output of the device inserted in the circuit than is applied to the input. This loss is called the insertion loss. Insertion loss varies with frequency. The performance of transformers and filters is often expressed in terms of their insertion loss expressed in decibels. See DECIBEL, MATCHING.

INSTANTANEOUS FREQUENCY. Rate of change of phase of a wave of any shape divided by 2π. See PHASE.

INSTANTANEOUS VALUE. Value, at a particular instant of time, of any quantity which varies with time. For example, the sine graph (Fig. 10) shows the variation of voltage with time; but it might be desirable to express the value of the voltage at times t_1, t_2, t_3, and so on. These values,

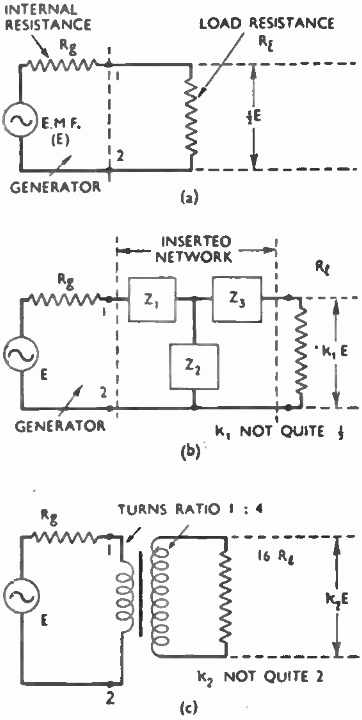


Fig. 9. Loss of power resulting from the insertion in circuit *(a)* of a network *(b)* or a transformer (c). It is assumed that $R_l = R_g$; the extent by which k_l is less than ½ in *(b)* and by which k_2 is less than 2 in (c) is a measure of the insertion loss that is produced.

which are maintained for an infinitely short space of time, are instantaneous values. See SINE GRAPH.

INSTRUMENT. Any small piece of apparatus that is complete in itself, such as a microphone or pick-up.

INSTRUMENTAL ERROR. Error due to defects in design and/or construction in direction-finding equipment; this error may or may not include polarization error.

INSTRUMENT RECTIFIER. Small metal rectifier which, when incorporated with a D.C. instrument, makes it possible for that instrument to function on A.C. It is commonly used in meter circuits, when a moving-coil meter is required to measure alternating currents or voltages, as illustrated in Fig. 11.

INSULANCE. Synonym for INSULATION RESISTANCE. The term is also associated with liquid and solid capacitor dielectrics as the numerical product (in ohm-farads) of insulation resistance and capacitance.

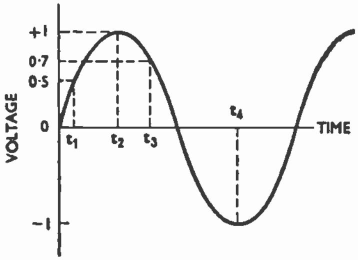


Fig. 10. Examples of instantaneous values at t_1, t_2, etc., of a voltage continually varying (alternating) in accordance with the sine graph.

INSULATION. Electrical isolation of conductors by non-conducting substances. In the earliest experiments with electricity, it was discovered that some materials, notably metals, allowed free passage of electric currents, while others, such as glass and rubber, did not. The two types of materials were called conductors and insulators respectively.

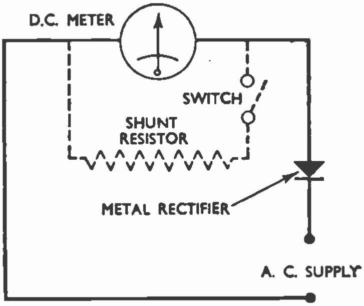


Fig. 11. Instrument rectifier connected in series with a moving-coil milliammeter for purposes of A.C. measurement. The shunt resistor is used when the current measured exceeds the capacity of the meter.

It was found that, to electrify a conductor, it was necessary to interpose an insulator between the conductor and earth; for example, if the conductor were held in the hand, it could not be electrified, for the charge leaked to earth through the body of the experimenter. These early experiments also proved that air was an insulator, for, so long as there was no physical connexion between the conductor and earth, the conductor could be electrically charged.

Insulators have the important property of relative permittivity. If, as in Fig. 12, two conductors are placed in space and given opposite electrical charges, an electric force exists between them. If the space is then filled by an

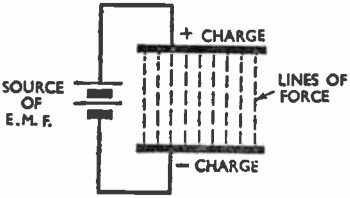


Fig. 12. Lines of force between two oppositely charged conductors. If the space (means of insulation) between the conductors is a vacuum, the permittivity is unity; if air, it is 1·006.

insulator other than air, the strength of the force changes. When this other insulator is a vacuum, the permittivity is said to be 1. Therefore, the relative permittivity of all other insulators is expressed in relation to permittivity in vacuo.

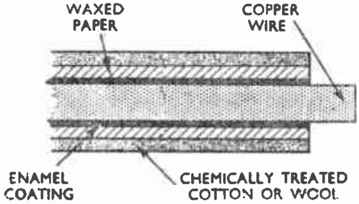


Fig. 13. Section through a telephone wire showing the insulation. Two such wires form a pair; usually, a cable contains a number of pairs.

Relative permittivity is sometimes called dielectric constant or specific inductive capacity. The higher the relative permittivity, the greater is the insulating efficiency of an insulator. Typical examples are: air 1·006, ebonite 2·8, shellac 3·5, mica 6·5 and porcelain 4·4 to 6·8.

Obviously, the voltage which an insulator will withstand before breaking down depends upon its insulating efficiency and hence upon its relative permittivity. Thus, where high voltages are concerned, materials having high relative permittivity must be used.

In the choice of insulating material for a specific purpose, consideration must be given to the mechanical stress as well as the electrical pressure to which the insulator will be subjected. It is because of this that porcelain is used for insulating electric power pylons and radio-sender masts. With capacitors, in which there is little mechanical stress, the insulating material used as a dielectric may be of paper or mica.

In the insulation of communication cables, due regard must be paid to possible chemical action between the conducting and insulating materials. The conductor is almost invariably copper; if this is insulated with rubber, the conductor must be tinned or enamelled to prevent chemical action between the copper and the sulphur content of the rubber. If the insulation is of waxed paper or cotton, it is highly inflammable and is thus unsuitable for use where high temperatures prevail; but, because this form of insulation is the most convenient for telephone cables, it is used extensively and is rendered flame-proof by chemical treatment, or by covering the insulator with non-inflammable material (Fig. 13).

In the construction of inductors or transformers for radio-engineering purposes, it is frequently necessary to incorporate a large number of turns of insulated wire in a small space; this precludes rubber or cotton insulation, and enamelled wire is therefore used.

In recent years, the use of plastic insulating materials has been widely adopted (see PLASTICS). These have the advantage of lightness and flexibility, and production costs are low.

Insulators used for high-power radio senders have to withstand exceedingly high voltages. To guard against the possibility of breakdown, they are tested, before installation, at voltages greatly in excess of their working voltages. Such tests involve highly

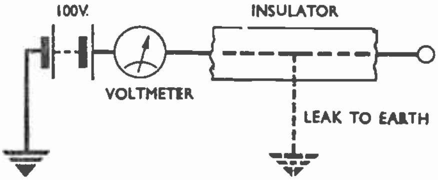


Fig. 14. In testing the insulation resistance of an insulated conductor in contact with earth, one side of the battery is earthed. The voltmeter indicates the battery voltage less the voltage drop across the leak.

complicated laboratory apparatus; voltages of a million, or even more, are applied across the insulator. The tests are applied gradually, the voltage being stepped up until the breakdown voltage is found. Comparison between the breakdown and working voltages indicates the margin of safety available with a given type of insulator.

The insulation efficiency of an insulated conductor can be obtained by measuring the insulation resistance (see INSULATION RESISTANCE). The test is a simple application of Ohm's law. Fig. 14 shows an insulated conductor, the insulation being in contact with earth. A battery and voltmeter are placed in series with one arm of the conductor and earth, the other arm of the conductor being open-circuited. The insulation resistance R can be obtained from $R = V/I$, where V is the voltage-drop across the leak and I is the meter current.

For example, suppose the test voltage to be 100 and the meter

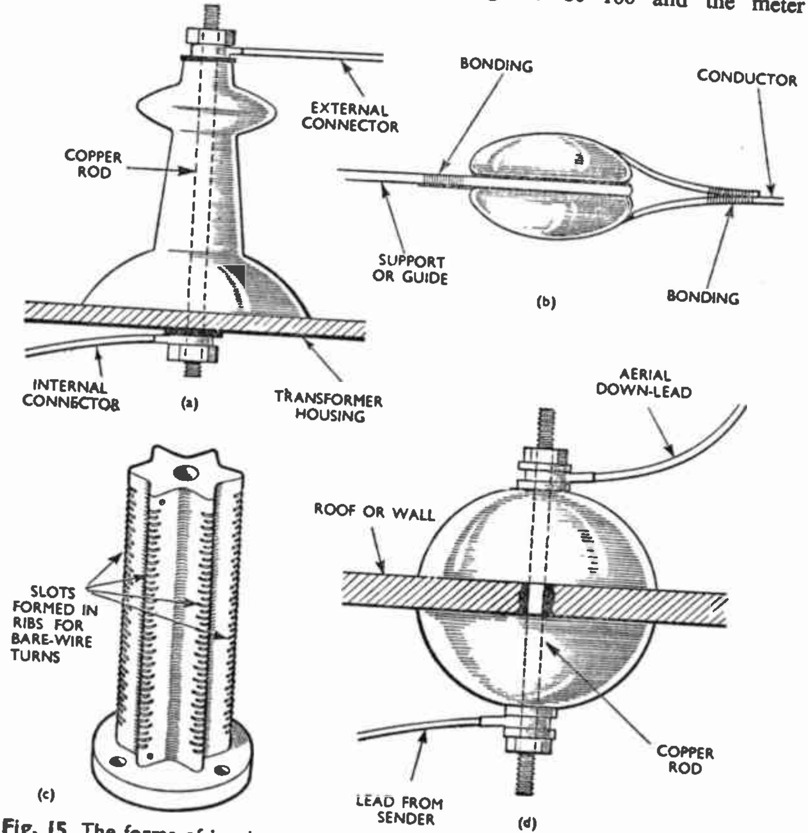


Fig. 15. The forms of insulator shown are (*a*) pillar-type porcelain insulator, frequently used with high-voltage transformers; (*b*) egg-type insulator, of porcelain or earthenware, used for aerials; (*c*) ribbed coil-former, which may be of ebonite, porcelain or plastics, for tuning inductors in receivers, and (*d*) dome-type porcelain insulator which is used between a sender and the aerial.

resistance to be 1,000 ohms per volt; the meter current will obviously be $\frac{100}{100 \times 1{,}000} = 0{\cdot}001$ amp.

Suppose that, on test, the meter reads 60 volts. This indicates a voltage drop of 40 and, applying the formula, the insulation resistance will be $\frac{40}{0{\cdot}001} = 40{,}000$ ohms.

It may seem that an ammeter would be more suitable for the test described, but a little thought will show that such a meter would have to be capable of carrying heavy currents in the event of a complete breakdown in insulation, whereas, if only a low test voltage were used, an insulation resistance of several thousand ohms would not cause a deflection on the meter.

In practice, the bridge tester is used for insulation tests (see BRIDGE MEGGER TESTER), such an instrument incorporating a hand generator of some 500 volts, and a meter which is calibrated in ohms.

INSULATION RESISTANCE. Resistance between two conductors, or a conductor and earth when separated by insulating material only.

INSULATOR. Any substance or body which offers high resistance to the passage of electric current. By reason of this high resistance, an insulator may be used to insulate a conductor from earth or from another conductor (see INSULATION).

Some typical examples are shown in Fig. 15; the first (a) being a type of insulator commonly used with high-voltage transformers. Such insulators are tested before use to ensure that they will withstand working voltages considerably higher than those likely to be encountered in the system with which they are used.

Also shown (Fig. 15b) is a very common type of insulator used for aerial insulation. Its construction is such that it needs no independent support, but is held in position by the supporting cable and the conductor. Such insulators are used with both sending and receiving aerials, and also for breaking up mast-supporting stays to prevent these stays from resonating at a particular frequency.

An insulating former on which the tuning coils for receivers can be easily constructed is illustrated in Fig. 15c. If bare wire is used, the ribs of the former are slotted to prevent neighbouring turns from touching.

The typical bell, or dome-shaped, lead-in insulator (Fig. 15d), is commonly used at radio sending stations. The domes are hollow and their mechanical construction is such as to withstand a strain considerably greater than the normal stress imposed by the aerial down-lead. Similarly, they are tested before use to ensure that they will withstand an electrical pressure considerably in excess of that to which they would normally be subjected.

INTELLIGIBILITY. Percentage of words or sentences correctly received over a transmitting or reproducing system.

INTENSITY MODULATION. Synonym for AMPLITUDE MODULATION.

INTERCALATED SCANNING. Synonym for INTERLACED SCANNING.

INTER-ELECTRODE CAPACITANCE. Capacitance existing between any two electrodes of a valve under specified conditions (Fig. 16). Inter-electrode capacitance may have a

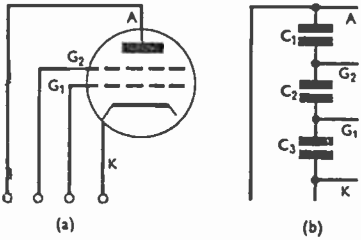


Fig. 16. Inter-electrode capacitance in a tetrode (*a*) may be considered as being made up as at (*b*). Anode-to-control-grid capacitance (C_1 in series with C_2 is less than the anode-to-control-grid capacitance in a triode.

profound effect on the performance of valve amplifiers. This effect becomes more noticeable as the frequency of the waves amplified becomes greater see ELECTRODE CAPACITANCE, ELECTRODE IMPEDANCE, MILLER EFFECT).

The screen grid of the tetrode was introduced in order to minimize control-grid-to-anode capacitance (see TETRODE).

It is, in nearly all cases, desirable to minimize inter-electrode capacitance. The MINIATURE VALVE (q.v.) goes a long way in this respect, maintaining a required amplification factor in spite of a reduction in dimensions. See AMPLIFICATION, AMPLIFIER.

INTERFERENCE. Confusion of a desired signal by atmospherics, unwanted signals (jamming), or signals produced by electrical apparatus; in other words, all unwanted voltages at the input of a receiver, as distinct from set noise, which originates in the receiver.

The effects of unwanted signals depend on the type of interfering signal, and on its strength and frequency relative to the desired signal being received. Type A0 waves give audible beat interference when the difference in frequency is sufficiently low, unless the interference is so strong as to paralyse or swamp the detector.

When the frequency difference is supersonic, type A0 waves of sufficient strength may reduce ability to extract the wanted modulation frequency by sweeping the detector to cut-off in one polarity and to a relatively linear part of its characteristic in the other. It is as if the modulation depth of the desired signal were reduced. Type A1 waves produce the same effects intermittently and, in addition, may cause key clicks.

Any interfering signals modulated at an audible frequency introduce that frequency clearly if the beat frequency is supersonic. Even if it is prevented, by selectivity in the later stages of a receiver, from intruding directly, it may sometimes be rendered audible by cross-modulation. If the beat frequency is audible, the character of the interfering modulation is generally masked or modified by the beat interference present at the same time.

In broadcast reception the commonest interference is between wanted and unwanted broadcast transmissions (type A3 waves), and may be present as intelligible interference, in which the modulation of the interfering station is reproduced; as beat interference, between the carrier waves, and as sideband interference, or "monkey chatter," in which a splashing or unintelligible chattering sound is caused by the sidebands of either station interfering with the sidebands and/or carrier wave of the other. What is heard of all these depends on the relative frequencies and the R.F. and A.F. selectivity of the receiver.

The term "interference" is sometimes used to refer only to the remaining types, as distinct from atmospherics and jamming. These are as varied in nature as the appliances causing them. Any change in electric current sets up a wave which includes components covering a band of frequencies depending on the suddenness of the change.

Theoretically, an instantaneous change covers an infinite frequency band. Any device in which there are more or less frequent sudden changes of current is, therefore, liable to interfere with radio reception, the interfering waves being transferred to neighbouring receivers by radiation or power lines, etc., or both.

Thus each operation of a switch or contact may cause a click, rotary machines with commutators set up a continuous singing or roaring sound, and other appliances are heard as buzzes, rustles, crackles, hisses and so on.

Although the interference is generally distributed fairly widely over the R.F. spectrum, it is usually strongest at the lowest frequencies, though it may be intensified at particular frequencies by resonance in the interfering appliance. Special cases, particularly troublesome on the higher frequencies, are diathermy and R.F.-heating sets, which have been known to cause interference at a range of thousands of miles.

With regard to anti-interference methods, it may be said that, in general, it is desirable to limit the R.F. band width of the receiver to the minimum necessary for the desired signal at a sufficiently early stage to prevent cross-modulation. Beat interference on a fixed frequency within the reproduced A.F. band can be minimized by a sharply tuned filter. As the most audible interference is generally relatively high in frequency, it may be reduced by de-emphasis. It is also beneficial to increase the desired carrier wave relative to the sidebands by extreme selectivity, correcting the resulting progressive attenuation of the sidebands by tone control.

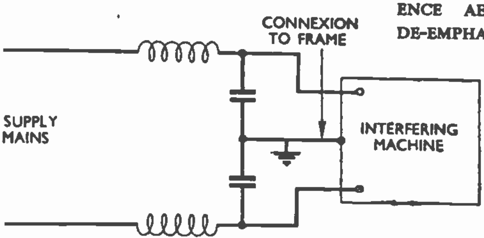


Fig. 17. Typical filter for suppressing interference caused by an electrical machine or appliance.

The best remedy for noise interference is suppression at the source, by-passing the interfering currents to earth by means of capacitors, and limiting or diverting them from undesired channels by series resistors or inductors. The only way to suppress diathermy and R.F. heating equipment is to operate it in a screened room. To prevent interference reaching the receiver via the mains a filter, such as that shown in Fig. 17, may be used. Interference coming via the aerial is more difficult to deal with, but the signal-to-noise ratio can often be greatly improved by installing an anti-interference aerial system.

Interference with television is due chiefly to ignition, diathermy, etc., and is severe if the equipment is not screened. Directional aerials may occasionally help, but the most useful remedy is to use limiters in both sound and vision channels. Interference on the vision channel is particularly undesirable because it mars the picture with spots and may upset the synchronization. See ANTI-INTERFERENCE AERIAL-SYSTEM, ATMOSPHERICS, DE-EMPHASIS, JAMMING, LIMITER, NOISE, SIDEBAND INTERFERENCE, SIGNAL-TO-NOISE RATIO.

INTERFERENCE NOISE. See INTERFERENCE.

INTERLACED SCANNING. Method of scanning, employed in television, in which the lines are not taken in numerical sequence. Thus, instead of scanning consecutive lines, such as 1, 2, 3, 4, 5, 6, etc. to the end, the lines are taken alternately, or two lines are missed after each one taken. In interlaced scanning, often referred to as interlacing, the picture is transmitted in two or three partly complete frames instead of one complete frame at a time. The result, to the eye, is that a greater number of pictures per second is being transmitted, with resultant reduction in flicker.

The rate of scanning is determined by two factors: the motion must be fast enough to appear continuous to the eye, and the whole field must be covered a sufficient number of times in a second to give the impression of continuous, flickerless movement. The number of complete pictures per second required to avoid flicker depends on the brightness of the picture; 25 per second are advisable when the picture is not very bright, and 50 when the picture is bright.

To avoid having to scan the complete picture 50 times in a second, and yet achieve the illusion that 50 pictures per second are being received, interlaced scanning is employed. If alternate lines are scanned, the eye is given the impression that the picture has been completely scanned when only half of it has been covered. This is because the lines are close together and alternate lines provide what is apparently a fully illuminated picture.

Thus, while the picture-frequency that has to be dealt with in the sender and receiver is only 25 per second, the benefit of a picture-frequency of 50 per second is obtained. This illusion is a valuable one technically. The sidebands that have to be dealt with by the sender and picked up and amplified by the receiver depend, for a given picture ratio, on two main factors, namely, the number of lines per picture and the number of frames per second (see HIGH-DEFINITION TELEVISION).

Now consider the two following cases: 405 lines per picture at 25 pictures per second, and 405 lines at 50 per second. The former is obviously preferable since it requires the smaller band width. The definition of the two schemes is the same; that is decided by the 405 lines. The flicker, however, is different, that of 50 pictures being less noticeable.

To attempt to obtain the benefits of both reduced flicker (50 pictures) and minimum band width (25 pictures), the interlacing system is used. We obtain our 50 pictures so far as the eye is concerned, and, in fact, we retain our 25 complete pictures and so reduce the band width. The lines are transmitted in frames of only 202½ lines each, 50 times per second.

Triple interlacing (taking every third line) has also been tried with success, and this provides the equivalent of 75 pictures a second so far as the eye can judge. But there is a limit to this interlacing since, if too many lines are skipped each time, the eye begins to realize that something is wrong, and the effect of constant illumination is lost.

INTERMEDIATE CIRCUIT. Synonym for INTERMEDIATE-FREQUENCY AMPLIFIER.

INTERMEDIATE FREQUENCY. Frequency to which incoming signals are converted (usually for further amplification) in a superheterodyne receiver.

INTERMEDIATE-FREQUENCY AMPLIFIER. That portion of a superheterodyne receiver devoted to amplification of the signals after frequency-changing and before detection.

INTERMEDIATE-FREQUENCY INTERFERENCE. Interference by signals at the intermediate frequency, which by-pass the pre-selector and frequency-changer and are picked up by the I.F. amplifier via stray coupling (see SUPERHETERODYNE RECEPTION). The cure is adequate screening and a wave-trap in the aerial lead. See SECOND-CHANNEL INTERFERENCE.

INTERMEDIATE-FREQUENCY OSCILLATOR. Oscillator beating with the intermediate-frequency signals in a superheterodyne receiver, to permit reception of type A1 signals. See BEAT RECEPTION, SUPERHETERODYNE RECEPTION.

INTERMEDIATE-FREQUENCY TRANSFORMER. Inter-valve coupling device used in the intermediate-frequency amplifier of a superheterodyne receiver. It usually has an iron-dust core, and is enclosed in a screening box.

INTERMEDIATE WAVE. See DECAMETRIC WAVE, HECTOMETRIC WAVE.

INTERMODULATION. Production of new, and usually unwanted, frequencies by the combination or interaction of other frequencies. See INTERMODULATION DISTORTION.

INTERMODULATION DISTORTION. Form of non-linear distortion which takes place when signals of two or more frequencies are present together. For example, if signals of

200 c/s and 900 c/s are being amplified, and the 200 c/s is strong enough to overload the amplifier, it modulates the 900 c/s signal, creating new frequencies of 900±200, 900±400, etc. (see MODULATION, SIDEBAND).

In the reproduction of music, these spurious frequencies are usually discordant and are more unpleasantly noticeable than the harmonics produced at the same time. Unfortunately they are more difficult to measure. See HARMONIC DISTORTION, NON-LINEAR DISTORTION.

INTERNAL ANODE-IMPEDANCE. See ANODE SLOPE-RESISTANCE, INTERNAL IMPEDANCE.

INTERNAL CAPACITANCE. Capacitance value of the capacitive reactance forming part of the internal impedance of a source of electric power. See INTERNAL IMPEDANCE.

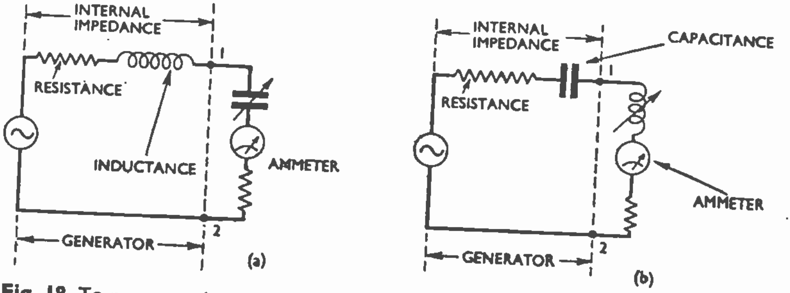


Fig. 18. To measure the internal impedance of a generator when this is inductive (*a*), a calibrated variable capacitor in the external circuit is adjusted so as to give maximum indicated current; when the internal impedance of the generator is capacitive (*b*), an external variable inductor is employed.

INTERNAL IMPEDANCE. Impedance of a source of electric power assumed to exist between an e.m.f. and the output terminals of the generator. It is obvious that any D.C. source must have internal resistance. If, for example, a dry cell is short-circuited, the current is, say, 5 amp. If the open-circuit voltage is, say, 1·5 volts, the e.m.f. acts on a resistance of $\frac{1\cdot5}{5} = 0\cdot3$; the internal resistance is 0·3 ohm. If the short-circuit current of a dynamo is 4,000 amp. and its open-circuit voltage 400 V, its internal resistance is $\frac{400}{4,000} = 0\cdot1$ ohm.

A more practical way of determining internal resistance is to connect across the output terminals a resistance of such value that the generator volts are halved. This resistance then equals the internal resistance of the source, because the drop of volts is the same across internal and external resistance, and current is the same in each.

A source of alternating power may have internal reactance; Fig. 18 shows a generator with internal reactance; if an external reactance of opposite sign to the internal reactance be adjusted until the current is a maximum, the two reactances are equal. This is because a series-tuned resonant circuit is set up. Knowing the value of the *external* reactance and its type (capacitive or inductive) to produce maximum current gives the value of the *internal* reactance and its type; the external and internal reactances must be of opposite types to produce resonance. See MATCHING, MISMATCHING FACTOR, REACTANCE, RESISTANCE, RESONANT CIRCUIT.

INTERRUPTED CONTINUOUS WAVE. Synonym for TYPE A2 WAVE.

INTER-STATION INTERFERENCE. See NOISE SUPPRESSION.

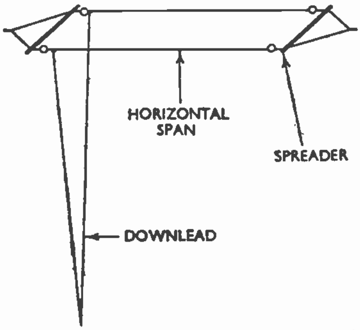


Fig. 19. Elementary form of inverted-L aerial with twin-wire span held on single-spar spreaders.

INTER-STATION NOISE SUPPRESSION. See NOISE SUPPRESSION.

INTER-VALVE COUPLING. Any device used to transfer the output of one valve to the input of another. Possibly the commonest circuits for inter-valve coupling are those which employ resistance-capacitance combinations or those using transformers. See AMPLIFICATION.

INVERSION. Reversal of order of speech-frequencies, used for purposes of secrecy. At the sending end of the system, each frequency is replaced by its difference from 3,000 c/s, the same process at the receiving end restoring intelligibility. See SPEECH INVERSION.

INVERTED AMPLIFICATION FACTOR. Measure of the performance of a valve which may be defined as the ratio between that differential change of voltage on the grid for unit change of anode voltage necessary to keep the anode current constant.

INVERTED AMPLIFIER. Amplifier using the LUNAR-GRID VALVE (q.v.). The term is also applied to the GROUNDED-GRID AMPLIFIER (q.v.).

INVERTED-L AERIAL. Aerial in which the main part is a horizontal span, with a down-lead, or lead-in, at one end to sender or receiver (Fig. 19). This type of aerial has distinct directive properties, its maximum efficiency being developed along the line of the horizontal section, in the direction of the down-lead end. Developed early in the history of radio communication, the inverted-L is still in considerable use on medium and low frequencies wherever a moderate amount of directivity is desired. It will be appreciated that this directivity is marked only when the horizontal span of the aerial is of adequate length; the small aerials used for broadcast reception, though often of inverted-L form, show little directivity because their length is so small compared with the wavelength.

The inverted-L aerial is often valuable for shipboard use, where space may be strictly limited. Here, too, little directivity will be apparent. The natural wavelength of the inverted-L is greater for a given length of horizontal span than that of the other principal flat-top type, the T-aerial. See DIRECTIVITY, FLAT-TOP AERIAL, T-AERIAL.

INVERTED-V AERIAL. Aerial, usually consisting of a single wire, with ends anchored at or near ground level and the mid-point raised to a suitable height. One end is connected to earth via the receiver and the other through a fixed resistor to an earth which may consist of crossed half-wave dipoles (Fig. 20). This aerial, sometimes used on the higher frequencies, is strongly

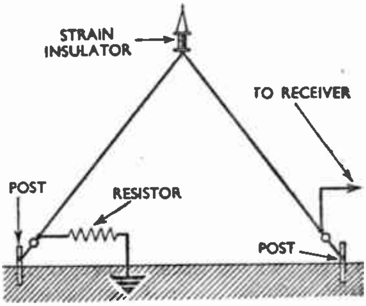


Fig. 20. Simple inverted-V aerial; the end remote from receiver is earthed through a resistor of about 600 ohms.

directive, receiving most efficiently those signals approaching from the end remote from the receiver.

INVERTER CIRCUIT. Apparatus, usually consisting of filters and modulators, for the inversion of music or speech.

ION. Charged particle in a liquid or gas, which is attracted by a negative or positive electrode, according to the charge on the ion. The ion, in moving to the electrode, sets up the equivalent of an electric current in the process. An ion may be a charged molecule, atom, or a radical (i.e. group of atoms which normally forms a section of a molecule).

IONIC BEAM. Beam of ions. See BEAM, CATHODE-RAY TUBE.

IONIC CURRENT. See GAS CURRENT, IONIZATION CURRENT.

IONIC FOCUSING. Synonym for GAS FOCUSING.

IONIC MODULATION. Method of amplitude-modulating a very-high-frequency wave by passing it through a gas which is ionized to a degree directly proportional to the instantaneous amplitude of the modulating wave. Modulation occurs because the carrier wave is absorbed to an extent which depends upon the degree of ionization. See AMPLITUDE MODULATION, IONIZATION.

IONIC VALVE. Synonym for VALVE (q.v.), better defined as "electronic valve." If a gas-filled valve or glow-tube is meant (since, in these devices, ions as well as electrons carry the space current) then it is better to call them by their more descriptive and accurate names. See GAS-FILLED VALVE, GLOW-TUBE, VALVE.

IONIZATION. Breaking up of molecules and atoms in a gas to form ions and electrons. In ionization by collision, which is the effect occurring in GAS-FILLED VALVES (q.v.) and GLOW-TUBES (q.v.), the process is set up by establishing a potential gradient through the gas. The process of ionization may be induced either by applying a sufficient potential between two conductive, but cold electrodes in a bulb containing the gas; or by arranging that one of the electrodes shall emit electrons and be negatively charged with respect to the other. The former principle is applied in the glow-tube, the latter in the gas-filled valve.

As the gas is at a very low pressure, there are relatively few molecules and atoms; in a glow-tube, the effect of gradually increasing the potential difference between the electrodes is that, when this reaches a certain value, one electron breaks away from a particle, leaving it positively charged, and is accelerated towards the anode. It collides with another neutral particle and knocks away another electron.

A chain of collisions is thus set up and electrons are rapidly liberated, leaving positive ions each time a collision occurs. In time, a state of equilibrium is reached, in which there is a number of free ions and free electrons, and as rapidly as some recombine, others are released. The free electrons and the free ions move in opposite directions, the former towards the anode, the latter towards the cathode. Thus the gas is made conductive.

In a gas-filled valve, the process is similar, but a smaller potential gradient is sufficient to start the process, because there is already a copious supply of free electrons from the cathode. Thus, in a gas-filled valve, ionization starts with a potential difference of, perhaps, 15 V, whereas in a glow-tube the so-called striking voltage is never lower than about 60–70 V.

Directly ionization starts in a GAS-FILLED VALVE positive ions begin to fall on to the cathode. The effect is to neutralize the space charge (see SPACE CHARGE). Thus more electrons become available to knock away others from the neutral atoms and molecules and so release more positive ions which further cancel the space charge. This neutralization of the space charge is the important feature of a gas-filled valve; it limits the current that may be safely passed through the valve. If the current is excessive, the bombardment of the cathode by positive ions is severe enough to destroy it (see GAS-FILLED VALVE, MERCURY-VAPOUR (HOT-CATHODE) RECTIFIER).

There are various terms relevant to the process of ionization; in connexion with voltage, the term ionization potential signifies the voltage necessary to start the chain process; the term striking voltage applies to a glow-tube. Once the striking voltage is exceeded, ionization starts, and may be maintained at a low voltage, which is the ionization potential. The voltage drop is the anode-to-cathode voltage when current is flowing. The current is called the ionization current, and that part of it which is carried by positive ions is called the gas current. See GAS CURRENT, IONIZATION CURRENT, IONIZATION POTENTIAL, STRIKING VOLTAGE, VOLTAGE DROP.

IONIZATION CURRENT. Total current flowing through an ionized gas. See GAS CURRENT.

IONIZATION GAUGE. Gas-filled triode used to measure the pressure of residual gas contained in a chamber connected to the valve envelope.

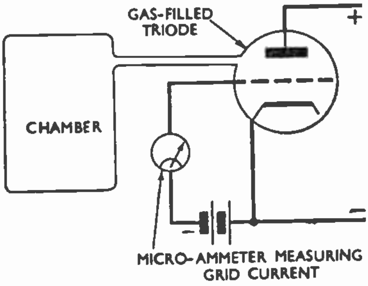


Fig. 21. Circuit connexions showing the principle of the ionization gauge. The envelope of the triode is connected to the chamber containing the residual gas in question.

When the grid of a gas-filled triode is negative with respect to cathode, it attracts positive ions. Thus a current will flow through a micro-ammeter connected between grid and cathode (Fig. 21), as the grid is equivalent to the positive pole of a battery. The pressure of gas within the valve envelope is related to the number of molecules in it, which number is related to the grid current. Thus the gas-filled triode can be used to measure the pressure of a gas. See GAS CURRENT, GAS-FILLED TRIODE, GRID CURRENT.

IONIZATION POTENTIAL. Minimum potential that will cause ionization of a gas. Where the glow-tube is concerned, the term "striking voltage" is often used instead of ionization potential. In a gas-filled valve, the ionization potential is very little different from the voltage drop, but in a glow-tube the potential necessary to start ionization is appreciably greater than that necessary to maintain it. In other words, the ionization potential of a glow-tube is greater than the voltage drop. See GAS-FILLED VALVE, GLOW-TUBE, IONIZATION.

IONIZED GAS DETECTOR. Early type of detector in which the received signal initiates a discharge through an ionized gas.

IONOSPHERE. That region of the atmosphere above the earth's surface which is capable of being ionized. Ionization is the name given to the action which takes place when some of the electrons detach themselves from the atoms of a gas and have free movement. At normal temperatures and pressures, ionization of the atmosphere is negligible, but as the pressure decreases, so the tendency to ionization increases. A gas that is ionized becomes capable of partial electrical conduction. The ionizing agent in the case of the upper atmosphere is the sun, ionization being due in part to direct electron bombardment of the gas atoms, and partly due to ultra-violet, and probably cosmic-ray, radiation.

It is the electrical properties of the

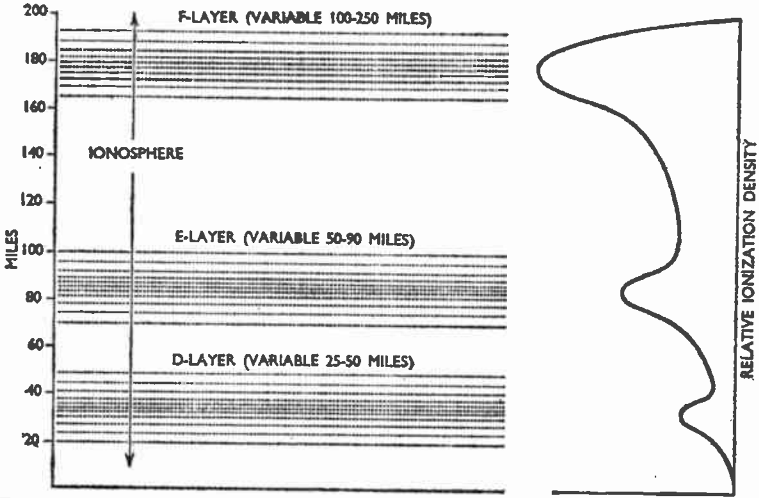


Fig. 22. Diagram showing how the ionosphere is divided into layers; the area contained by the curve (*right*) gives an approximate indication of the ionization.

atmosphere in which radio engineers are directly interested. Electrically, the region from about 10 to 50 miles above the earth's surface is called the D-region, and in this region there is evidence that at least one ionized layer exists at a height varying from 25 to 50 miles. This is known as the D-layer (Fig. 22) and is probably due to cosmic-ray radiation from the sun. Slight evidence exists for a C-layer at a height of some 20 miles, the characteristics of which seem very variable.

In 1902, Kennelly in the U.S.A. and Heaviside in England suggested that a reflecting layer of ionized gas must exist high up in the atmosphere. This has since been proved by pulse measurements, and is thought to be due to direct electron bombardment from the sun. This reflecting layer is known as the E-layer; its height is variable and between 50 and 90 miles. The density of the E-layer varies with the sun's altitude. Thus it is greatest at noon in summer, and at a minimum during the night. The density of the E-layer is known sometimes to increase considerably for a short time, and there may be patches of increased density. The reasons for these sporadic conditions are not definitely known.

Further investigations by Appleton in 1925 disclosed the presence of a still higher layer at a height varying between 100 and 250 miles. This higher layer has been called the F-layer, and appears to be due to ultra-violet radiation from the sun. During the day, when the intensity of ionization is greatest, the F-layer divides into two separate layers spaced about 100 miles apart. The upper sub-layer is called the F2-layer, and the lower the F1-layer.

The actual density of the various ionized layers depends not only upon diurnal and seasonal changes, but also upon the 11-year solar cycle. During the years when sunspots are most numerous the electron density becomes greater. The last two years of maximum sunspot activity were 1937–38 and 1948–49; another maximum will occur in 1959–60.

It appears, therefore, that there are at least three semi-conducting layers, widely separated in space, and each capable of reflecting waves of certain frequencies, within a wide region known as the Ionosphere. See B-LAYER, C-LAYER, D-LAYER, E-LAYER, F-LAYER, IONOSPHERIC REFLECTION, IONOSPHERIC REFRACTION.

IONOSPHERIC-PATH ERROR. That component of the total error of a direction-finding system which arises from lateral deviations of the radio-waves which reach it by reflection from the ionosphere.

IONOSPHERIC RAY. Component part of a radio-wave arriving at a receiving aerial by way of reflection from an ionized layer. A radio-wave emanating from a sending aerial is propagated into space in all directions and has an infinite number of paths; but when energy going in one direction only, within an extremely thin sector of the radiated hemisphere is considered, it is permissible to regard rays of radio energy as having similar characteristics to those of light rays. The rays which are drawn in explanatory diagrams have no separate existence, however, and are merely representative of an infinite number of other possible paths. See IONOSPHERE.

IONOSPHERIC REFLECTION. Reflection of radio-waves by the various ionospheric layers. The waves from a non-directional sending aerial travel outwards in space as well as along the surface of the earth, the large majority of them eventually reaching one or other of the ionospheric layers. When a ray arrives at the effective surface of an ionized layer, reflection, refraction, or both may take place, depending upon the angle of incidence, frequency in use, and the ionic density of the layer (Fig. 23).

The velocity V of an electromagnetic wave is given by the formula $V = \frac{3 \times 10^8}{\sqrt{\mu K}}$, where μ is the permeability of the medium, K the relative permittivity of the medium, and V is given in metres per second.

The permeability is approximately unity for all except ferro-magnetic materials. The relative permittivity K is approximately unity in air, but for ionized gases, such as the E- and F-layers, it is less than unity. The exact value of K depends upon the ionization density and the frequency in use.

Consequently, a ray striking, say, the E-layer, starts to move with greater velocity, and the deeper its penetration of the layer, the greater its velocity. As a result, the higher parts of the wave front travel faster than the lower parts, and cause the wave to bend. The higher part of the wave front is said to possess greater phase velocity than the lower part; the velocity of the whole of the wave front is called the group velocity.

The group velocity cannot exceed the

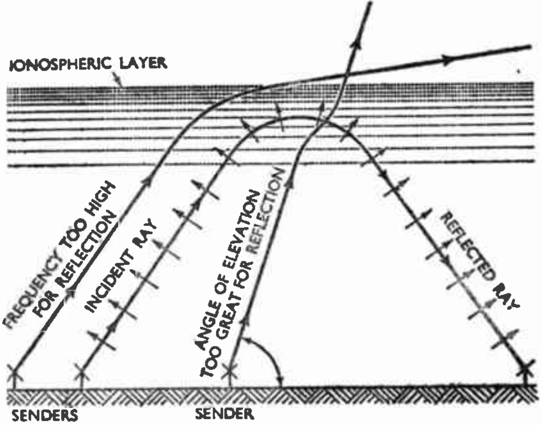


Fig. 23. Simplified diagram illustrating the reflecting properties of the ionosphere. Some rays are not subject to ionospheric reflection because the frequency of the radio-wave is too high, or because the angle of elevation of the ray is too great.

velocity of light. The effect of an ionized layer is thus to cause a gradual bending of the direction, and if the bending is sufficient to direct the ray toward the earth at a distance from the sender, a process akin to reflection of light by a mirror takes place. In general, the higher the frequency the less does the value of K depart from unity, and in any particular layer the degree of bending will be less. See E-LAYER, F-LAYER, IONOSPHERE, IONOSPHERIC REFRACTION, SKIP DISTANCE, WAVE VELOCITY.

IONOSPHERIC REFRACTION. Refraction or bending of radio-waves by one or more of the ionized layers. The ratio of the velocity of radio-waves in free ether to the velocity of waves in an ionospheric layer is known as the refractive index of the layer. The degree of refraction that the wave undergoes depends on the refractive index of a layer and the angle of incidence of the wave.

The refractive index of air at normal temperatures and pressures is approximately unity; but the refractive index n of any other medium is given by the formula n (refractive index) $= \sqrt{K}$, where K is the relative permittivity. In the case of the E- or F-layers, K varies according to the intensity of ionization and wave frequency, but is always less than unity. It follows from this that the lower the frequency and the greater the intensity of ionization, the greater will be the degree of refraction.

If the angle of incidence is sufficiently great for the conditions prevailing, then the angle of refraction becomes so large that reflection occurs and the radio-wave is returned to earth (Fig. 24). The angle of refraction is, in fact, constantly changing all the time the wave is in the layer, being at a maximum in the centre of the layer where the ionization density is greatest, and decreasing at the edges of the layer. See ANGLE OF INCIDENCE, E-LAYER, F-LAYER, IONOSPHERIC REFLECTION, REFRACTION.

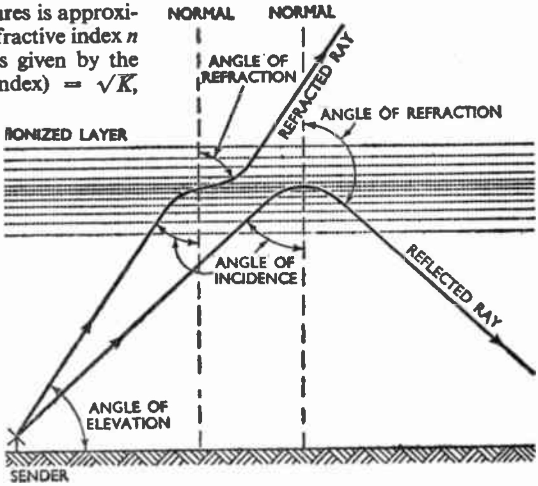


Fig. 24. Diagram illustrating how the degree of refraction of rays entering an ionized layer varies according to the angle of refraction, reflection of the ray occurring only when the angle of refraction is greater than 90 deg.

IONOSPHERIC WAVE. Wave which travels along an IONOSPHERIC RAY (q.v.).

IRON-CORED COIL. See IRON-CORED INDUCTOR, IRON-CORED TRANSFORMER.

IRON-CORED INDUCTOR. Inductor having a core of magnetic material, usually an alloy of iron, in order to reduce its volume for a given inductance. The benefit of a magnetic core is most pronounced at low frequencies where the iron losses are of small magnitude. Nevertheless, even at mains frequencies it is found beneficial to build up the core from insulated laminations of the material so as to reduce the eddy-current losses.

At mains and audio frequencies, silicon alloys of iron, which have a higher permeability and lower losses than ordinary soft iron, are used. At audio and carrier frequencies, nickel-iron alloys are used which, although more expensive, are better than silicon alloys in the respects mentioned. At radio frequencies, the losses become impracticably large, except in the case of cores moulded from finely divided particles of magnetic material (called dust-cores) which have a limited use.

In construction, iron-cored inductors are similar to iron-cored transformers. See FIXED INDUCTOR, IRON-CORED TRANSFORMER, IRON LOSS, LAMINATION.

IRON-CORED TRANSFORMER. Any transformer having an iron core. Such transformers are commonly used at audio frequencies and power frequencies, but by using very thin laminations they are made suitable also for frequencies up to hundreds of kilocycles. See IRON DUST, LAMINATION, TRANSFORMER.

IRON DUST. Finely powdered soft iron often used in inductor cores to increase efficiency by increasing inductance and concentrating the magnetic field in a narrow area. Such an inductor occupies less space than an air-cored one of similar value and, because of the smaller magnetic field, where screening is required, the screen may be placed closer to the inductor.

IRON LOSS. In an iron-cored transformer or iron-cored inductor, the loss due to eddy currents and hysteresis in the iron. When an alternating current flows in the windings of an iron-cored transformer or inductor, it sets up varying magnetic flux in the iron.

This flux induces eddy currents in the iron and, in magnetizing the iron first in one direction and then the other, produces what is known as hysteresis (see HYSTERESIS FACTOR). Energy is inevitably absorbed by these effects, which results in a loss of efficiency in the transformer or inductor. See EDDY CURRENT, IRON-CORED TRANSFORMER.

ISOCHRONISM. See SYNCHRONISM AND ISOCHRONISM.

ISOLATOR. Synonym for BUFFER STAGE. The term is also used to denote a mains switch controlling a number of circuits.

ISOTOPES. Substances whose chemical properties are similar but whose atomic weights are different. Their atomic nuclei are considered to differ in mass but to be the same in charge, and to be surrounded by the same number of electrons.

ITERATIVE IMPEDANCE. Of a quadripole, the value of an impedance measured at one pair of terminals, when the other pair of terminals is terminated with an impedance of equal value. Fig. 25 shows a quadripole and illustrates the meaning of the term; when terminals 3 and 4 are connected to a 500-ohm resistor, terminals 1 and 2 show an impedance of 500 ohms; when 1 and 2 are terminated by 1,000 ohms, terminals 3 and 4 have an impedance of 1,000 ohms. The two iterative impedances are, in general, unequal; but in the special case when they are equal, their common value is called the characteristic impedance of the network. Symmetrical networks thus have a characteristic impedance, and asymmetrical ones an iterative impedance. See CHARACTERISTIC IMPEDANCE, IMAGE IMPEDANCES.

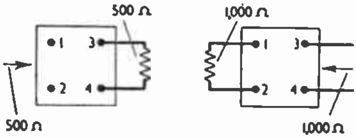


Fig. 25. Iterative impedance of a quadripole; the diagrams illustrate the example quoted in the text.

J

J. Abbreviation for JOULE(S).

JACK. Device used to obtain quick connexion to a circuit. Connexion is obtained by inserting a plug in the jack, the tip, ring and sleeve of the plug respectively making contact with corresponding springs (Fig. 1) in the jack. Jacks are extensively used in telephone switchboards.

JAMMING. Interference due to unwanted signals, sufficiently strong to render the desired signal wholly or partly unintelligible. The term is often used for deliberate interference, the use of which was developed to a high pitch in the Second World War. See INTERFERENCE.

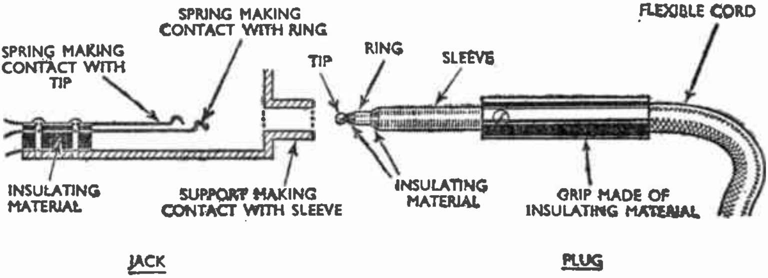


Fig. 1. Section through a jack into which a plug (*right*) is inserted; it is employed to make quick connexion. The drawing is not to scale.

JANSKY NOISE. See ATMOSPHERICS.

JAR. Obsolete unit of capacitance once much used in the British Navy. It is equal to 0·0011 microfarad.

JIGGER. Auto-transformer at one time used in spark senders as a coupling between an intermediate circuit and the aerial.

JOHNSON NOISE. See THERMAL-AGITATION VOLTAGE.

JOULE. Energy unit defined as the amount released by a current of one ampere flowing for one second through a resistance of one ohm. The abbreviation is J. See WATT.

JOULE'S LAW. Law which states the relation between heating effect and current, resistance and time. It states that the heat generated is directly proportional to the product of the resistance (R) and the time (t) for which the current flows, multiplied by the square of the current (I). In symbols, therefore,

$$\text{heat produced} \propto I^2Rt.$$

K

k. Abbreviation for kilo, a prefix meaning thousand, as, for example, in kW (kilowatt), kV (kilovolt).

KALLIROTRON. Untuned circuit in which two triodes are used to give an effective negative resistance.

kc/s. Abbreviation for KILOCYCLES PER SECOND.

KEEPER. Substance which is placed in the bulb of a hard-vacuum valve and tends to absorb, by chemical action, any gas released in the bulb after manufacture is completed. In the manufacture of a hard-vacuum valve, the process of degassing involves pumping, heating of electrodes while pumping, and sometimes the use of a getter. In spite of these processes, it is possible for occluded gas to be released some time after manufacture and the valve may, in consequence, go "soft" (see SOFT-VACUUM VALVE). In order to minimize this effect, a keeper may be placed within the bulb which tends to absorb any gas released when the valve is in operation. Certain getters may also act as keepers. See DEGASSING, GETTER.

KENNELLY-HEAVISIDE LAYER. Original name for that ionospheric layer now more commonly known as the E-layer. The E-layer was discovered by the scientists Kennelly and Heaviside, working independently of each other, in the year 1902. Appleton, in 1925, introduced a new terminology for the two layers known to exist at that time, calling them the E- and F-layers. See E-LAYER, IONOSPHERE.

KENOTRON. American name for a VACUUM-VALVE RECTIFIER. See also DIODE.

KERR CELL. Device for the electrical modulation of light. The cell consists, fundamentally, of a transparent container filled with nitro-benzine. Polarized light is passed through the liquid and between two banks of metal plates resembling the plates of a variable capacitor. As the potential across the two banks of plates is varied, so the polarized light beam is more or less rotated, away from its axis of vibration.

In itself, the Kerr cell will not provide a form of light modulation that can be used for television because it is not a *quantity* controller, merely twisting the plane of the light passing through it. Owing to capacitance effects, the Kerr cell cannot be used for high-definition television; it can, however, be used in low-definition television as follows: Ordinary light is passed through a polarizer of Iceland spar. It emerges plane-polarized and is then passed through the Kerr cell as illustrated in Fig. 1.

The output of the television receiver is connected to the plates of the cell, already biased to its most sensitive condition. The light emerges from the Kerr cell, and is passed through a second polarizer which will pass light only in a plane at right-angles to the light passed by the first filter. Thus, when no potential is applied to the Kerr cell and no rotation of the plane of polarization occurs, no light passes through the second polarizer.

As the plane of the light is rotated by the Kerr cell, operated by the television signal, more and more light is allowed to pass by the second polarizer, maximum light passing when the plane rotation is 90 deg. In practice, the Kerr cell is biased to a point where light is just beginning to pass, and any added potential causes more light to pass. Synchronizing signals, which reduce the potential across the cell plates, reduce the rotation of the plane of

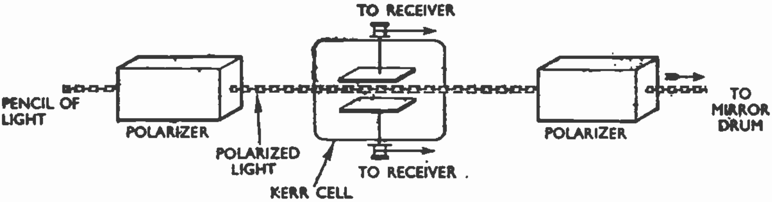
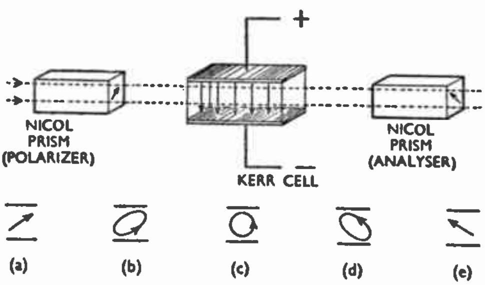


Fig. 1. The Kerr cell rotates the plane of polarized light according to the potential across the plates of the cell. The second polarizer passes only light which is in a plane at right-angles to that passing the first polarizer.

Fig. 2. If monochromatic light, which is plane-polarized at 45 deg. to the electrostatic field in a Kerr cell, is passed through the cell, the plane of polarization can be rotated by increasing the potential. An indication of this is given in the small diagrams from (*a*) to (*e*).



the light and cut it off altogether.

Many attempts have been made to reduce the self-capacitance of the Kerr cell sufficiently for it to be used with high-definition television. Results, however, have not been promising. Divergent plates assist in reducing the capacitance, but it is still a serious drawback. A further drawback, not directly connected with the Kerr cell, is the fact that light-modulation of this type is of use only with mechanical methods of scanning, and these, in themselves, are clumsy and unsatisfactory for high definition.

KERR EFFECT. Phenomenon, discovered by Professor Kerr, that, when certain media are subjected to electrostatic stress between a pair of plates, the media become birefringent. Instead of light vibrations passing in their full proportions through a medium of this type, regardless of the plane of the vibrations, only vibrations in one particular plane are passed fully.

Other vibrations are retarded. The resultant vibration is one that is a component of the various vibrations passed, and is in a direction dependent on the optical axis of the cell formed by the medium between the metal plates, and on the potential between the plates.

Tourmaline is a substance which is naturally birefringent, but Kerr discovered that the effect can be produced and controlled by forming cells of such liquids as carbon disulphide, chloroform, nitrobenzene and metanitrotoluene, with two metal plates as electrodes between which the electrostatic potential could be applied.

Now, if plane-polarized light is passed between the plates (Fig. 2) when a potential difference between them is applied, the liquid will become birefringent and will split the plane-polarized light into two rays moving with unequal velocities in the liquid. On emergence, the two rays, which are unequally retarded, will join to form elliptically polarized light from which a component can be selected by a Nicol prism. This component can be changed by varying the potential across the Kerr cell, and thus varying the retardation of the two light rays passing through the cell.

Rotation of the plane-polarized monochromatic light can be seen from the diagrams in

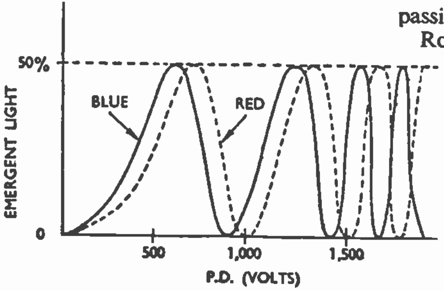


Fig. 3. Graph which gives an indication of the difference over the spectrum of emergent light at increasing values of the potential across the plates of a Kerr cell.

Fig. 2, where light, polarized in a plane at 45 deg. to the direction of the electrostatic field in the Kerr cell, is passed through the cell and rotated through 90 deg. This rotation can be increased or decreased by varying the potential across the plates of the Kerr cell.

If the polarizer (first Nicol prism) and the analyser (second Nicol prism) are so crossed that their planes of polarity are not at 90 deg. to one another, the maximum amount of light that can be passed is decreased and it is impossible to cut off the light completely, no matter how the voltage of the Kerr cell is varied. If the electrostatic field in the cell is not at 45 deg. to the planes of polarization passed by either of the prisms, complete cut-off of light can be achieved, but the maximum amount of light which can be transmitted is reduced. The best conditions are those illustrated, where the planes of polarization accepted by the prisms are 90 deg. to each other, and each is 45 deg. to the field of the Kerr cell.

In this condition, not only can the best effects be obtained with monochromatic light, but variations with wavelength are at minimum, as shown by Fig. 3, provided the potential across the Kerr cell is kept low. If the potential is increased, the amount of light emerging varies considerably with position in the spectrum band. To overcome this disadvantage, and to allow the steepness of the high-voltage characteristics to be used to gain sensitivity, it has been proposed to use a compensating retardation plate of mica so that a higher bias potential can be applied to the Kerr cell.

The time-lag of the Kerr cell is very short, being of the order of less than 0·00002 second. This has enabled Kerr cells to be used for television where modulation of light is necessary. See KERR CELL.

KEY. One of several classes of switch used in communication and test equipment. A telegraph or morse key is a single-pole, two-way switch designed for rapid manual operation for generating telegraph signals of the morse type (see MORSE CODE).

A telephone key is a switch having laminar cantilever contacts which are flexed rather than pivoted (Fig. 4) like contact springs of a relay. For applications where the inter-contact capacitance of the standard key is excessive, a "low-capacitance" key is available having stiff-wire contact members instead of leaf springs.

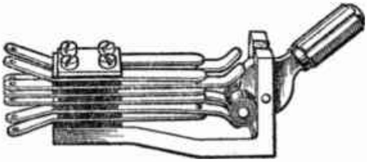


Fig. 4. Key switch with leaf-spring contacts, for use where low capacitance is not essential. A modified type can be used in some R.F. circuits.

KEY CLICK. Transient sidebands produced by the sudden stopping and starting of a carrier wave due to keying. These may be sufficiently remote in frequency from the carrier wave to cause interference, heard as clicks, on other channels. The time constants of the keying system should be arranged so that the growth and decay of the carrier wave is not more rapid than is necessary for well-formed characters. See KEYING.

KEYED CONTINUOUS WAVE. See TYPE A1 WAVE.

KEYED MODULATED WAVE. See TYPE A2 WAVE.

KEYING. Operation of interrupting electrical circuits in a telegraph or radio-telegraph system. The operation may be manual or, for high-speed keying, automatic.

KEYSTONE EFFECT. Distortion of a television frame, as shown in Fig. 5, caused by the line scanning being modulated by the frame scanning. It is produced also when the screen is not normal to the axis of the beam, as

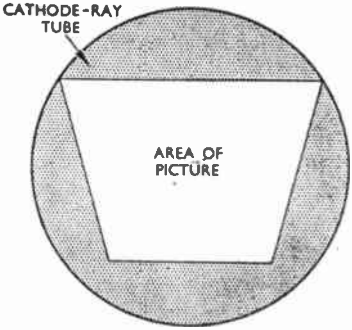


Fig. 5. Distortion of a television frame, known as keystone effect, which may be caused by modulation of the line scanning by the frame scanning.

in the electron camera. Here deliberate keystone distortion is introduced in the scanning system in order to counteract the distortion due to the screen not being at right-angles to the beam. See ELECTRON CAMERA.

KILOCYCLES PER SECOND. See CYCLES PER SECOND.

KILOMETRIC WAVE. Radio-wave of 1,000 to 10,000 metres wavelength; that is, within a frequency range of 30–300 kc/s. See LOW-FREQUENCY WAVE.

KILOVOLT-AMPERE. Unit of apparent or nominal power (abbreviated kVA), equal to 1,000 VA. See VOLT-AMPERE.

KILOWATT. Unit of power (abbreviated kW), equal to 1,000 watts. See WATT.

KILOWATT-HOUR. Unit (abbreviated kWh) which expresses the rate of power delivery or consumption, taking into account both the magnitude of the power-flow and its duration. A power of 5 kW in use for 2 hours represents a power consumption of 10 kWh.

KINKLESS TETRODE. Term used to describe a tetrode in which the effects of secondary emission have been eliminated. The term recalls the shape of the anode-volts/anode-current characteristic of early tetrodes in which a negative slope resistance appears. It is this negative resistance which makes possible the construction of dynatron oscillators. See SECONDARY EMISSION, TETRODE.

KIRKIFIER. Circuit devised by H. L. Kirke before low-impedance diode rectifiers were available. It uses a triode with a positive voltage applied to the grid. Such an arrangement exhibits a marked non-linear characteristic, and has a performance similar to that of the low-impedance diode rectifier.

KLYSTRON. Valve in which the electron stream is made to form into bunches by the action of a RHUMBATRON (q.v.), or cavity resonator. The valve may be used as either an amplifier or generator of centimetric waves. The action of the klystron is shown in Fig. 6, in which it is seen that the valve comprises an oscillator whose feedback arrangement is formed by the interconnexion, by a tube, of two cavities which are known respectively as the buncher and the catcher.

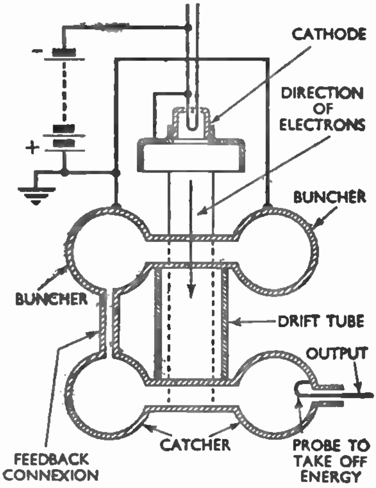


Fig. 6. Diagram showing in section a klystron as used for the generation of centimetric waves; connexions to external circuits are also indicated.

The cathode is biased negatively with respect to the earthed anode (catcher). Thus electrons are accelerated towards the opening of the buncher, which acts as a grid in controlling the electron stream.

Imagine that the field in the gap in front of the buncher is rising and falling in intensity; rising from zero positively, it accelerates electrons coming towards it from the cathode and slows down electrons that have passed beyond it into the drift tube. Rising from zero negatively, the field slows down the electrons approaching on the cathode side of it and repels, i.e., accelerates, the electrons which have passed the buncher and are in the drift tube. The total effect is that of a periodic concentration (or bunching) of electrons in the stream in the drift tube.

The bunched beam passing the mouth of the catcher excites the rhumbatron into oscillation; thus, by means of the interconnexion of the two cavities, there is a feedback of energy from catcher to buncher and the action, like that of any oscillator, is regenerative. The natural frequency of oscillation is that of the rhumbatron, which resembles a tuned-anode circuit and tuned-grid circuit in a triode oscillator, the former being the catcher, the latter the buncher.

Energy is taken from the catcher by a probe. (The same method of drawing-off energy is used in the multi-cavity magnetron.) Since the velocity of the electrons in the drift tube must be changed to cause bunching, the valve is often called a velocity-modulation valve. See MAGNETRON, OSCILLATOR.

kVA. Abbreviation for KILOVOLT-AMPERE.

kW. Abbreviation for KILOWATT.

kWh. Abbreviation for KILOWATT-HOUR.

L

LABORATORY OSCILLATOR. Synonym for FREQUENCY-STABILIZED OSCILLATOR.

LADDER NETWORK. Term describing a cascade connexion of similar networks with series and shunt arms. A multi-section filter may be described as a ladder network. See FILTER SECTION.

LAG. Extent to which an alternating current falls behind the voltage cycle in an inductive circuit. See LAGGING CURRENT.

LAGGING CURRENT. Alternating current which reaches its successive maximum values after the voltage reaches its maximum values, a condition characteristic of circuits which are predominantly inductive. The extent of the lag decides the power factor of the circuit; it is calculated in terms of an equivalent angle in the 360-deg. cycle. See POWER FACTOR.

LAGGING LOAD. Alternating-current circuit in which the current is caused to lag behind the voltage by the mainly inductive effect of the load. The load is consequently sometimes called an inductive load.

LAMINATION. Of an iron-cored transformer or inductor, a ferromagnetic sheet shaped so that, with other similar sheets, a structure may be built up as a partly or wholly closed iron circuit suitable to form the core of the transformer or inductor. An iron core is made up of laminations so as to prevent serious loss due to eddy currents. The thinner the metal, the less is the eddy-current loss. Laminated iron-cored transformers can be used up to frequencies of hundreds of kilocycles provided the laminations are very thin. One of many different types of iron may be used, depending upon the requirements of flux density, iron loss, incremental permeability and the frequency of a cycle of magnetization. See CORE, INDUCTOR, TRANSFORMER.

LATERAL DEVIATION. Deviation or divergence of the ground wave when the great-circle route between sender and receiver is roughly parallel to a coast line. The accuracy of any radio direction-finding system is based on the assumption that the radio-waves follow a great-circle route, which is the shortest distance between any two points on the earth's surface. If the great-circle bearing is parallel to a coast line, then the ground wave suffers greater attenuation whilst passing over land than it does over sea. This results in a shifting of the wave front, and the wave arriving at the receiver tends to be bent in such a way as to cause the sender bearing to be displaced seawards from the true bearing of the sender.

Bearings that are within about 15 deg. of a coast line are likely to be inaccurate, particularly if the distance from the sender is great. A similar deviation is often found in mountainous areas, since the attenuation of a ground wave travelling up a valley is less than that of a wave travelling crosswise from ridge to ridge. See ABSORPTION, DIFFRACTION, DIRECTION-FINDING.

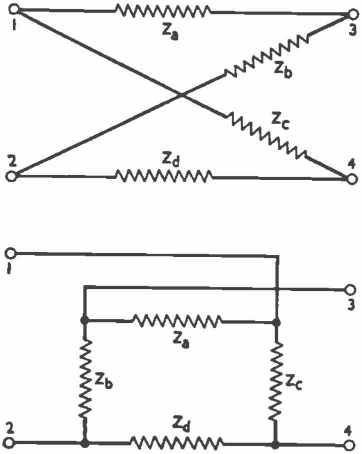


Fig. 1. Two different ways of representing diagrammatically exactly the same lattice network.

LATERAL INVERSION. Mirroring of a television picture. The right-hand side appears on the left, and vice versa, although the picture is the correct way up. Deliberate lateral inversion has to be used when a cathode-ray picture is to be indirectly viewed through a mirror, or when mirror-drum or mirror-screw pictures are viewed on a reflecting screen (see MIRROR DRUM, MIRROR SCREW).

LATERAL RECORDING. Recording system, particularly gramophone, in which the recording stylus moves sideways about a mean position, the depth of the recorded groove remaining constant. See ELECTRICAL RECORDING.

LATOUR ALTERNATOR. High-frequency synchronous generator developed and used in France for radio telegraphy. See SYNCHRONOUS GENERATOR.

LATTICE COIL. Special type of wave-wound coil. See WAVE-WINDING.

LATTICE NETWORK. Network composed of four impedances connected to form a closed circuit. Two non-adjacent junction points are connected to the input terminals and the other two to the output terminals. Fig. 1 illustrates lattice networks and shows two ways of drawing the same network. See BRIDGED T-NETWORK, C-NETWORK, H-NETWORK, L-NETWORK, O-NETWORK, PI-NETWORK, T-NETWORK.

LATTICE-WOUND INDUCTOR. Inductor having a special type of low-capacitance wave-wound coil in which there is a regular pattern of diamond-shaped air-spaces. See WAVE-WINDING.

LEAD. (1) Time or angular interval by which one phase of one alternating quantity preceeds that of a second alternating quantity; (2) general term for connexion by means of a wire.

LEAD-IN. Conductor joining a radio receiver or sender to an aerial.

LEADING CURRENT. Alternating current which reaches its successive maximum values before the voltage reaches its maximum values, a condition characteristic of circuits which are predominantly capacitive. The extent of the lead determines the power factor of the circuit; it is calculated in terms of an equivalent angle in the 360-deg. cycle. See POWER FACTOR.

LEADING-IN INSULATOR. Synonym for LEAD-IN INSULATOR.

LEADING-IN WIRE. Synonym for LEAD-IN.

LEADING LOAD. Alternating-current circuit in which the current reaches its successive maximum values before the voltage reaches its maximum values. See LAGGING LOAD, LEADING CURRENT.

LEAD-IN INSULATOR. Insulating bush mounted in a wall or bulkhead through which passes the conductor joining a radio receiver or sender to an aerial.

LEAK. Circuit of relatively high resistance. A resistor of the order of a megohm connected across a capacitor so that this cannot maintain a charge for very long is termed a leak. A resistor of high resistance value in the grid to the cathode circuit of a valve is known as a grid-leak. (A "bleeder" is not precisely the same thing as a leak but is similar.)

The term "leak" may also be used to describe the effect of bad surface insulation. See BLEEDER RESISTOR, GRID-LEAK, LEAKAGE CURRENT.

LEAKAGE CURRENT. Current, usually small, flowing between circuit points or from a circuit point to earth, either through, or more probably across, the surface of a poor or faulty insulator. See LEAK.

In a valve, a leakage current may flow over the surface of the envelope or from the valve pins to earth. Because of this, an electrode may be, in effect, connected to a point of low potential through a resistor of high value; for example, the grid may be connected to the cathode through a resistance of several million ohms. The electrode collecting electrons or ions becomes charged, and this charge can leak away over the surface of the bulb (from a grid top-cap, for instance) or along the surface of the valve holder. See GRID-LEAK, WATER-COOLED VALVE.

LEAKAGE INDUCTANCE. Of a transformer, the inductance which may be considered to exist in the primary and secondary windings of a transformer due to failure to achieve complete coupling between the windings. If all the flux produced by the primary coil of a transformer cuts all the turns of the secondary coil, the leakage inductance will be zero. If there is not complete coupling, the effects produced are the same as would be produced if an inductor were connected in series with the secondary terminals of an equivalent transformer with perfect coupling, and the load. The value of such an inductor is the value of a leakage inductance. In other words, an imperfectly coupled transformer is the equivalent of a perfectly coupled transformer which has a series inductor connected between it and an output terminal.

The effect of leakage inductance is to produce a falling-off of the secondary voltage as the frequency of the primary current is increased. It is possible to treat leakage inductance as the series arm of a low-pass filter. In such a case, the falling-off of the frequency-response characteristic takes place more rapidly, but at a higher cut-off frequency. This cut-off frequency depends upon the value of the leakage inductance and the terminating resistance.

The value of the leakage inductance may be found by adjusting a capacitor connected across the secondary of the transformer until maximum voltage is developed across the capacitor. Then $\frac{1}{2\pi fC} = 2\pi fL_L$, where C is the value of the capacitor to give voltage resonance, f is frequency, and L_L is the leakage inductance. Thus

$$L_L = \frac{1}{4\pi^2 f^2 C}.$$

See COUPLING COEFFICIENT, FILTER, FILTER SECTION, RESONANCE, TRANSFORMER.

LEAKANCE. Reciprocal of the equivalent resistance of an insulator; the term is derived from "leakage conductance," and denotes simply the conductance equivalent to the very high resistance of an insulator or insulating material. See CONDUCTANCE.

LEAKY-GRID DETECTION. See GRID DETECTION.

LECHER WIRE. Length of two-wire transmission line which is used as a tuned-circuit element, or as a resonant line for the purpose of obtaining wavelength measurements. Such lines are, in general, between $\frac{1}{4}$ and 4 wavelengths long, and usually have a shorting bar which can be moved to any part of the line.

When used for wavelength measurement, the input end may be coupled inductively or capacitively to the source of radio-frequency energy. Fig. 2 shows a pair of Lecher wires capacitively coupled to the output circuit of a radio-frequency oscillator, and the shorting bar is adjusted at a point which makes the line an odd multiple of $\frac{1}{4}$ wavelength long; the diagram shows this length as $\frac{3}{4}$ wavelength. There is reflection of current at the shorting bar and high voltage at the input end; the successive reflections build up a standing wave such that maximum current flows in the shorting bar.

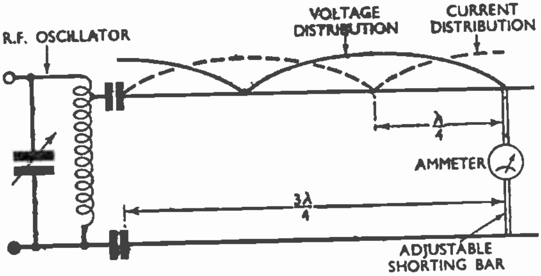


Fig. 2. Standing waves set up on capacitively coupled Lecher wires. The ammeter in the shorting bar reads maximum current at the points of maximum-current distribution, these points being located at half-wave intervals along the line.

An ammeter inserted in series with the bar indicates a high current but, as this current is out of phase with the voltage, no power is supplied by the oscillator. If the bar is now slowly moved along the line towards the oscillator, the current reading on the ammeter will decrease until $\frac{1}{4}$ wavelength has been covered, when the meter will read zero. By moving the bar another $\frac{1}{4}$ wavelength in the same direction, a second current maximum is reached, and the difference between the two current maxima is seen to be $\frac{1}{2}$ wavelength. This is a simple, practical method of measuring the wavelength of an oscillator or sender, but the method is obviously practical only at fairly short wavelengths; a $\frac{1}{4}$-wavelength Lecher line at medium frequencies would be impossibly long and impracticable.

An important application of Lecher lines is as a component in oscillator circuits at very high frequencies. Since standing waves may be set up on a quarter-wave, short-circuited feeder, Lecher lines act as parallel resonant circuits and may be substituted for the ordinary coil and capacitor circuits normally employed in oscillators. Lecher wires used in this manner give the advantages of high circuit-magnification, low resistance-losses, and efficient oscillation at frequencies higher than those readily obtainable with coils and capacitors.

The resistance losses of a well designed feeder are almost negligible, and the circuit amplification is the ratio of its inductive reactance to its resistance. If the resistance is low for a given value of reactance, the circuit amplification is correspondingly high. In a single-valve oscillator, the concentric line is commonly used, as it has the advantage that the inner conductor is screened by the outer conductor, which reduces unwanted radiation. Push-pull circuits make use of the balanced twin-wire type of feeder.

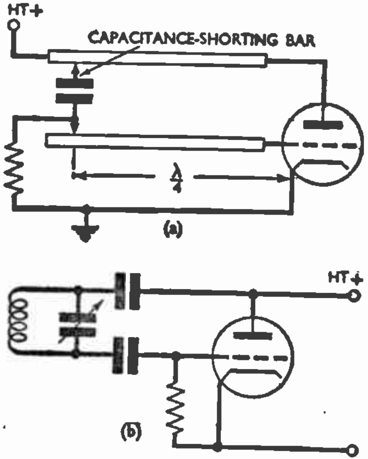


Fig. 3. Simple Lecher-line oscillator suitable for use at very high frequencies (*a*), and its equivalent circuit (*b*). There would, of course, be an anode load (resistor or inductor) between the terminal marked H.T.+ and the positive supply terminal in each case.

Fig. 3 shows a simple form of Lecher-line oscillator and its equivalent conventional circuit of coil and capacitor; this form of valve oscillator readily oscillates at the highest frequency of which the tube is capable. See OSCILLATOR, OSCILLATING CURRENT, Q-FACTOR, STANDING WAVE.

LECLANCHÉ CELL. Form of primary voltaic cell in which the positive electrode is made of carbon and the negative electrode of zinc. The former is usually in the form of a bar, the latter a rod. The electrolyte is a solution of sal ammoniac.

Without means to prevent it, hydrogen forms round the positive electrode and polarizes the cell (see POLARIZATION). A de-polarizer is used, therefore, and consists of a mixture of black manganese dioxide and granulated carbon held around the positive electrode in a porous pot (Fig. 4). The electrolyte soaks through this pot.

When current flows, hydrogen is liberated and combines with some of the oxygen of the de-polarizer. If, however, the current exceeds a given amount, more hydrogen is released than can be absorbed. Thus the current that can be drawn from the cell is limited by polarization; in other words, the internal resistance of the cell is dependent, among other things, upon the effects of polarization. The internal resistance of a Leclanché cell holding about one pint of electrolyte is two or three ohms.

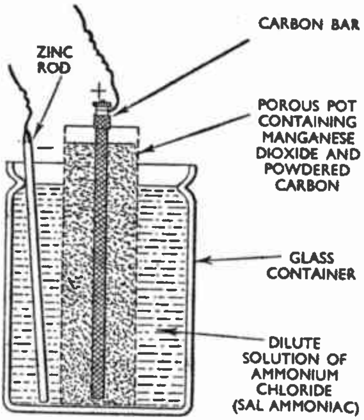


Fig. 4. Section through a wet-type Leclanché cell. The manganese dioxide acts as the de-polarizer, and it is mixed with powdered carbon in order to render it conductive of ions.

A dry cell is basically a Leclanché cell, but the electrolyte takes the form of a paste rather than a liquid. See DRY CELL.

LENS DISC. Form of television scanner in which lenses are used instead of holes in the rotating disc. The lenses concentrate the light and enable a brighter picture to be obtained.

LENZ'S LAW. Law which relates the factors involved in the phenomenon of self-induction (see INDUCTANCE). It states that the voltages induced by a change in the linkages between a conductor and a magnetic field are in a direction which tends to oppose the change of linkage. The law applies in all cases of electromagnetic induction, including that of the transformer.

LEPEL DISCHARGER. Form of QUENCHED SPARK-GAP (q.v.).

LEVEL. See ACTUAL LEVEL, RELATIVE LEVEL, TEST LEVEL.

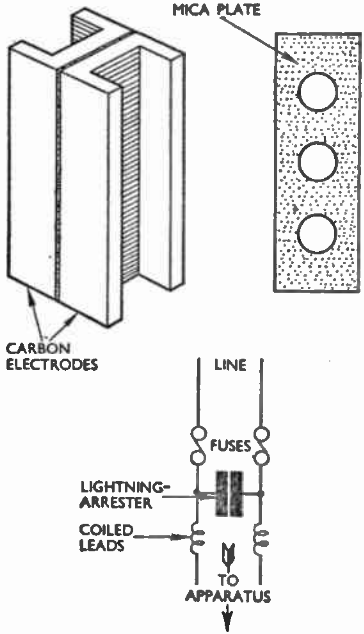


Fig. 5. Form of lightning arrester in which a mica plate, perforated as shown to provide spark-gaps, is clamped between two carbon electrodes.

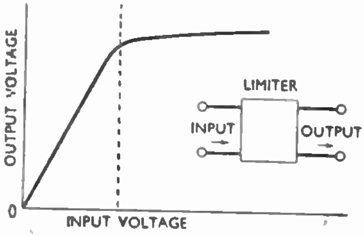


Fig. 6. Characteristic of a practical limiter. An ideal limiter would restrict the output voltage exactly to a fixed maximum when the input voltage increased beyond a certain value.

LEVEL-MEASURING SET. Set of instruments used to measure voltage or power levels at selected points in an electrical transmission system. Basically, it consists of an audio-oscillator, a variable attenuator and a calibrated meter, such as a valve voltmeter. The instruments are normally calibrated in decibels, zero level being taken as 1 milliwatt, or 0·775 volt developed across 600 ohms.

LEYDEN JAR. Earliest form of capacitor, devised in the University of Leyden. It consisted of a glass jar as dielectric, with the inside and outside surfaces of the walls and base coated with metal foil as electrodes. See CAPACITOR.

LIGHT CURRENT. Current provided by electron emission from the cathode of a photocell.

LIGHT FLUX. A measure of the quantity of light energy passing through an area. The light flux passing through a given area depends on the intensity of the source and the distance of the area from it. The unit of light flux is the lumen and is defined as the energy passing through unit area at unit distance from a source with an intensity of 1 standard candle. From this definition it may be seen that 1 standard candle gives rise to 4π lumens. See LUMEN.

LIGHTNING. See ATMOSPHERICS.

LIGHTNING ARRESTER. Device for protecting equipment connected to an outdoor aerial or overhead line from surges due to lightning. In one form, shown in Fig. 5, a multiple spark-gap to earth is provided by perforated mica sandwiched between carbon electrodes. For power-line protection, use is made of special minerals, such as Metrosil, the resistance of which decreases very steeply when the working voltage is exceeded.

LIGHT RAY. Path traversed by electromagnetic wave forms which produce visual sensations on the eye.

LIGHT RELAY. Synonym for PHOTO-CELL.

LIGHT RESISTANCE. Resistance of a photo-conductive material when under the influence of light. See PHOTO-CONDUCTIVITY.

LIMITER. Any device with input and output terminals which maintains the amplitude of a wave at the output terminals substantially constant when the amplitude of the wave at the input terminals exceeds a certain value. The graph of a typical limiter is shown in Fig. 6. It may be noted that there is a proportionality between input and output voltages when the input voltage is less than a certain value; but that when a certain value is exceeded, the output voltage remains almost constant.

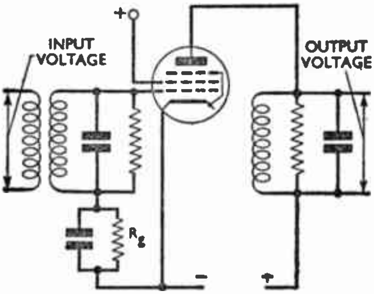


Fig. 7. Circuit of a limiter; grid current flows in R_g to provide negative grid bias whenever the input voltage exceeds a certain value. The ideal characteristic is shown in Fig. 8.

The device is extensively used in frequency and phase modulators to ensure that the amplitude of the modulated wave shall not vary with modulation. The limiter is also used in television reception. The circuit of a limiter is given in Fig. 7. The action is due to the fact that increasing the input voltage beyond certain limits causes grid current to flow in R_g and biases the grid negatively. The amplification of the valve decreases as its grid is made more negative, as illustrated in Fig. 8. See FREQUENCY MODULATOR, NOISE LIMITER, PHASE MODULATION, TELEVISION.

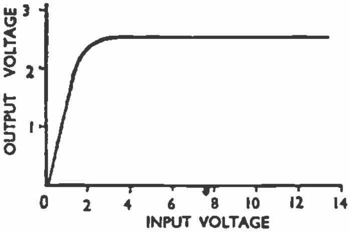


Fig. 8. Form of the response of the limiter circuit illustrated in Fig. 7.

In broadcasting technique, a limiter taking the form of an amplifier is interposed between a programme source and the sender or recording system to prevent overloading of the sender or recording system. It consists of a main amplifier and a side chain, the gain of the former being reduced at excessive programme peak volume by the action of the latter.

Suppose the normal modulation depth of a sender to be 40 per cent and the peak modulation 100 per cent, then the maximum programme volume applied to the sender input must not exceed the normal volume by more than 8 db. ($20 \log_{10} \frac{100}{40} = 8$). The action of the limiter is illustrated in Fig. 9. Programme signals are applied to the input of the main amplifier V_1, one output of which is connected to the sender and the other to the side chain. The valve V_2 is normally

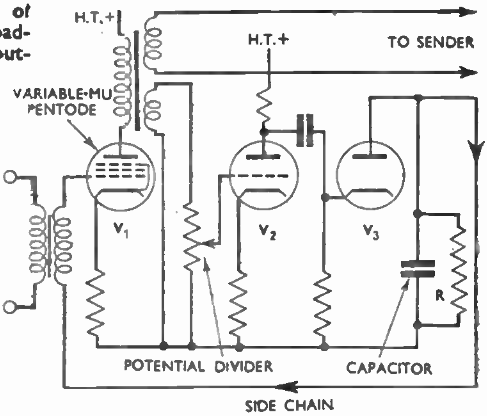


Fig. 9. Theoretical circuit of a typical limiter used in broadcast technique. When the input-signal exceeds a predetermined value, the cut-off bias of V_2 is partly offset, and V_2 passes current. The output of V_2 is rectified by V_3, and the output of V_3 applied to V_1 as negative bias; the gain of V_1 is thus reduced. When the peak signal has passed, the capacitor discharges through *R*, and V_1 is restored to normal gain. It may be mentioned that, in practice, V_1 is a push-pull stage.

biased beyond cut-off and passes no signal. If the input signal reaches a peak value exceeding 8 db. above normal, the excess signal voltage partly offsets the bias on V_2 which now operates.

The output of V_2 is rectified by V_3, this rectified signal being applied to V_1 as bias, reducing the gain of V_1 by an amount proportional to the excess signal. Thus, if the signal is 2 db. above maximum permissible peak volume, the gain of V_1 will be reduced by 2 db. The example quoted is for 8 db. limitation; other values may be obtained by adjustment of the potential divider.

The source of the biasing potential is the capacitor. To restore the side chain to normal after the excessive peak has passed, a resistor *R* discharges the capacitor. The value of *R* is critical; if too low, the capacitor discharges too rapidly and the limiter behaves as a compressor; if too high, soft passages following an excessive peak may be unduly attenuated, producing a "fading" effect on the programme. See COMPRESSOR.

LINE. Abbreviation of TRANSMISSION LINE.

LINE AMPLIFIER. Amplifier associated with the input to a line running from a control room to a sender, or to a trunk exchange for simultaneous broadcasting. The distinction is made to differentiate a line amplifier from a microphone or A-amplifier.

LINE AMPLITUDE. In a television receiver, the output of the line-scanning generator or the length of the horizontal line produced by the scanning generator on the screen.

LINEAR AMPLIFICATION. Process of amplification in which the final product is a perfect, though enlarged, copy of the original. More precisely, amplification in which the amplitude of the output current or voltage at any instant is greater than the input by a fixed ratio.

Thus, if the output voltage is 20 times the input at a particular instant, so will it be 20 times the input at any other instant, no matter what the actual amplitude or frequency of the input voltage may be; if the input is 1 volt, the output will be 20 volts; if the input is 2 volts the output will be 40 volts; and so on, up to the limit of the apparatus. If one plots a graph of input against output the result will obviously be a straight line; hence the name *linear* amplification.

LINEAR AMPLIFIER. Amplifier in which the output wave of voltage or current is a perfect copy of the input wave. This implies that the output is directly proportional to the input; i.e., there is a linear relationship between output and input. A linear amplifier produces no distortion. See LINEAR AMPLIFICATION.

LINEAR DETECTION. Process of detection in which the audio-frequency output is directly proportional to the modulation. This is not fully achievable in practice because any practical detector exhibits non-linear characteristics to small signals. In other words, the change from the non-conducting to the conducting condition is always gradual.

With a strong signal, however, of the order of 1 volt upwards, the diode detector behaves very nearly as a true linear detector, and a good approximation to linear detection can also be obtained, even with rectifiers which have a fairly large bottom bend, such as an anode-bend detector.

The average depth of modulation of a high-quality broadcast sender is about 40 per cent, and modulation peaks up to 100 per cent are comparatively rare. Thus good reproduction can be obtained even if the rectification is not completely linear. Fig. 10 shows the characteristic of an anode-bend rectifier with a strong applied signal. It will be seen that the limits of variation of carrier amplitude occur over a portion of the characteristic which is tolerably linear.

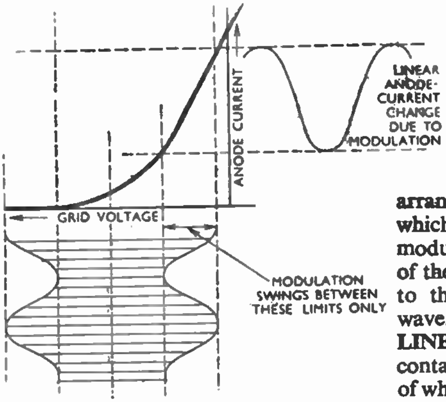


Fig. 10. Graph showing that linear detection is obtained when the depth of modulation is only, say, 40 per cent, even though the characteristic of the detector has a bottom bend.

LINEAR DETECTOR. Detector in which the rectified output is proportional to the modulation depth of the input signal. See LINEAR DETECTION.

LINEAR DISTORTION. See NON-LINEAR DISTORTION.

LINEAR MODULATION. Modulation in which linear amplifiers are used in the modulators, and in which the conductivity or impedance of circuit elements of the modulators is constant. Non-linear modulation is based on the addition of the amplitudes of carrier and modulating waves, and the rectification of the resulting wave; a filter is used to select the modulated wave from the distorted wave.

In linear modulation, the modulating wave influences the carrier-wave amplitude by means of devices which have a linear response. Thus the modulated amplifier, in anode modulation, gives a carrier-wave output proportional to its anode voltage; in commutation modulation, the modulator is a switch arranged to have the same conductivity whichever way it is conducting the modulating wave, and the amplitude of the modulated wave is proportional to the amplitude of the modulating wave. See NON-LINEAR MODULATION.

LINEAR NETWORK. Any network containing circuit elements the values of which are independent of the current flowing through them. A network which contains rectifiers or valves, for example, is not a linear network. See NETWORK, PASSIVE NETWORK.

LINEAR RECTIFICATION. See LINEAR DETECTION.

LINEAR RECTIFIER. See LINEAR DETECTOR.

LINEAR TIME BASE. Oscillator giving a saw-tooth wave form which, when applied to the deflector plates or coils of a cathode-ray tube, causes the spot to move across the tube at a constant velocity in one direction, to return quickly to its starting point and to continue this cycle of events indefinitely.

LINE DISTORTION. Distortion of signals resulting from transmission along a line, such as a telephone line. As the attenuation of a line is, in general, not the same at all frequencies, attenuation distortion takes place; for this the remedy is an equalizer. The velocity of propagation is also a function of frequency, causing phase distortion and delay distortion, to counteract which loading is practised. See ATTENUATION DISTORTION, DELAY DISTORTION, EQUALIZER, LOADING, PHASE DISTORTION, TRANSMISSION LINE.

LINE-FREQUENCY. Rate, in television, at which scanning lines are repeated. In the British high-definition television system now in use, the line frequency is 405 × 25, there being 405 lines to a complete picture, and 25 pictures a second. The line frequency is, therefore, 10,125 per second.

LINE-FREQUENCY GENERATOR. Special type of oscillator which provides a saw-tooth wave form at the rate, in British television, of 10,125 complete saw-teeth per second.

There are numerous kinds of circuit that can be employed, including multivibrators and gas-filled discharge valves, but all must be capable of providing accurately shaped saw-teeth, with perfect regularity, at the correct repetition frequency. Also, they must be capable of synchronization. This may be done by using the synchronizing impulse to discharge a capacitor, by triggering a gas-filled relay, to cause the scanning spot at the end of each line scan to fly back and recommence scanning. Or the oscillator may be held by the synchronizing pulse between lines so that it cannot commence oscillating until the removal of the line-synchronizing impulse.

A simple form of scanning generator is indicated in Fig. 11, where a gas-filled triode is shown employed as a discharge device for a capacitor, across which the scanning voltage is built up.

The capacitor is charged up from the H.T. supply through the resistor R_1, the rate of charge (which is the rate of scan) being set by the value of R_1. The gas-filled relay V_1 obtains grid bias from a tapping on the cathode resistance of V_3, which is an amplifier used to amplify the saw-tooth voltage developed across the capacitor. V_2 is an amplifier also and, with V_3, provides push-pull application of the saw-tooth to the deflector plates of the cathode-ray tube. The balance adjustment R_2 ensures that the push-pull voltages are equal. V_1 bias is set so that the valve will not discharge until the

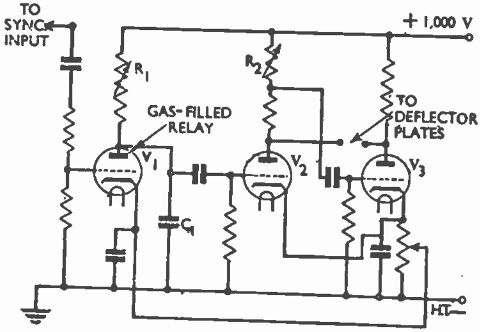


Fig. 11. Simplified circuit (omitting valve-heater circuits) of a line-frequency generator in which a gas-filled triode is employed as a capacitor-discharging device. The output wave form is a saw-tooth having a comparatively slow build-up and a rapid fly-back or discharge, and an amplitude which depends on the voltage across R_1—C_1 and duration of the charge.

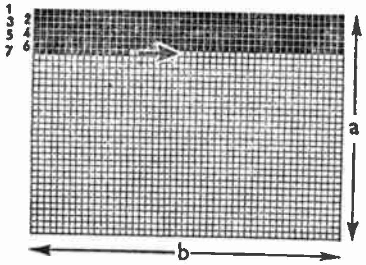


Fig. 12. Television raster divided into elements, showing how the lines are scanned. The number of elements is given by n^2b/a, where n is the number of lines, and b and a are respectively the width and height of the frame.

positive synchronizing impulse is applied to its grid.

The sequence of operation is as follows: The cathode-ray spot is set so that it is normally stationary at the end of a line, that is, on one side of the screen. When the line-frequency generator is switched on, the capacitor commences to charge through R_1. V_1 is biased back so that it draws no current. By arranging that the voltage across R_1–C_1 is very high in relation to the maximum voltage required across the capacitor for scanning purposes, use is made of only the early part of the normal exponential charging curve of a capacitor.

As the capacitor charges, so the grids of V_2 and V_3 are affected in reverse phase, and a potential difference is set up across the deflector plates. The spot is deflected across the tube.

When the synchronizing pulse arrives, the grid of V_1 is made positive, the gas ionizes and the capacitor is suddenly discharged at a rate very much greater than the rate of charge. This discharge causes the grids of V_2 and V_3 to be brought immediately back to their original condition and the difference of potential between the deflector plates, due to the anode potentials of V_2 and V_3, is removed. The spot flies back to its starting point.

When the line-synchronizing impulse is removed, V_1 grid becomes negative again, the valve de-ionizes and the charging of the capacitor is recommenced. The speed of charge must be so set that the line scan can be completed between the arrival of successive synchronizing impulses. The result is a saw-tooth wave form with a repetition rate dictated by the repetition rate of the line-synchronizing impulses, and an amplitude dependent on the voltage applied across R_1–C_1 and the time allowed for the charge to take place.

The rate at which maximum amplitude is reached, that is to say, the speed at which the spot is pulled across the screen, depends on the size of the capacitor, the value of R_1 and the applied H.T. voltage. Thus, all three must be carefully chosen to provide the correct rate of scan, and the bias of V_1 must be adjusted so that the valve will not fire before the arrival of the synchronizing impulse, but will do so readily when the impulse does arrive.

LINE-JUMP SCANNING. Synonym for INTERLACED SCANNING.

LINE NOISE. Noise picked up by telephone lines because of induction from power lines, other telephone lines, earth currents, etc. See CROSS-TALK.

LINE SCANNING. Process, in television, of dividing a picture into and reconstructing from a series of lines. Each line is made up of a number of picture elements transmitted and received in a definite order in lines. By means of scanning, the elements are considered one by one, and the lines, when taken in their correct sequence, form the complete picture. Fig. 12 shows how the image is analysed into elements and lines.

LINES OF FORCE. Lines representing the direction of an electric or magnetic field of force; the direction of the line at any point indicates the direction of the force of attraction or repulsion (Fig. 13) exerted at that point.

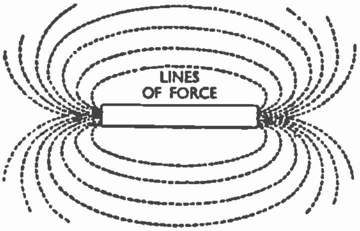


Fig. 13. The lines of force round a bar magnet, indicate the angle at which a magnetic needle placed near the bar would set itself at any point

A "line" is also the unit of field intensity; in a magnetic field, it is equal to 1 Maxwell. See ELECTROSTATICS, MAGNETISM, MAXWELL.

LINE-STABILIZED OSCILLATOR. Master oscillator the frequency of which is controlled by electrical oscillations of a section of a transmission line simulating a resonant circuit.

LINE SYNCHRONIZATION. Process of ensuring, by the transmission of a separate radio impulse, that the scanning device at a television receiver shall carry out its line scanning in the correct order and at the right time. Each line scan is controlled by a synchronizing impulse so that it commences at the same time as the corresponding line in the vision pick-up.

LINE TRANSMISSION. In telecommunication, the transmission of intelligence over a line as distinct from sending by radio.

LINE VOLTAGE. Voltage at the end of a transmission line and available for operating the terminating equipment.

LINKAGE. Interlinking of magnetic lines of force with a conductor, or more precisely, a measure of this condition. In the latter sense, linkage describes the product of the two relevant quantities, namely, the number of lines of force cutting across the circuit and the number of turns across which they cut. The unit value of linkage is thus one line cutting across a circuit consisting of a single closed turn or loop.

LISSAJOUS FIGURES. In general, the curves traced out by a point which describes simultaneously two simple harmonic motions with respect to mutually perpendicular axes, there being a simple integral ratio between the frequencies.

In a cathode-ray tube Lissajous figures are the stationary patterns obtained on the screen when two alternating voltages are applied to the two pairs of deflector plates or the two coils, there being a simple integral ratio between the frequencies.

LITZENDRAHT. German name for LITZ WIRE.

LITZ WIRE. Conductor consisting of a number of separate insulated strands of copper wire offering low resistance to radio-frequency currents. The strands are joined at the end of the conductor. Because of the reduced skin effect, such a conductor has a higher Q-factor than a solid wire of similar cross-sectional area.

L-NETWORK. Network composed of two impedances, two free ends being connected to one pair of terminals, the junction point and one free end being connected to another pair of terminals (Fig. 14).

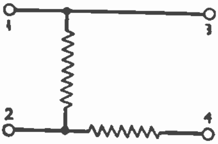


Fig. 14. A network containing two impedances thus is an L-network.

LOAD. With reference to any source of electricity, the circuit connected across the terminals of the source and to which power is delivered from the source.

An example of the use of the term is in the familiar phase "load shedding"; the mains power supply is connected to all sorts of electrical devices representing the load on the generator. Load shedding means decreasing or cutting off the supply of power to this load.

We speak also of the "anode load," which is the circuit to which power is delivered by an amplifier valve. The heaters of valves are the load of the heating transformer and the anode-feed currents are the load on the mains unit. See ANODE LOAD, INTERNAL IMPEDANCE, MATCHING.

LOADED AERIAL. Aerial in which a concentrated amount of inductance and/or capacitance has been added for the purpose of tuning the aerial to a frequency considerably lower than its natural one.

LOADED BALANCED-VALVE AMPLIFIER. Form of balanced-valve amplifier in which comparatively low-resistance shunt paths are provided across inductive components in the grid circuits (Fig. 15). The impedance of these circuits is thereby rendered practically uniform at all working frequencies and the effects of grid current are considerably reduced. See BALANCED VALVE-OPERATION.

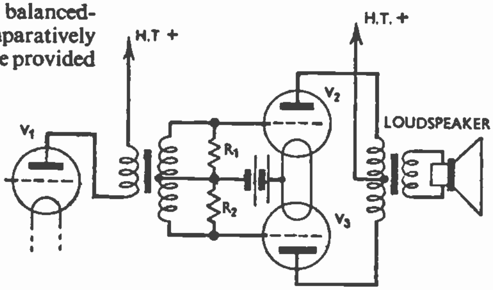


Fig. 15. In a loaded balanced-valve-amplifier (output) stage, the grid impedances (transformer-secondary sections) of V_2 and V_3 are shunted by the two resistors R_1 and R_2.

LOADED PUSH-PULL AMPLIFIER. Synonym for LOADED BALANCED-VALVE AMPLIFIER.

LOADING of a cable, or feeder transmission line, insertion of reactors at regular distances along the cable or line. When signals were first sent over lines, it was thought that the line was equivalent to a network of series resistance and shunt capacitance in parallel with a large resistance, called "leakance." Heaviside showed the inductance of the line to be a profoundly important factor in determining its behaviour, and that the equivalent section must have an inductor in the series arm to be properly equivalent.

Prepin, basing his work on Heaviside's analysis, showed how it is possible to improve the characteristics of a line by inserting reactors at points along it. The reactors are usually inductors known as "loading coils." The effect of the loading is to increase the characteristic impedance of the line, to lower the phase velocity, and, when most of the loss is due to the resistance of the line, to reduce attenuation. The latter effect is more marked at the higher frequencies and so the attenuation-frequency characteristic of a loaded line may be flatter than that of an unloaded line.

The B.B.C. "music lines" on trunk routes, which are rented to the B.B.C. by the Post Office for simultaneous broadcasting, are loaded lines with a cut-off frequency of about 8,000 c/s. See TRANSMISSION LINE.

LOADING COIL. In line transmission, a coil used to minimize attenuation distortion on the line. Such coils are often inserted at distances of 2,000 yards. Adding inductance to the line in this manner increases the electrical inertia of the line in the way that the addition of weights to a stretched string increases the inertia of the string. Hence the line is said to be loaded, the effect being to cause the line to simulate a pure resistance, thus reducing attenuation distortion.

LOAD LINE. Line to show certain factors in the operation of a valve which is delivering power to a load. The line is drawn on a family of anode-current/anode-voltage curves, to pass through the operating point at a slope which is equal to the reciprocal of the load resistance or impedance. The line is useful as a graphical device for certain calculations on power output and distortion.

LOCALIZER. Synonym for MARKER BEACON.

LOCAL OSCILLATOR. Oscillator used for frequency-changing. This distinguishes it from a beat oscillator, which is the oscillator used to produce beating. See BEATING, BEAT RECEPTION, FREQUENCY-CHANGER VALVE, SUPERHETERODYNE RECEIVER.

LOCAL RECEPTION. Reception of signals from a radio sending station within its service area. See LOCAL STATION, SERVICE AREA.

LOCAL SENSITIVITY. Voltage level required at the input terminals of an echo-suppressor to produce a suppression loss of 6 db. The measurement is taken at the frequency of maximum sensitivity, the reference level being 0·775 volt. See ECHO-SUPPRESSOR.

LOCAL STATION. Term relating the distance of a broadcasting station from any place where broadcast programmes are received. A station is called a local station relative to any receiver location when it produces an A-, B- or C-service area at this location. The term *local* station contrasts with *distant* station. A distant station is one so far away that its signals are prone to fade or to be accompanied by noise; a local station gives a steady service because, being near-by, it creates service-area conditions of listening. See DISTANT RECEPTION, SERVICE AREA.

LOCKING. Synonym for COGGING.

LODGE-MUIRHEAD COHERER. Early form of coherer constituting an improvement over the original type in that it does not require any tapper to restore its sensitivity. It is not, however, a true coherer since it consists of a rotating metal disc which dips into a shallow trough filled with paraffin oil, as shown in Fig. 16. In the bottom of the trough is a mercury bubble and the height of the disc is so arranged that it is just clear of the mercury.

The application of a voltage between the disc and the mercury bubble breaks down the thin film of oil and allows the current to flow. The device is polarized with a battery so that it is just on the point of breakdown. A signal, which causes an increase in the total voltage, will then produce this breakdown and allow current to flow, while a voltage in the reverse direction will not produce any current.

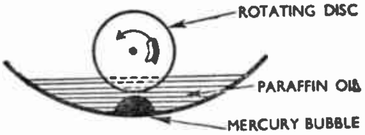


Fig. 16. Diagrammatic representation of the Lodge-Muirhead coherer. Increase in voltage produced by a signal causes the oil film between the disc and the mercury bubble to break down.

LODGE VALVE. Obsolete term for GLOW-TUBE.

LOGARITHM. Index of the power to which the base (a reference number) must be raised to give the number in question. The base of common logarithms is 10. Thus if the common logarithm of y is x, this may be expressed: $\log_{10}y = x$, or $10^x = y$.

In general, common logarithms have a whole number and a decimal part. The whole number is known as the characteristic, and it depends only on the size of the number of which the logarithm is required and not on the actual figures comprising the number. For example, the characteristic is positive for numbers greater than 10, is zero for numbers between 1 and 10, and is negative for numbers less than 1. The decimal part is always positive and depends only on the actual digits forming the number, being independent of the size of the number. It is this part which is given in logarithm tables Logarithms are used to reduce the labour involved in multiplying or dividing large numbers and in problems involving fractional indices.

Napierian logarithms have the base *e* (2·718 . . .) and are convenient for solving certain types of problem, for example, those on the growth and decay of currents or voltages in inductive or capacitive circuits.

LOGARITHMIC DECREMENT. Term describing the way in which electrical oscillations decrease in amplitude when the supply of energy which created the oscillations is cut off. The term was in common use in the days when spark senders were used for radio-telegraphy communication.

The essential feature of a spark sender is a source of high voltage, and a closed-tuned circuit connected across a spark-gap. When the voltage across the gap rises to a certain value, a spark forms and closes the tuned circuit. Oscillations then take place through the conductive spark until this is finally extinguished because the charge on the capacitor is too low to maintain it (see SPARK SENDER). The rate at which the amplitude of the oscillations die away is determined by a logarithmic function (Fig. 17). Hence the term "logarithmic" decrement.

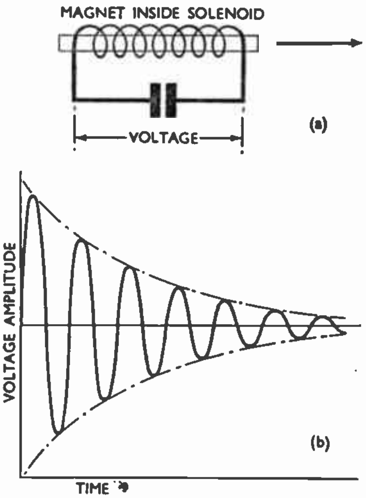


Fig. 17. If the magnet in (*a*) be suddenly withdrawn, inducing a voltage in the inductor, the voltage across the tuned circuit would appear as at (*b*), the wave having a logarithmic decrement; i.e., the amplitude decays according to a logarithmic law at a rate dependent upon the resistance in the circuit.

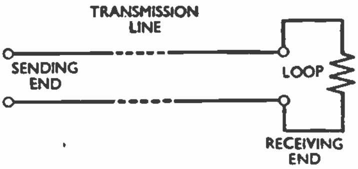


Fig. 18. The terminating metallic circuit at the end of, for example, a transmission line is called a loop.

If a magnet were suddenly drawn through the coil of a parallel-tuned circuit, oscillations would be set up at the resonance frequency of the circuit and would die away according to a logarithmic function.

LOGATOM. Isolated syllable, usually meaningless, consisting of an initial and final consonant with intermediate vowel, used in articulation tests. See ARTICULATION.

LOGATOM ARTICULATION. Percentage of logatoms correctly received over a transmitting or reproducing system.

LONG WAVE. Radio-wave of low frequency.

LOOP. Conductive (metal) circuit closed at one end. The closure may be made by a capacitor, inductor, resistor or rectifier (Fig. 18). Used in connexion with the testing of lines, the term denotes the circuit which bridges the end of the transmission line and is purely resistive. See LOOP RESISTANCE, LOOP TEST.

LOOP-AERIAL. Form of highly directive aerial in which the conductor consists of a winding on a frame or other suitable support. It may contain one or more complete turns of wire, and forms a closed system with both ends brought out to a tuning device which is normally a variable capacitor.

The efficiency of the loop as a means of abstracting energy from passing radio-waves is lower than that of most types of open aerial, as a vertically polarized wave induces voltages only in the vertical sides of the loop, and at most instants these voltages are in opposition. If the induced voltage is, say, upwards in one side it will be upwards in the other side also; and these voltages will meet in opposition to each other in the top and bottom horizontal members of the loop. These two voltages will not in general cancel completely because of a slight phase difference between them and so there is, in fact, a resultant voltage which builds up oscillatory currents in the loop.

The low pick-up efficiency of the loop is, for some purposes, outweighed by the advantage of its outstanding directive properties. Since the phase differences which enable it to respond at all are fundamentally a matter of the time interval between the cutting of the two sides of the loop by a given element in the passing wave, it is obvious that the maximum response is obtained when the time interval is as great as possible.

This will be when the loop orientation is such that the wave has to travel as far as possible to pass from one side to the other, i.e. when the two sides are placed along the line of travel of the wave. Clearly, if the two sides of the loop were set at right angles to the line of travel the wave would cut them simultaneously and there would be no phase difference and no induced voltage.

These considerations indicate what happens when a loop is slowly turned about a vertical axis. Starting from a position broadside-on to the oncoming wavefront, where there is no response at all, the induced voltage rises to a maximum as the plane of the loop comes into line with the direction of wave travel, then falls to a minimum as the other broadside position is reached, again rising to maximum at the next in-line setting. For one complete revolution of the loop there are thus two maxima and two minima, and the polar diagram is in the form of a figure-of-eight (Fig. 19).

Under favourable conditions the minimum positions are extremely sharply defined, and by indicating to within a degree or two when the exact broadside setting has been reached, enable the direction of the distant sender to be measured with accuracy. This is the working principle of the loop direction-finder (see DIRECTION-FINDER, DIRECTION-FINDING).

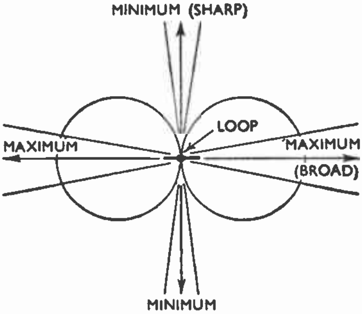


Fig. 19. Polar diagram of a loop-aerial; it is in the form of a figure-of-eight. In using the loop for direction-finding purposes, it is swung for the minimum or "null" position, as this is more sharply defined than the maximum.

Whereas the minimum is normally confined to a few degrees of loop setting, the maximum position is comparatively broad. These two properties of the loop make it of great value in eliminating interference in certain cases. The procedure is simple; the loop is carefully swung to find the minimum for the interfering station, whereupon the desired sender will probably be heard clearly, provided, of course, that it is not in precisely the same direction or 180 deg. from it.

LOOP DIRECTION-FINDER. Apparatus for determining the bearing of a distant sender by means of the directive properties of a loop-aerial. See DIRECTION-FINDER, LOOP-AERIAL.

LOOP RESISTANCE. Resistance of the complete circuit when the ends of a transmission line are bridged in making a loop test. See LOOP, LOOP TEST.

LOOP TEST. Test made on a transmission line when its receiving end is terminated by a loop resistance. See LOOP, LOOP RESISTANCE.

LOOP TUNING ERROR. Error in a tuned Bellini-Tosi direction-finder due to a slight difference in tuning between the two frame circuits. A phase difference is thereby produced in the signal currents, and the minimum setting of the radiogoniometer is consequently vague and possibly erroneous (if the currents in the goniometer field windings are not in phase a rotating magnetic field results). See BELLINI-TOSI DIRECTION-FINDER.

LOOSE-COUPLED CIRCUITS. Term applying to coupled circuits when the coupling coefficient is small. When two tuned circuits tuned to the same frequency are loose-coupled, the effective band width of response is narrower than when the coupling is tighter. The term applies to any coupled-circuit system, but is used mostly in connexion with inductively coupled circuits. See COUPLING, COUPLING COEFFICIENT, LOOSE COUPLING.

LOOSE COUPLER. Early method of tuning in which inductance was varied by moving one solenoid along the axis of another.

LOOSE COUPLING. Condition in which a current in one circuit causes a small voltage in another. The circuits may be coupled by mutual inductance, by capacitance or by both.

LORAN. See NAVIGATIONAL AID.

LORENZ BLIND-LANDING SYSTEM. System enabling aircraft to land in poor visibility, developed in Germany about 1933. The primary function of a blind-landing system is to enable the pilot to land an aircraft safely with only the indications given by instruments. These must provide continuous, positive and three-dimensional guidance to enable the pilot to select the desired runway and land on it under the most adverse visibility conditions. The improved present-day version of the original Lorenz system is widely known as Standard Beam Approach or S.B.A.

Although its chief use is at night, the system is useful during daylight in expediting aircraft landing manœuvres and enabling more planes to land in a given time interval.

The Lorenz system has been extensively used on European aerodromes. It provides the pilot with visual indication of the following information: (1) the course to the runway, that is, position in the horizontal plane; (2) the glide path to be taken, that is, position in the vertical plane, and (3) the distance from the runway. A single sender provides (1) and (2); two separate senders provide (3).

Guidance to the runway is given by a sender situated at one end of the runway and operating on a frequency of 33 Mc/s. The sender energizes a vertical dipole radiator, and two vertical reflectors have the effect of concentrating the radiation into two overlapping beams, the runway being situated in the centre of the region of overlap. One reflector is connected to a key providing a series of dots and the other to a similar key giving dashes.

The dashes and dots are interlinked so that, in the region of overlap immediately over the runway, the electromagnetic field is effectively modulated by a steady note. The output of the aircraft receiver thus gives a direct aural indication of the position of the plane relative to the runway, giving dots if the plane is to one side of it, dashes if to the other, and a steady note if the plane is directly over the runway. This type of signal lends itself very well to visual presentation of the aircraft position.

Because of reflection at the surface of the ground, the distribution of field strength in the vertical plane takes the form shown in Fig. 20. Very approximately, the field strength is directly proportional to the angle of elevation, being zero at the surface of the ground. If, when the plane enters the field of the sender, the pilot allows the aircraft to glide so that the received signal strength is constant, the plane will trace a path such as that shown dotted.

Such a path is approximately parabolic in shape, and is the type of course taken by an aircraft on landing. It can be arranged for the output of the receiver to control the reading of an instrument which then indicates directly whether the plane is tracing a correct vertical path. Usually, the position of the aircraft in the horizontal and vertical planes is indicated by a combined course-guidance and glide-path indicator operated by the output of the aircraft receiver.

To indicate to the pilot the distance of the aircraft from the runway, two "milestones," or "markers," are provided. These take the form of small senders operating in the 30 Mc/s band and each radiates a vertical cone of energy. One is situated at a point where the descent should commence and the other at the end of the runway. The signals from these senders control warning lights within the combined course-guidance and glide-path guidance indicator.

The procedure to be adopted in a blind landing is to fly the aircraft into the field of the course-guidance sender, maintaining a predetermined altitude and steering the plane so that a steady note is obtained from the receiver. When the first marker signal is received, the pilot has to fly along a line of constant signal strength, at the same time manœuvring the aircraft so as to produce a steady note at the receiver output. When the signal from the second marker is received, the aircraft is at the end of the runway.

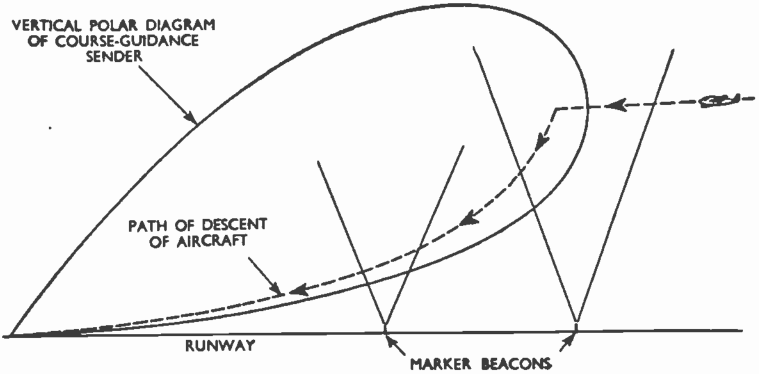


Fig. 20. Fundamentals of the Lorenz blind-landing system. The pilot of the aircraft commences his downward glide on receiving a signal from the first marker beacon, and follows a path along which the signal strength of the course-guidance sender is constant. When a signal from the second marker beacon is received, the aircraft has reached the approach end of the runway.

This system was still in operation at many airports until 1940, but has since been replaced at some by an improved system using higher carrier frequencies and giving better accuracy. It is probable that future blind-landing systems will include radar installations in the aircraft, giving the pilot a direct view of the objects ahead.

LOSS. See ATTENUATION, INSERTION LOSS, IRON LOSS, TRANSMISSION LOSS.

LOUDSPEAKER. Electro-acoustic device for converting audio-frequency currents into audible sound waves. In general, a loudspeaker consists essentially of a metal or paper diaphragm, shaped like a shallow cone and connected to some form of motor (electro-mechanical device). Some diaphragms radiate directly, the low-frequency response being maintained by a BAFFLE (q.v.); others feed into a horn.

The commonest types of driving motor are moving-coil and moving-iron, but capacitive and crystal loudspeakers have also been produced. See CAPACITIVE, CONE, CRYSTAL, INDUCTOR, MOVING-COIL, MOVING-IRON, REED, VOGT, and VOIGT LOUDSPEAKERS.

LOUDSPEAKER RESPONSE. Relationship between the loudness of the undistorted sounds produced by the loudspeaker and the value of the e.m.f.s producing them. If the e.m.f. values are constant over a given audio range, the response is said to be level when the sounds produced have equal loudness over that range.

To measure loudspeaker response, sinusoidal tone is applied to the terminals at a power level calculated to avoid overloading the instrument. The tone source must be variable in frequency and constant in output over the whole audio range. A microphone, the frequency characteristics of which are known, is placed at a suitable distance from the speaker and along the axis of the cone, as shown in Fig. 21. The output of the amplifier following the microphone is connected to a suitable measuring instrument. To avoid sound reflection from enclosed walls, the test is made in open air unless special laboratory conditions, simulating those which exist in open air, are available.

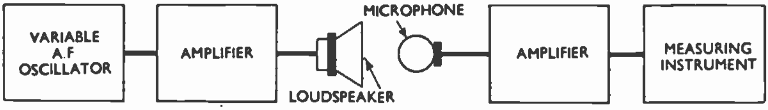


Fig. 21. To measure loudspeaker response, pure tone is fed to the loudspeaker from the oscillator, the sound wave being reproduced through a microphone and amplifier, and recorded by a measuring instrument such as a valve-voltmeter or oscilloscope. The frequency of the oscillator is varied over the audio range.

Readings on the meter are taken at certain specified frequencies and the results plotted on a graph. Unless the specified frequencies are in very small steps, the resultant curve may be misleading because of sharply defined resonances likely to be present between the steps. If the tone source is continuously variable, and its control rotated slowly from 30 to 10,000 c/s, the frequencies at which resonance occurs can be observed on the meter or cathode-ray tube, and the frequency reading of the tone-source dial noted.

LOUDSPEAKING RECEIVER. In telephony, a highly sensitive headphone performing the functions of a small loudspeaker.

LOW-DEFINITION TELEVISION. System of television in which the number of picture elements per picture is small. Normally, the term is used to denote television systems in which fewer than 200 scanning lines per picture are used.

LOWER SIDEBAND. Sideband containing sideband waves having frequencies less than that of the carrier wave. See SIDEBAND, SIDEBAND WAVE.

LOW FREQUENCY. Term usually implying audio frequency. When used for comparative purposes in the audio range, it implies frequencies of 30 to 300 c/s (see AUDIO FREQUENCY).

LOW-FREQUENCY AMPLIFICATION. Amplification at audio frequencies

LOW-FREQUENCY AMPLIFIER. Synonym for AUDIO-FREQUENCY AMPLIFIER.

LOW-FREQUENCY WAVE. Radio-wave between the frequency limits of 30 and 300 kc/s, that is to say, a wave within the length of 1,000–10,000 metres. It appears probable that, during the daytime, most low-frequency waves are reflected by the lightly ionized D-layer; and at night they are certainly reflected by the E-layer. At very low frequencies, reflection is sharp; during the time the wave is actually in the E-layer attenuation is appreciable, but as the depth of penetration is small the loss is not serious. The attenuation is proportional to the square-root of the frequency; hence the lower the frequency, the less the attenuation. On the other hand, the field strength of a radio-wave is proportional to the frequency of the current; hence, as we decrease frequency, so must we increase the aerial power. It is possible to send halfway round the world on frequencies of about 20 kc/s, but very high power is required and heavy atmospheric disturbances are likely to be encountered.

The ground-wave attenuation of low-frequency waves is very small, and is given with a fair degree of accuracy by the Austin-Cohen formula. The propagation characteristics are affected by diurnal, seasonal, and year-to-year variations, with their consequent effect upon the D- and E-layers. The difference between day and night field strength increases as the frequency is raised.

Magnetic storms have a marked effect upon the propagation of low-frequency waves. The daytime field strength is increased above normal, and the usual drop in field strength at night does not occur. The night field strength actually approaches a value comparable with the normal daytime strength. Fading is never in evidence on low frequencies, as any changes in signal strength that take place occur gradually over a period of several hours. See E-LAYER, FIELD STRENGTH, IONOSPHERIC REFLECTION, MAGNETIC STORM.

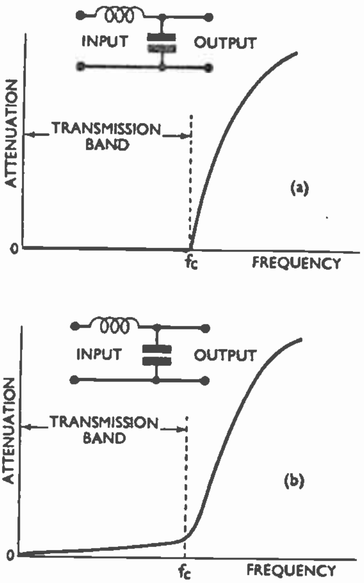


Fig. 22. Attenuation characteristic of a low-pass filter: (*a*) that of a filter composed of pure reactances and ideally terminated, and (*b*) that of a practical filter consisting of manufactured components and having a resistive termination; f_c is the cut-off frequency.

LOW-LEVEL MODULATION. Synonym for LOW-POWER MODULATION.

LOW-LEVEL MODULATOR. Synonym for low-power modulator. See LOW-POWER MODULATION

LOW-PASS FILTER. Filter which has a single transmission band extending from zero frequency up to the cut-off frequency (see TRANSMISSION BAND). The attenuation-frequency characteristic of a low-pass filter is illustrated; that shown in Fig. 22a is the characteristic that would be obtained if the reactances forming the filter elements were pure and the filter was ideally terminated; Fig. 22b shows the effect of loss inevitable in manufactured inductors and capacitors. Also shown is the basic form of a low-pass filter section containing a series arm consisting of an inductor, and a shunt arm consisting of a capacitor. See BAND-PASS FILTER, BAND-STOP FILTER, FILTER, HIGH-PASS FILTER.

LOW-POWER MODULATION. Modulation in which the modulated wave is amplified before passing to the transmission channel. In low-power modulation, the carrier wave is modulated at a power level less than that used for transmission at the output from the sender. See HIGH-POWER MODULATION.

LOW-STOP FILTER. Synonym for HIGH-PASS FILTER.

LOW TENSION. Term used to describe the source of electrical power used to heat valve cathodes; it distinguishes the source of power for this purpose from that, namely, high tension, which supplies power to the anodes of a valve or valves. The terms low-tension battery and low-tension transformer are associated with apparatus supplying power to the cathode or filament of a valve.

In modern practice, the low-tension supply may be taken from the secondary of a transformer, the primary of which is energized from the mains. Where very high-gain amplifiers are employed, a direct-current source is sometimes used to avoid hum. The L.T. supply for battery-operated receivers or amplifiers is also D.C.

LOW-TENSION BATTERY. Battery of cells used for supplying power to the cathode of a valve. The term is sometimes wrongly used if a single cell supplies cathode power to a valve or tube; in this case it is a low-tension cell. See LOW TENSION.

LOW VOLTAGE. Qualitative term used in some cases to distinguish voltage applied to certain circuits which, in other cases, may have higher voltages applied to them. As an example, the mercury-vapour (hot-cathode) rectifier is designed with what might be described as a low-voltage filament (about 5 volts) in order that the anode voltage (of the order of 20 volts) may always be relatively large; whereas, in other forms of rectifier, notably where kilowatts of power are used, a "high-voltage" filament (25–50 volts) may be used without impairing the efficiency of the device.

L.T. Abbreviation, used in describing battery or supply, for LOW TENSION.

LUMEN. Unit of light flux; it is defined as the total light energy passing through an area of 1 sq. ft. placed at a distance of 1 ft. from a standard candle. The total light flux emitted by the standard candle is 4π lumens.

LUMPED VOLTAGE. Sum total of all the D.C. and A.C. voltages effectively acting at the anode of a valve. The space current of a valve depends on this quantity. The lumped voltage is obtained by adding to the anode voltage the sum of all the products of all the electrode potentials and the amplification factors associated with these electrodes.

LUNAR-GRID VALVE. Valve connected in an unconventional way. The valve is sometimes described as an "inverted" valve, as the connexions may be said to be inverted, but the valve has no peculiar constructional features. The valve itself is not, therefore, "inverted." The inversion of the

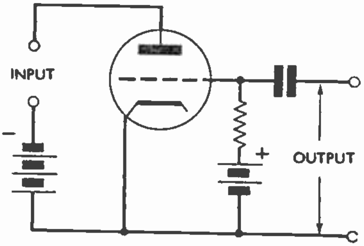


Fig. 23. Connexions to a lunar-grid valve; this "inverted" arrangement is employed so that a large current may be controlled by a high voltage.

connexions of the valve amplifier consist in applying the input wave to the anode, thus producing the output wave at the control grid (Fig. 23).

The space current of a valve depends upon the potential gradient at the cathode (see VALVE). The potential gradient at the cathode is determined by the relative potentials of grid and anode. In the connexions shown in Fig. 23, the negatively charged anode is, in a sense, equivalent in effect to the normally negatively biased grid; and similarly, the positively charged grid is equivalent in effect to the normally positively biased anode. There is, however, the fundamental difference that the anode potential has far less control of the space current than the normally positioned grid because the grid is very much closer to the cathode; thus the grid shields the cathode from the anode. If the normal amplification factor were 10, then the inverted connexions make it 1/10. The object of the connexion is to enable a large current to be controlled by a high voltage. The input impedance of the device is high because the anode D.C. resistance is infinite. The current controlled is high because the grid is close to the cathode. Obviously, the valve is a power amplifier, but it does not give a voltage gain; on the contrary, the ratio of input to output voltage is fractional. See AMPLIFICATION FACTOR, VALVE.

LUX. Unit of illumination, and equivalent to one lumen per square metre. It is the illumination obtained on a surface 1 m. from a standard candle and is sometimes known as the metre-candle. From this standard are derived the millilux and microlux, being the thousandth and millionth of a lux respectively.

LUXEMBOURG EFFECT. Ionospheric effect occasionally noticeable on medium- and low-frequency broadcast stations. This effect was first noticed when radio-telephony stations began to use high power. English listeners to Radio Luxembourg, operating at 230 kc/s, noticed that the modulation of Radio Paris (182 kc/s) could be heard in the background; similar effects are apparent on other signals. The effect is most noticeable when the two sending stations are approximately on the same great-circle bearing from the receiver, and when the interfering station is nearer to the receiver than is the wanted station.

The high-power interfering station appears to affect the ionosphere in such a way that any other waves reflected from the affected area become modulated by the powerful unwanted station. Elimination of the ionospheric wave would obviate this effect but, at the comparatively low frequencies involved, this is not practicable. See IONOSPHERE, IONOSPHERIC REFLECTION.

M

M. Abbreviation for the prefix mega, signifying one million; thus 1 Mc/s = 10^6 c/s.

m. Abbreviation for the prefix milli, signifying one thousandth of a unit; for example, 1 mH = 0·001 H.

"MAGIC-EYE" TUNING INDICATOR. Device employing the cathode-ray-tube principle to indicate when a radio receiver is accurately in tune with a carrier. The indication is commonly in the form of a shadow area on the fluorescent screen which contracts in accordance with the voltage applied to the control electrode, this voltage being derived from the incoming signal. Minimum shadow area denotes a maximum signal at the detector.

MAGNET. Piece of steel or iron which has the property of attracting other iron or steel objects, and of producing characteristic reactions with conductors carrying electric currents (Fig. 1). See MAGNETISM.

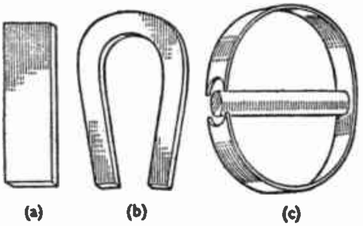


Fig. 1. Three forms of magnet: (*a*) a straight bar of steel; (*b*) a horseshoe, and (*c*) a more complex magnetic circuit upon which that used in certain moving-coil loudspeakers is based.

MAGNET COIL. Winding through which a current is passed to energize an ELECTROMAGNET (q.v.).

MAGNETIC BEARING. Direction of some distant point expressed in degrees measured clockwise from magnetic north.

MAGNETIC CIRCUIT. Path followed by the magnetic flux round the cores and yoke-piece of a double electromagnet, or the "iron circuit" of any other piece of apparatus such as a transformer, dynamo or motor. See YOKE.

MAGNETIC COMPONENT. Component part of an electromagnetic wave; it refers to the magnetic field of the wave, and is in a plane at right-angles to the electric field. See POLARIZATION, RADIATION.

MAGNETIC CORE. Synonym for iron core. See CORE.

MAGNETIC COUPLING. Synonym for INDUCTIVE COUPLING.

MAGNETIC DECLINATION. Variation between true and magnetic north. The extent of the declination varies according to the geographical position of the observer, and with time.

MAGNETIC DEFLECTION. In a cathode-ray tube, the deflection of the electron beam by means of magnetic fields set up in coils which are in close proximity to the outside envelope of the tube.

MAGNETIC DETECTOR. Early form of detector, invented by Marconi, depending upon magnetic hysteresis. The arrangement is shown in Fig. 2. An iron wire is caused to move relatively slowly (about four feet per minute) past two horseshoe magnets. These induce magnetism in the wire but, owing to the effects of magnetic hysteresis, the induced magnetism is not immediately underneath the inducing poles, and is a little displaced in the direction of movement of the wire.

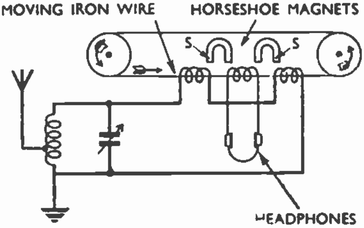


Fig. 2. Diagram illustrating the operating principles of the magnetic detector.

Around the wire are located coils which carry radio-frequency currents from the tuned circuit of the receiver. The action of these currents is to reduce the magnetic hysteresis, with the result that the position of the magnetization of the iron wire moves back underneath the inducing poles. This momentary shift of the magnetization induces a current in the detecting winding and causes a click to be heard in the telephones.

MAGNETIC FIELD. Space or region in which magnetic forces are apparent; the neighbourhood of a magnet or any conductor of current. In common usage, the term "field" includes the forces themselves. See MAGNETISM.

MAGNETIC FIELD STRENGTH. Synonym for MAGNETIZING FORCE.

MAGNETIC FLUX. Measure of the intensity of a magnetic field of force over a surface area perpendicular to the lines of force at the chosen point. More broadly, the flux means the total magnetic field, and the word is commonly used in that sense.

MAGNETIC FLUX DENSITY. Quantity of magnetic flux per unit area across the field of force, commonly expressed in lines per square centimetre. The flux density is the principal criterion of the strength of a magnet, and the efficiency of a material used as the core of an electromagnet. The practical unit of measurement is the Gauss; this is one line per square centimetre. See MAXWELL, PERMEABILITY.

MAGNETIC FOCUSING. In a cathode-ray tube, the focusing of the electron beam by means of a magnetic field parallel to the axis of the tube. See FOCUSING COIL.

MAGNETIC FORCE. Synonym for MAGNETIZING FORCE.

MAGNETIC HYSTERESIS. Phenomenon in which the growth or decay of the magnetic flux in some magnetic substance is delayed and does not keep pace with the agency producing the flux. For example, the flux in the core of an electromagnet takes time to reach its full value when the current is first switched on, and the lag is proportional to the magnetic hysteresis of the particular core material.

MAGNETIC HYSTERESIS LOSS. Form of energy loss which occurs whenever a varying magnetic flux is produced in a magnetic material. The greater the magnetic-hysteresis effect in the particular material, the greater the losses when it is subjected to varying magnetizing forces.

MAGNETIC INDUCTION. Production of a magnetized condition in a paramagnetic material when placed in a magnetic field. See MAGNETISM.

MAGNETIC LEAKAGE. Term used instead of leakage flux. See LEAKAGE INDUCTANCE.

MAGNETIC MERIDIAN. Imaginary line encircling the earth and indicating at any point in it the direction of the earth's magnetic field at that point.

MAGNETIC MODULATION. Any system of modulation using the non-linear relationship between the magnetization of iron and its incremental permeability. See INDUCTOR MODULATION.

MAGNETIC POLE. Geographical position to which the compass needle points. The actual locations of the magnetic poles of the earth are variable, causing the varying differences between true and magnetic north. See POLES OF A MAGNET.

MAGNETIC REACTION. Synonym for INDUCTIVE FEEDBACK.

MAGNETIC RECORDING. System by which sound or electric impulses are recorded on a strip of steel tape, wire or other material susceptible to variations in magnetism. See ELECTRICAL RECORDING, MARCONI-STILLE RECORDER.

MAGNETIC RESIDUAL-LOSS. Loss of energy, proportional to the frequency of the period of magnetization in a ferro-magnetic material. Magnetic residual-loss is additional to eddy-current and hysteresis loss. It is independent of flux density. See CORE, IRON LOSS, TRANSFORMER.

MAGNETIC RETROACTION. Synonym for INDUCTIVE FEEDBACK.

MAGNETIC SCREEN. Screen of magnetically permeable material used to reduce or prevent the penetration of a magnetic field into a certain region. See SCREENING.

MAGNETIC STORM. Rapid and erratic fluctuations of the earth's magnetic field, generally of several days' duration. The magnetic storm occurs at the same time all over the world, and is most intense at the polar regions. It is thought that these storms are caused by the periodical emission of particles from the sun during times of abnormal sunspot activity. The solar corpuscles cause abnormal movement of the ions in the atmosphere, and this movement constitutes electric currents of great magnitude; the magnetic fields associated with these currents interfere with the earth's normal magnetic field and so produce the magnetic storm.

The effect of the storm is to increase the received signal strength of low-frequency waves, but the effect on short waves below about 50 metres may be catastrophic. In several cases, signals have completely disappeared for as long as two days, and serious fading has been encountered throughout the short-wave band. The fading is probably due to the more intense ionization of the F-layer causing increased attenuation. See INTERFERENCE, IONOSPHERE.

MAGNETISM. Phenomenon observed in various magnetic effects, or the science which studies such effects. Some magnetic phenomena have been known from very early times, because they are displayed by certain natural materials such as the iron-oxide ore called magnetite; this, when found in a magnetized condition, is called lodestone. A lodestone of suitable shape hung on a thread will come to rest in a particular position geographically like a compass, and will attract pieces of unmagnetized iron. If another piece of lodestone is brought near, it will attract one end of it and repel the other.

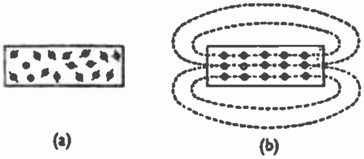


Fig. 3. Theory of magnetism: (*a*) the random arrangement of molecular magnetic units in a normal piece of steel, and (*b*) their supposed alignment after the steel has been magnetized.

Simple experiments of this sort indicated that there must be something different about the two ends of the lodestone; the same end always faces north, and if two lodestones are brought together the north-seeking ends repel each other, and so do the south-seeking ends. The north-seeking end of one, on the other hand, attracts the south-seeking end of another. The ends of magnets are called the poles, and the first rule of magnetism is that like poles repel each other, unlike ones attract.

These are physical forces, and their presence is readily ascertained with the aid of a small suspended magnet such as a compass needle; if this is moved close to and along a long, bar-shaped magnet, it is obvious that the magnetic effects are confined almost entirely to the regions round the poles; there is very little sign of them in the middle of the bar. But if the bar is cut in two, poles appear at the two new ends which result from the cut.

This and other phenomena suggest that magnetism is some force which runs through the whole length of the bar magnet, and becomes apparent only when it leaves the metal and passes into the air, setting up what is called a field of force. The nature of magnetism is probably bound up with the molecular structure of the metal. Just what it may be is likely to remain conjectural, but some conception can be gained from a consideration of some of the elementary properties of a magnet.

First, when it attracts a piece of soft iron placed in its neighbourhood, the iron begins to show all the characteristics of a magnet; if the iron is removed to a distance it ceases to show any symptoms of magnetism. But repeat the experiment with a piece of hard steel, and the result is different; some trace of magnetism remains in the steel after it is taken away again. In fact, by repeatedly stroking a piece of steel with one pole of a magnet, taking care to move the pole along the steel always in the same direction, the steel can be strongly magnetized, and will retain its magnetism more or less indefinitely if it is not treated roughly. (A piece of magnetized steel or other magnetic material is called a "permanent" magnet.)

However, if the newly made magnet is dropped several times on a hard surface, it will be found to be much weaker; if it is hammered severely for a while it will lose all its power, as it will if heated and cooled several times or exposed to a rapidly alternating magnetic field of force. All these demagnetizing processes have something in common; they involve the shaking up and disturbance of the interior structure of the steel. It seems reasonable to assume, therefore, that when a piece of iron or steel is magnetized, some special arrangement is set up in its structure; and that the rigid steel can retain the new arrangement thereafter, losing it only when violently disturbed.

An attempt to suggest the process has been made in Fig. 3 in which (a) shows the structural units of a bar of steel arranged haphazardly, each with its own magnetic force oriented regardless of the rest. In (b), the structural units have been drawn into alignment so that they join up and produce chains of force lengthwise through the bar. These chains emerge at the ends to form the poles of the magnet. The dotted lines in (b) are the conventional representation of the field of force of the magnet; they indicate the directions in which a freely suspended magnetic needle would come to rest at any point in the field of magnetic force.

The same conventional representation of fields of force has been used in Fig. 4 to show what presumably happens in the neighbourhood of two magnets placed in proximity. The lines from the north pole of the bar magnet join up with those of the south pole of the horseshoe type, and here there is a force of attraction—magnetic lines of force are sometimes regarded as having a desire to contract and shorten themselves. Between the two north poles, on the other hand, there is no linking up of lines, and here the force is one of repulsion.

Magnetic forces are also found around any conductor carrying an electric current. Around a straight wire they are comparatively weak, and are arranged in concentric circles, with the wire at the centre. If the wire is coiled up, however, a stronger field results, and a long winding on a tube produces a field just like that of a bar magnet.

An inductor carrying a direct current will, if mounted on a sufficiently delicate suspension, behave just like any other magnet; it will come to rest with its axis pointing north and south, its poles will attract and repel those of other magnets, and it can be used to magnetize a piece of steel (see ELECTROMAGNETISM).

A stationary charge of electricity produces no magnetic effects but they appear directly the charge begins to move along a conductor; this suggests what may be happening when the structure of a piece of steel is altered to turn it into a magnet; it is, perhaps, a matter of re-aligning the molecular structure so that the electron systems are oriented in a particular manner.

A coil of wire carrying a direct current is used in producing permanent magnets. An inductor carrying a large current has a powerful magnetizing effect, and the method is simply to insert the steel to be magnetized in the hollow centre of the winding and switch on the current. There are

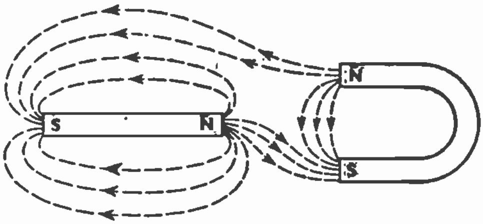


Fig. 4. The distribution of the lines of force around a bar magnet and a horseshoe magnet demonstrates the forces of attraction between opposite (unlike) poles, and of repulsion between like poles.

practical refinements in the method, but that is the principle.

A final instance of the identical nature of the magnetic field of force produced by a permanent magnet and that set up by a current of electricity can be found in the process of electromagnetic induction. In this process, currents are generated in a coil of wire when a magnetic field cuts across the turns of the winding; the result is the same whether the movement of magnetic lines of force comes from the rise and fall of an alternating current in a nearby inductor, or from the physical to and fro movement of a permanent magnet in the neighbourhood. See ELECTROMAGNETIC INDUCTION.

MAGNETIZATION. Process of producing a temporary or permanent magnetized condition in a magnetic material. See MAGNETISM.

MAGNETIZATION CURVE. Graph which shows the relation between the magnetizing force and the flux density which it produces in a particular type of magnetic material, or individual specimen of such material. An alternative meaning concerns the D.C. generator or dynamo; here, the graph is one relating output voltage with the excitation current. See EXCITATION, MAGNETIC FLUX DENSITY.

MAGNETIZING COIL. Coil of insulated wire which is part of, and is used for exciting, an electromagnet.

MAGNETIZING CURRENT. Of a transformer, the current which flows in the winding of an unloaded transformer energized from a source of alternating voltage. The value of the current is equal to the voltage applied to the winding divided by the impedance of the winding.

The primary coil has, mainly, the characteristic of inductance to waves of high frequency; the resistance, however, becomes a greater part of its impedance as the wave-frequency gets less. Thus the magnetizing current becomes greater as the frequency of the waves lessens. At zero frequency (D.C.) the magnetizing current is limited only by the D.C. resistance of the winding.

In designing a transformer, it is necessary to arrange that the magnetizing current at the lowest frequency is limited to a certain value, otherwise the primary winding may be overheated. It is usual to make the inductive reactance of the primary two to three times greater than the reflected load impedance. Thus, if a transformer has a step-up voltage ratio of 1 : 2 from primary to secondary, and if the secondary is loaded by 10,000 ohms, the reflected impedance is $\frac{10{,}000}{(2)^2} = 2{,}500$ ohms.

If the lowest frequency at which the transformer is to function is 25 c/s, the reactance of the primary should be, say, three times 2,500, i.e. 7,500 ohms. This gives an inductance of $\frac{7{,}500}{2\pi \times 25}$, or $\frac{150}{\pi}$ henrys—about 50 henrys. If the maximum voltage is 20 volts, the magnetizing current is $\frac{20}{7{,}500}$ amp., or $\frac{20}{7{\cdot}5}$ mA, that is, roughly 3 mA. See TRANSFORMER.

MAGNETIZING FORCE. That which causes the magnetic flux at some particular point. It is evaluated by determining the strength of the physical force of attraction or repulsion which would act on a unit magnetic pole located at the point concerned. See MAGNETIC FLUX DENSITY.

MAGNETOMOTIVE FORCE. Force which sets up a magnetic field of force, usually the magnetizing force of a current in an inductor winding.

MAGNETOSTRICTION. Change in dimensions of a magnetic material when it is magnetized. The effect is most marked in nickel.

MAGNETRON. Diode in which the path of the electrons is determined by the resultant forces on them due to a magnetic field produced externally to the valve and an electric field produced internally. The fields act at right-

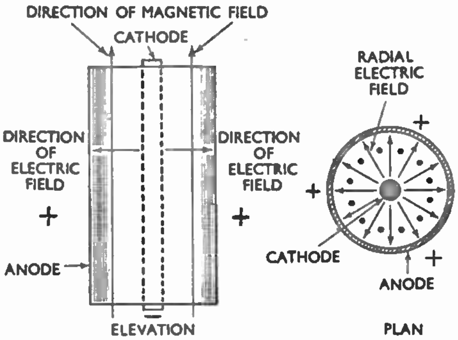


Fig. 5. Basic principles of the magnetron, in which a cylindrical anode surrounds an axial cathode. Biasing the anode positively with respect to the cathode sets up a radial electric field. The magnet (not shown) is the source of a magnetic field the direction of which is shown by dots in the plan view as it is at right-angles to the electric field.

angles. The basic features of a magnetron are indicated in Fig. 5. A positively charged cylindrical anode surrounds the cathode; the anode tends to accelerate the electrons in straight lines towards it. The electric field acts radially from the axis of the cylindrical anode and a magnetic field acts along the axis of the cylindrical anode; these produce what is described as an axial field. This field tends to make the electrons move orbitally round the cylindrical cathode. When the fields have comparable strength, the electrons are given a circular and radial component of motion, so that the orbits may allow electrons eventually to reach the anode, return to cathode, or circulate continuously.

Fig. 6 shows a typical path of electrons in the space between anode and cathode of a magnetron, according to the relative strength of electric and magnetic fields. The magnetic field is assumed constant and the electric field is changed by changes of anode volts. As the electric field weakens, the electrons have a greater component of rotary motion.

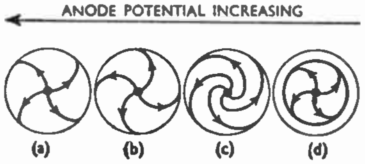


Fig. 6. Magnetron in plan showing the average paths of electrons with the anode voltage (*a*) at its highest, (*b*) lower, (*c*) still lower, and (*d*) lowest value. The anode current is unchanged except in (*d*), when none flows (Fig. 7).

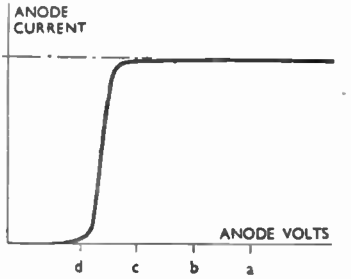


Fig. 7. Anode-volts/anode-current characteristic of a magnetron; values marked off by the letters *a*-*d* correspond with the diagrams in Fig. 6.

With low anode volts, the electrons circulate continuously and never reach the anode. The transition between full and zero anode current, with all electrons behaving alike, theoretically takes place for an infinitesimal change of anode voltage, but because of numerous factors the transition is made over a relatively considerable anode-voltage change, as shown in Fig. 7. In practice, some of the circulating electrons trace an ascending and descending spiral, and so escape from the space between anode and cathode. The effect can be overcome

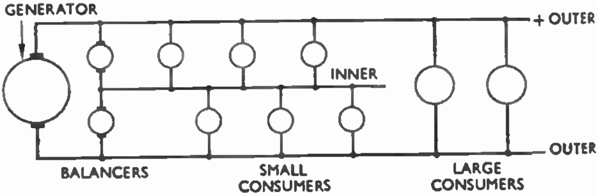


Fig. 8. Arrangement of D.C. mains showing the use of balancers between the inner and the outer.

by the use of an END PLATE (q.v.), or by setting the cathode at a small angle to the axis of the anode.

Little use is made of the cylindrical-anode magnetron in its simple form, with one cylindrical anode, but developments of the basic principle here described have had a profound importance in the generation of centimetric waves. See MULTI-CAVITY MAGNETRON, SPLIT-ANODE MAGNETRON.

MAGNETRON RECTIFIER. Magnetron used as a rectifier. The magnetron can, under suitable conditions, be used to rectify an alternating current as can any form of valve. It is, however, not usually employed as a rectifier, its characteristics suiting it for producing radio-frequency current of very high frequency. See MAGNETRON.

MAGNIFICATION FACTOR. Synonym for amplification factor. See STAGE GAIN.

MAGNIFIER. Synonym for AMPLIFIER.

MAINS. General term used to describe the cable connexions from power stations to substations and distribution stations, and from these to the consumers' premises.

D.C. distribution mains usually consist of three wires, two "outers" and an "inner," the inner being of half the sectional area of the outers. Large consumers are connected across the two outers and small consumers between an outer and the inner, it being arranged that, as far as possible, equal loads are connected to each side.

The inner carries only the difference between the loads of the two sets of small consumers and, at the generating station, it is connected to some device for disposing of the out-of-balance current. This may be in the form of a connexion to the generator armature through choke coils, or a special balancer connected as shown in Fig. 8.

Practically all bulk supply of A.C. electricity is generated three-phase, and the mains contain three conductors which are labelled Red, Yellow, Blue. One main is connected to each winding of the synchronous generator, and the opposite ends of the three windings are connected together to form the neutral point which is earthed through an earthing resistance. Large motors and other apparatus take a three-phase supply and may be delta-connected as at *A* in Fig. 9, or star-connected as indicated at *B* in the diagram.

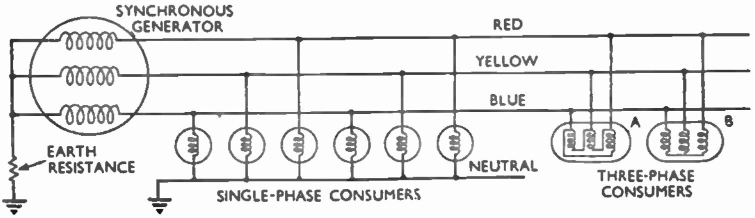


Fig. 9. Diagram which shows the arrangement of A.C. mains, and, at points *A* and *B*, two methods of connecting certain heavy loads into the three-phase supply.

Single-phase consumers are connected between the lines and an earthed neutral wire, as shown in the diagram, and, as far as possible, the three loads are kept equal.

MAINS AERIAL. Device for enabling the aerial system of a radio receiver to be connected to electric-mains wiring to obtain radio-frequency signals therefrom. The term "mains aerial" is, however, something of a misnomer, since the device is not in any sense an aerial but rather a means of employing the mains wiring as such without ill effects.

The device usually consists of a capacitor of low value, such as 0·0001 μF or less, and is connected between the mains and the aerial terminal of the receiver; but occasionally two capacitors are used so that radio-frequency energy may be obtained from both wires of the mains.

MAINS RADIO-RELAY SYSTEM. Radio relay system using the electric-power network as its conductive network. See RADIO RELAY SYSTEM, WIRE BROADCASTING.

MAINS RECEIVER. One obtaining its power supply from the electric mains, not from batteries. See ALL-MAINS RECEIVER.

MAINS RECTIFIER. Synonym for MAINS UNIT.

MAINS UNIT. In telecommunication, an assembly of components arranged so that alternating current may be converted into direct current by the use of rectifiers. The essential components are a transformer, rectifier, inductor and capacitor. The inductor and capacitor, or a number of inductors and capacitors, form what is called the smoothing circuit. The alternating current is usually derived from the supply mains at a frequency of, say, 50 c/s (60 c/s American standard).

The term "mains unit" was introduced in the early days of broadcasting. The majority of receivers as used at first by listeners were energized from batteries. When the idea of using the mains power to energize receivers was put into practice, assemblies of components were marketed as separate units and used to replace the batteries. These were called battery eliminators, or mains units.

The latter term has persisted, and it is now used, rather loosely, when it is convenient to distinguish the components providing a source of anode power from other parts of an equipment. The term is not always logically used. In a radio receiver, the transformer, rectifier, inductor, and capacitor for converting the mains power to a direct-current source can hardly be termed "a unit," for the components are

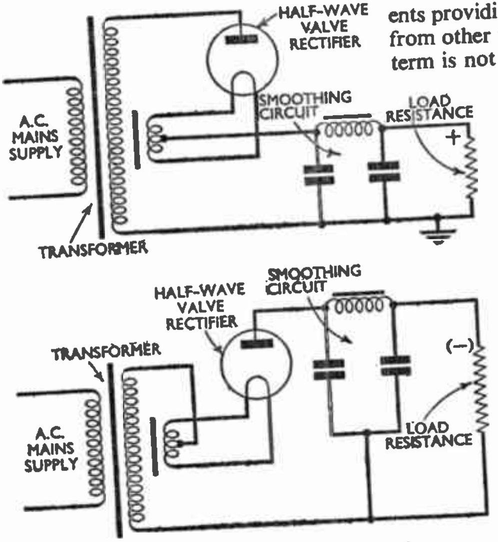


Fig. 10. Alternative circuits for mains units using half-wave rectification; one is intended to supply a positive and the other a negative potential in respect to earth. Direct current flows in the secondary winding of the transformer.

mounted alongside those used for radio reception proper and are part of the set itself.

An engineer, moreover, would be unlikely to describe the mercury-arc rectifier supplying several hundreds of kilowatts for the anode circuits of a high-power sender as a "mains unit." This would more probably be called the H.T. power-supply unit or, more simply, the H.T. supply.

In rack-mounted equipments, for example, multi-channel carrier equipments, the separate rack which mounts the apparatus from which the anode power is drawn might well be called the mains unit. In American phraseology, the terms "pack" and "power pack" are used to describe what we call a mains unit.

Fig. 10 shows a half-wave rectifier mains unit. The principle is that, when the voltage across the transformer acts in one direction, the rectifier is conductive; when it acts in the other, non-conductive. Without the smoothing circuit, the current in the load resistance would take the form of a sinusoid in which one half of the wave is suppressed.

The smoothing circuit may be likened to a tank into which water is fed in gushes intermittently, and out of which water flows uniformly, the mean level of the water remaining much the same. In electrical terms, the capacitors and inductors form a low-pass filter which attenuates the alternating current and transmits the zero frequency, i.e., direct current (see FULL-WAVE RECTIFICATION, SINGLE-WAVE RECTIFICATION, SMOOTHING CIRCUIT).

Full-wave rectification is shown in Fig. 11. It has the advantage that the direct current does not magnetize the iron core of the transformer because it flows in opposite directions through the two halves of the secondary which are wound in the same sense. While, generally speaking, mains units provide a terminal which is positive with respect to earth, the circuits, as can be seen from Figs. 10 and 11, may be adapted to give a negative voltage if required.

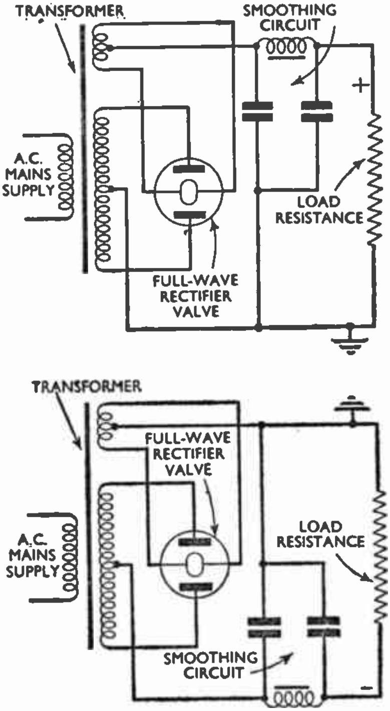


Fig. 11. Mains-unit circuits using full-wave rectification but otherwise corresponding to those in Fig. 10. Direct current flowing in the secondary of the transformer does not magnetize the core, as it flows in opposite directions in both halves of the winding.

Any form of rectifier may be used. In general practice, for which perhaps 100 mA at 250 volts may be the order of the quantities specifying the output, vacuum-valve rectifiers are used. These may be of either the filament type or the indirectly-heated-cathode type. In some cases, it is arranged that the cathode of the rectifier valve takes a longer time to heat up until the valve is conductive than that taken by valves in the equipment which is energized from the mains unit.

This ensures that high tension is not

applied to the electronic apparatus until the valves in it are in a condition to function normally. In other words, H.T. power is not applied to valves giving, momentarily, insufficient emission.

For larger powers, the mercury-vapour (hot-cathode) rectifier may be used. In this case, a time-delay switch ensures that the cathodes of the mercury-vapour rectifiers are hot enough to ensure normal operation before the transformer is connected to their anodes. The arrangement is essential, otherwise the rectifiers are liable to be damaged.

Metal rectifiers are more likely to be used in voltage-doubler mains units. This is because the cathodes of the rectifiers in a voltage-doubler are necessarily at different potentials and, if the rectifiers are valve rectifiers, require separate and insulated windings on the transformer to energize them.

When large power output is required from mains units, it is economical to use polyphase rectifiers. In a three-phase supply system, all these phases can be used to give a direct-current output (Fig. 12). The alternating-current components in the rectified current have, in polyphase-rectifier systems, higher frequencies than when single-phase rectifiers are used. This means that the smoothing circuit requires smaller capacitors and inductors for a given power when polyphase rectifiers are used. Thus, power for power, polyphase rectifiers are cheaper.

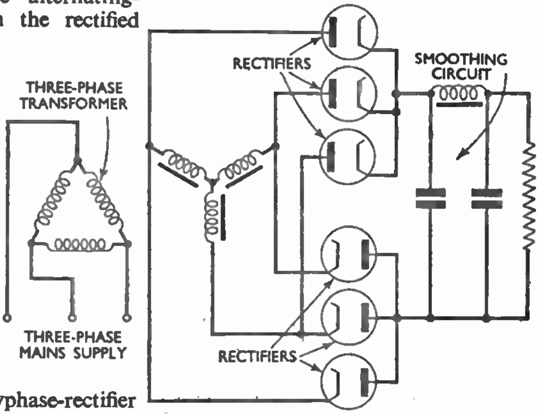


Fig. 12. Full-wave-rectification circuit used when a large power output is required and the mains unit is connected to a three-phase supply.

Three-phase rectification cannot be used for domestic broadcast receivers because the household supply is, in all circumstances, taken from one phase.

MAINS-WIRE BROADCASTING. See MAINS RADIO-RELAY SYSTEM, WIRE BROADCASTING.

MAKE IMPULSE. Impulse produced in a circuit by connecting it suddenly to a source of e.m.f., thus starting a current.

MANSBRIDGE CAPACITOR. Obsolescent form of fixed capacitor constructed from metallized paper.

MANSBRIDGE CONDENSER. See MANSBRIDGE CAPACITOR.

MARCONI AERIAL. Aerial usually somewhat less than a quarter-wave in length, connected to earth through receiver or sender, and tuned by means of added inductance or capacitance to the working frequency. One of the first aerial arrangements to be developed for practical radio communication, this is still one of the most generally useful for medium and low frequencies. See QUARTER-WAVE AERIAL.

MARCONI BEAM AERIAL. Broadside array consisting of individually tuned vertical elements with spacing related to the wavelength, giving a comparatively narrow beam suitable

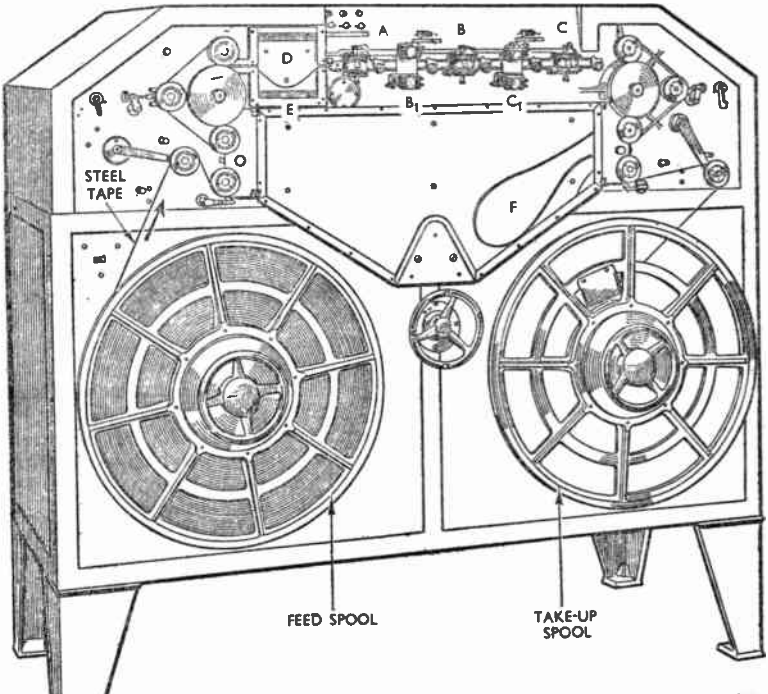


Fig. 13. Marconi-Stille recording and reproducing machine. The steel tape passes through a magnetizing head *A*, a recording head *B*, and then a reproducing head *C*. B_1 and C_1 are spare heads.

for communication between fixed points.

MARCONI DETECTOR. See MAGNETIC DETECTOR.

MARCONI-STILLE RECORDER. Steel-tape recorder developed for repetition of broadcasting programmes. A programme is recorded during first transmission and subsequently rebroadcast. The system was originally used in the B.B.C. Empire Service. The 3-mm. tape passes through three heads, marked *A*, *B*, *C* in Fig. 13, wiping or magnetizing, recording or de-magnetizing, and reproducing. Spare recording and reproducing heads are also provided.

Tape speed is maintained constant at 90 metres per minute by using a synchronous motor to pull the tape through the heads. The spools are independently driven, each by a separate motor. The left-hand (feed) spool runs faster than the main tape drive, hence a loop is formed at *D*; when this loop touches the contact *E*, a thyratron strikes, operating a relay which switches resistance into the motor circuit and slows down the motor, taking out the loop. The process then repeats itself.

The right-hand (take-up) spool runs slower than the main drive, causing a loop to form at *F*. A similar thyratron relay circuit speeds up the motor, etc. Thus, the tape when passing through the heads, is not subjected to strain. The left-hand drive is used for rewinding; the main drive being disengaged. Rewinding time is 18 minutes for a full spool of 30-minute recording.

The system requires no processing and the record may be reproduced as many times as required. After the last reproduction, the tape may be used for a new recording, the existing programme being automatically "wiped" out by the magnetizing head. The system has good frequency characteristics (level between 100 and 6,000 c/s), but inherent surface noise is higher than for the direct-recorded disc system. See ELECTRICAL RECORDING, ELECTRICAL REPRODUCTION, MAGNETIC RECORDING.

MARKER BEACON. Sender, usually automatic, which emits a characteristic signal so that an aircraft flying over it can note the change of signal strength which occurs as it passes directly above, and can thus fix its position; alternatively, a similar sender (covering some localized area) whose signals give a rough indication of position. Such beacons often form part of a blind-landing system; for example, a pilot approaching a landing-ground with the aid of some kind of beam radiation needs an indication to tell him when to put his aircraft into the final glide for the landing; a marker beacon is employed to give such an indication (see LORENZ BLIND-LANDING SYSTEM).

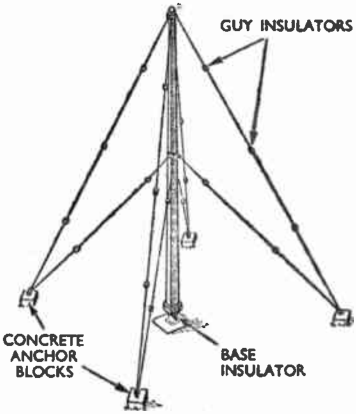


Fig. 14. One form of mast aerial; it consists of a steel tube standing on an insulating base and supported by stay-wires subdivided with insulators.

MARKING WAVE. In radio telegraphy, the wave radiated by the sender when the telegraph key is depressed. See SPACING WAVE.

MAST AERIAL. Aerial of vertical type which consists of a metal mast, suitably supported with insulated guys and usually standing on a base insulator (Fig. 14). The mast aerial is an important type, especially in broadcast and other services requiring an omni-directional emission. It offers a simple method of erecting a high and rigid aerial of low resistance and large capacitance. Constructionally, it presents the engineer with two problems: that of ensuring a high-conductivity path from top to bottom; and that of devising a base insulator of sufficient strength to carry the great weight of, say, a steel-lattice mast 600 ft. high.

Insulation at this point, however, need not be of the highest quality, since, if the aerial is roughly a quarter-wavelength high, this will be a position of low voltage and large current; mechanical strength can therefore be the main consideration. The high-conductivity requirement is commonly met by strapping across all structural joints with welded bonding-strips. See QUARTER-WAVE AERIAL.

MASTER OSCILLATOR. Oscillator which, in a radio sender, determines the frequency of the carrier wave, the stability of the oscillator governing the constancy of the carrier frequency. In modern senders the frequency variation may be only 1 part in 10^8.

MATCHING. Adjustment of one impedance to have the same magnitude and phase angle as another. Two impedances are said to be matched when each has the same magnitude and phase angle (Fig. 15). A very important fact, met with again and again in transmission, is that the maximum power is delivered to a resistive load by a generator with a resistive internal impedance when the

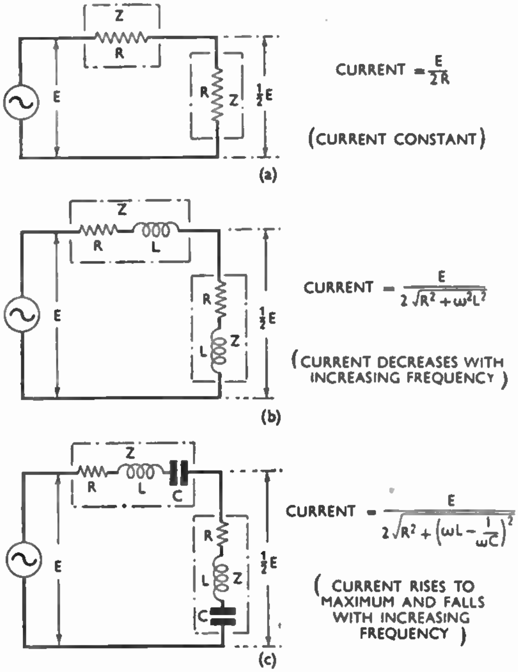


Fig. 15. Three examples of matching are shown; in each the internal impedance *Z* of the generator is matched by another impedance *Z* having the same magnitude and phase angle. On the right of the diagrams (*a*), (*b*) and (c) are stated the formulae for calculating the current, and the effect in each case of increase in frequency.

external load resistance equals the internal resistance of the generator.

Thus, in Fig. 15a, a generator is drawn as an e.m.f. in series with an internal impedance, which is assumed to be a pure resistance. Such a generator delivers maximum power to the load when the load resistance equals the internal resistance of the generator (see INTERNAL IMPEDANCE).

Clearly, the open-circuit voltage of the generator is twice that across the load when this is connected. Thus maximum power can only be delivered to the load by reducing the voltage at the generator terminals by half. Thus it is by no means always possible to match load resistance with an internal resistance.

For instance, if the mains-supply voltage were reduced to nearly half under full-load conditions, lamps and fires would either be damaged by too high a voltage on lightly-loaded mains, or would be useless when the mains were fully loaded. If a valve amplifier were loaded by a resistance equal to the slope resistance of the output valve, distortion would be intolerable in many cases. (Negative voltage feedback will reduce this distortion.)

The question of what happens when reactances are involved is best dealt with in terms of the output current from a generator. The MISMATCHING FACTOR (q.v.) determines the current output; there may well be a considerable gain in current when mismatching occurs.

For example, in Fig. 16 a generator is shown with an internal impedance composed of pure inductance and pure resistance; if the external circuit is a capacitor in series with a resistor, there is a gain of current when the capacitor is connected, compared with the current when it is not (the capacitor is assumed to have a reactance of the same order as the internal reactance of the inductor). This means that if the two reactances are equal but of opposite sign, more power will be developed in the load resistance if there is a mismatch than when the circuits are matched. It should be noted, however, that this perfect power matching occurs only at one frequency.

Cases may arise in which both the load resistance and the generator's internal resistance are fixed; in such a case, a matching transformer or matching network (see MATCHING TRANSFORMER) is used so that each resistance is matched to the resistance of the terminals at which it delivers or takes power.

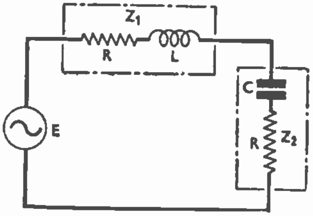


Fig. 16. Example of a circuit impedance Z_2 which includes a capacitor for matching the internal impedance Z_1 of a generator. Current, given by $I = E/\sqrt{4R^2 + (\omega L - 1/\omega C)^2}$, is at a maximum when the reactances of Z_1 and Z_2 are equal.

MATCHING IMPEDANCE. That value of impedance which takes maximum power from a source. In general, the load impedance should equal the source impedance for maximum power transfer. See MATCHING.

MATCHING TRANSFORMER. Transformer used to transfer maximum power from a generator into a load. It is assumed that the load connected to the secondary has a different value from that of the internal resistance of the generator, which is connected to the primary. The maximum power is delivered to a load resistance when this has a value equal to the internal resistance of a generator which supplies it with power (see MATCHING).

Cases can arise when the load resistance is perforce different from the internal resistance of a source of power; thus a source might have an internal resistance of 1,000 ohms and be required to energize a load of 10 ohms. A transformer (Fig. 17) can be used with an impedance ratio from primary to secondary of $\frac{1{,}000}{10}$, or 100 : 1 (voltage ratio $\sqrt{100} : 1 = 10 : 1$). The internal impedance of the secondary of the matching transformer is 10 ohms, matching the load resistance; the load seen by the generator is 100 × 10 ohms = 1,000 ohms, which matches the internal resistance of the generator.

Although a transformer is shown, any network with appropriate image impedances and zero attenuation could be used equally well. Band-pass filters can be made of the impedance-transferring type and constitute a matching network with the same property as a matching transformer. See INTERNAL IMPEDANCE, MISMATCHING FACTOR.

MAXIMUM USABLE FREQUENCY. Highest frequency that can be used in long-distance short-wave transmission to ensure reliable reception at a specific distance from the sender. Higher frequencies than the maximum usable frequency are not reflected by the

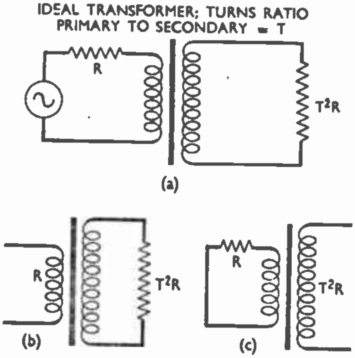


Fig. 17. Use of a matching transformer: in (*a*) matching is achieved between a generator having an internal resistance *R*, and a load of value T^2R; in (*b*) the primary of the transformer has an effective resistance of *R*, and in (*c*) the load "looks back" into an impedance T^2R which is its own impedance.

F-layer because, although bending of the sky wave may occur, the angle of refraction is not sufficiently great to ensure reception, at the receiver.

The maximum usable frequency depends upon the time of day, time of year and general ionospheric conditions. In general, the greater the ionic density of the F-layer, the higher is the maximum usable frequency, so that for reliable communications between two widely spaced stations, a higher frequency would be used during the day than at night. See F-LAYER, IONOSPHERIC REFLECTION, IONOSPHERIC REFRACTION.

MAXWELL. Magnetic-field unit corresponding to one line of force. See MAGNETISM.

MAXWELL'S LAW. Law which states that there is a force in an electric circuit which tends to make every part thereof move in a direction which will cause it to embrace the greatest possible amount of the magnetic field of force.

Mc/s. Abbreviation for MEGACYCLE(S) PER SECOND.

M.C.W. Abbreviation for modulated continuous wave.

MEAN SPHERICAL RESPONSE. Of a *loudspeaker*, the average of a number of response determinations made at various points in the surface of an imaginary sphere with the loudspeaker as centre and having a radius that is large compared with the dimensions of the loudspeaker. This response is useful in determining the total power radiated by a loudspeaker.

Of a *microphone*, the average response to sound of a given intensity when the direction of the sound is moved so as to strike the microphone at all possible angles within a sphere surrounding the microphone.

MEASURING INSTRUMENTS. Devices for enabling the size and properties of materials or the performance of apparatus to be determined. Those used in radio are of many types, but all may be conveniently classified under three headings:

1. *Direct-reading Instruments.* These include A.C. and D.C. meters used in electrical, as distinct from radio, engineering practice, such meters being connected directly in the circuits to be tested.
2. *Indirect-reading Instruments.* Each of these incorporates a subsidiary circuit between the apparatus being tested and the meter itself, which may be of either the A.C. or D.C. type. A typical example of such an instrument is the valve voltmeter.
3. *Special-purpose Instruments.* These consist of measuring devices designed to meet specific needs, such as valve-testers, harmonic analysers, etc.

The D.C. moving-coil meter is the most widely used of the meters in group 1. Its more usual functions are as a D.C. meter for the measurement of voltage, current and resistance. Also, it is the basis of many instruments for the measurement of alternating current and voltage, the D.C. meter being provided with a thermo-couple or metal rectifier interposed between itself and the A.C. circuit.

Calibration is generally made at 50 c/s with current of sinusoidal form. This limits the value of the instrument as an indicator of absolute values when used for R.F. (radio-frequency) measurements, but, as many of the measurements are of an arbitrary nature, it is still useful at frequencies other than 50 c/s. An instance of this occurs in tuned R.F. circuits where the meter often serves to indicate a maximum rather than the absolute current.

Other meters in group 1 are the moving-iron meter, the hot-wire meter and the electrostatic meter. The moving-iron meter is usually less expensive than its moving-coil counterpart, and its lightly damped action can be useful. For example, as an anode-current meter in a class-A amplifier, where it will give a quick indication of overloading. In addition, it may be employed to measure A.C. at audio frequencies.

The hot-wire instrument is often used

for measuring current in R.F. circuits, but its accuracy may easily be impaired if it is overloaded. The electrostatic meter, essentially a voltmeter, is mainly used at senders where high voltages are in use. Many tests in radio circuits involve the measurement of very small voltages across high impedances over a very wide band of frequencies. These requirements disqualify most of the meters in group 1.

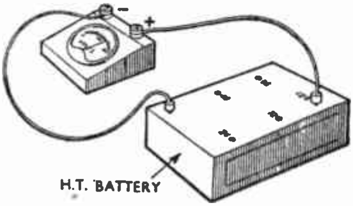


Fig. 18. D.C. voltmeter being used to measure the voltage of an H.T. battery.

Perhaps the most useful device in group 2 is the valve voltmeter, a well-designed model of which is capable of giving accurate voltage readings of either D.C. or A.C. up to several megacycles per second. Its sensitivity, wide frequency response and high input impedance make it useful in all branches of testing. In receiver servicing, the instrument may be successively used to measure the anode and screen voltages (D.C.), to assist in ganging the tuned circuits (R.F.) and to measure the frequency response of the A.F. (audio-frequency) circuits.

Also in group 2 is the bridge "Megger" tester, which instrument, because of its comparative robustness and portability, has a wide field of application. It can measure a wide range of resistance, and is particularly valuable for circuit testing.

A number of measuring instruments, which may be termed audio-frequency voltmeters, also come within the definition of group 2. Certain of these are used for testing, and others for monitoring purposes. An example of the former is the amplifier-detector which measures the frequency-response characteristics and noise level of telephone lines, giving a reading in decibels. In such a test, two instruments are employed, one to measure the tone voltage applied to the sending end of the line and the other to measure the received voltages. The voltage at the sending end is usually kept constant at a number of frequencies and, as both instruments are calibrated to a common standard, the attenuation of the line may be read directly at the receiving end. The amplifier-detector must have a flat frequency response, and its ability to measure low noise levels is limited by the inherent noise level of the instrument itself.

An example of a monitoring instrument is that used to check broadcast programme volume in terms of the electrical counterpart of sound which is continually changing in both frequency and amplitude. Such instruments are, therefore, designed to have a wide, flat frequency response and a specified time constant.

A compromise must be made between

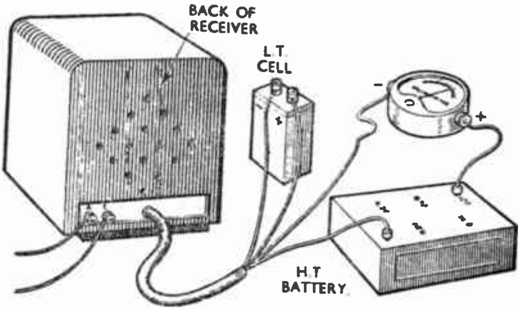


Fig. 19. D.C. milliammeter, connected in series with the positive H.T. lead and the battery, measuring the total anode current of a radio receiver.

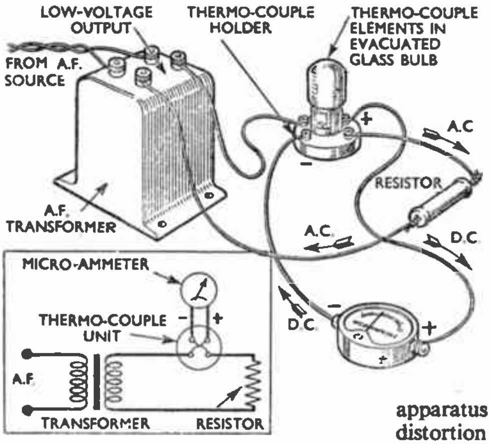


Fig. 20. Method of measuring the minute audio-frequency current through a resistor by means of a D.C. micro-ammeter employed in association with a thermo-couple. A circuit diagram of the arrangement is also shown.

an instrument which attempts to give instantaneous values and one which gives the average volume over a relatively long time. The former type cannot be read satisfactorily, whilst the latter, with its sluggish action, gives no indication of the short-term increases or decreases on the average level. The time-constant value is a matter for controversy, and, generally, each broadcasting organization has its own standard.

The B.B.C. "Programme Meter" consists of a D.C. moving-coil meter in association with a specially designed amplifier known as a "Programme-meter Amplifier." This instrument is calibrated to standard reference levels, and may be used for measurement of volume as well as for monitoring. Simpler types of volume indicator usually consist of a valve circuit with an anode-current meter which shows a reading when a predetermined level of volume has been reached.

Modulation meters, as used on senders, are of two types. Some are directly connected to the modulation circuits and comprise a D.C. moving-coil meter plus a rectifier. Other types are connected to the output of a receiver, the A.F. signal output from which is applied to a meter scaled to show modulation levels as percentages of the carrier level.

Among the special-purpose instruments, group 3, may be mentioned apparatus for measuring harmonic distortion in A.F. amplifiers, the field-strength and frequency of senders, and the impedance of aerial-arrays. The first type may also be used for tests on modulated R.F. stages, in which case it must be preceded by a detector. Field-strength measuring apparatus, covering a wide range of radio frequencies, has been developed to check the calculated performance of broadcasting senders with respect to their service areas.

Radio-frequency bridges are employed for measuring the impedance of aerial-arrays and tuned circuits, and wavemeters and frequency-measuring apparatus for determining the frequency of oscillatory circuits and senders.

Special instruments, such as valve testing panels, have been developed for checking the characteristics of the receiving types of valve, so that they may be withdrawn from service if below a certain standard. The mutual conductance, emission and insulation of the valve is measured with specified applied voltages. Although these voltages are not necessarily the same as would be used under working conditions, the results obtained will show whether the specimen is up to the average standard of its type.

A few practical applications for measuring instruments are given in the

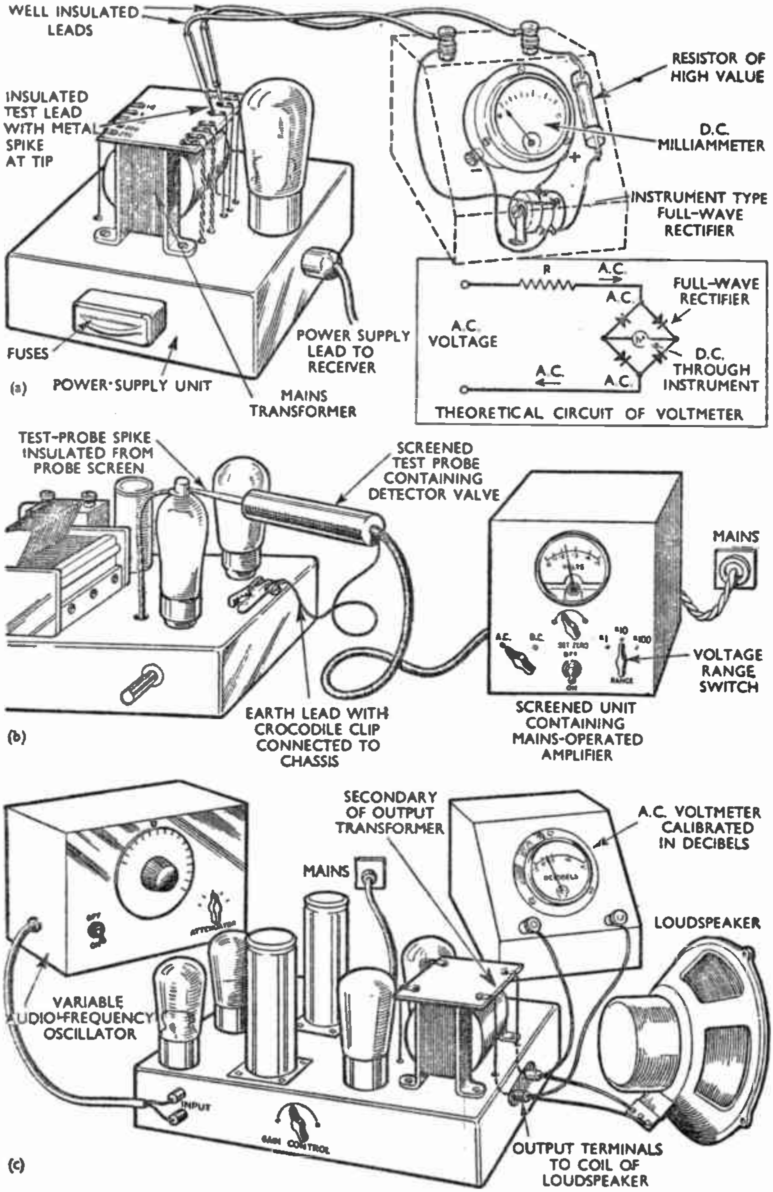


Fig. 21. Measuring instruments in use: (*a*) D.C. milliammeter with full-wave rectifier measuring alternating voltage; (*b*) method of measuring A.F. voltages, and (*c*) A.C. voltmeter used for determining frequency response of an amplifier.

accompanying illustrations. Fig. 18 indicates the method of measuring the voltage of a H.T. battery by means of a D.C. voltmeter, and Fig. 19 the method used for obtaining the total anode current of a radio receiver by connecting a D.C. milliammeter in series with the battery and the positive H.T. lead.

A method of measuring extremely small audio-frequency current is shown in Fig. 20. With this measuring circuit, the current being measured is passed through the heater element of the thermo-couple; this causes current to pass through the circuit formed by the dissimilar metals of the thermo-couple in series with the micro-ammeter.

Fig. 21a shows a common method of measuring alternating voltages such as those used in the power-supply transformer of a receiver. The measuring instrument comprises a D.C. milliammeter used in conjunction with a full-wave rectifier connected in bridge form. A method of measuring audio-frequency voltages is given at Fig. 21b. The meter scale of such an instrument is sometimes calibrated in decibels.

The use of an A.C. voltmeter for determining the frequency response of an amplifier or a receiver is shown in Fig. 21c. Tone is fed to the input of the amplifier, the tone source consisting of a variable audio-frequency oscillator. One frequency (usually 1,000 c/s) is chosen as a datum line and the output level at all other frequencies is measured with reference to the datum frequency. If the level of the latter is called zero, that at any other frequency may be expressed as $\pm N$ db., where N is the number of decibels by which one output differs from that of the datum frequency.

MECHANICAL RECTIFIER. Mechanically operated switch that, at suitable instants of time, reverses or interrupts the circuit path in which alternating currents are flowing. The reversals or interruptions produce a unidirectional current. Any graph showing the wave form of a rectified alternating current is formed by drawing a sinusoid in which alternate half-waves are reversed, or suppressed (Fig. 22).

Any mechanical switch which is made to interrupt a circuit path or made to reverse it every half-cycle of alternation of current flowing in it is therefore a rectifier.

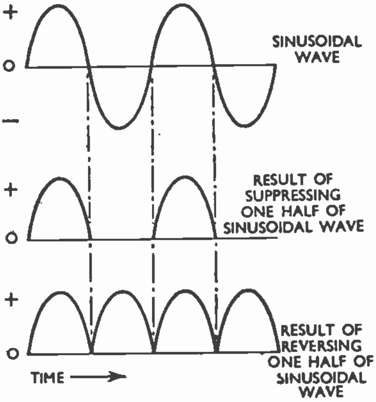


Fig. 22. Effect of rectification on a sine wave when the circuit path in which it flows is interrupted or reversed at half-wave intervals, as by, for example, a mechanical rectifier.

The mains unit using full-wave rectification is the electronic equivalent of a mechanical rectifier which reverses a circuit path. The action of the mains unit is automatic. A ring modulator in which modulated and modulating waves have the same frequency is also the equivalent of a mechanical rectifier.

The mechanical rectifier is suitable where very high power is involved and power-efficiency is of paramount importance (Fig. 23). If the change-over of the contacts could be made in an infinitely short space of time and at the instant of reversal of the alternating current, and if there were no loss at the contact when conducting current, the mechanical rectifier would have an efficiency of 100 per cent. See FRE-

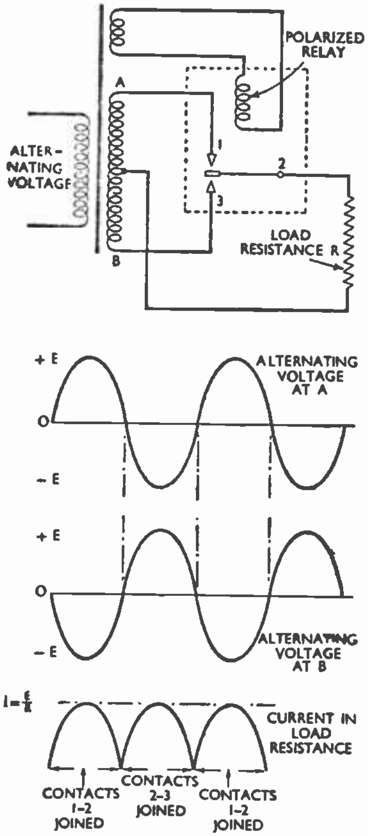


Fig. 23. Circuit of a mechanical rectifier, and graphs showing the principle of its use for the full-wave rectification of an alternating voltage.

QUENCY-CHANGING, FULL-WAVE RECTIFICATION, HALF-WAVE RECTIFICATION, RECTIFICATION.

MECHANICAL SCANNING. Analysing a picture into its elements by mechanical means. Disc prisms, disc scanners, mirror drums, mirror screws are all in this category.

MEDIUM-FREQUENCY WAVE. Radio-wave between the frequency limits of 300 and 3,000 kc/s, that is, within a wave range of 100–1,000 metres. The propagation characteristics of the lower frequencies in the medium-frequency bands are precisely the same as those of low-frequency waves. During the daytime, reception is almost entirely by means of the ground wave, with, perhaps, some reflection by the D-layer. The ground-wave attenuation is small. At night the E-layer attenuation due to absorption is small and considerable reflection occurs; there is interaction between ground wave and ionospheric wave with subsequent fading.

Frequencies of 150–750 kc/s are in what is known as the critical wave band. When the mean free time of electron travel in the E-layer coincides with the period of oscillation of the electric wave itself, a resonance effect occurs resulting in very heavy absorption of the electric wave. The resonant frequency depends upon the ionization conditions of the layer, and therefore varies from hour to hour, and day to day. Frequencies in the critical wave band are therefore reflected very erratically and the ionospheric wave is useless for reliable transmission.

Most medium-wave broadcasting stations use frequencies within this band. During the daytime, communication is confined to an area covered by the ground wave; but during the dark hours there is considerable reflection from the E-layer, and signals may be received over an increased area. This longer night range is not completely reliable because interference between the reflected ionospheric wave and the ground wave usually gives rise to fading and distortion. See ABSORPTION, FADING, HECTOMETRIC WAVE, IONOSPHERE, LOW-FREQUENCY WAVE.

MEDIUM WAVE. Synonym for MEDIUM-FREQUENCY WAVE.

MEGACYCLES PER SECOND. See CYCLES PER SECOND.

MEGAWATT. One million watts, or one thousand kilowatts, a unit of power sometimes used when large numbers are concerned.

MEGOHM. One million ohms, a unit of resistance in common use in radio, where resistance values tend, in general, to be higher than in most other branches of electrical work.

MEISSNER CIRCUIT. See INDUCTIVE-FEEDBACK OSCILLATOR.

MEISSNER OSCILLATOR. See INDUCTIVE-FEEDBACK OSCILLATOR.

MERCURY-ARC RECTIFIER. Rectifier in which rectification takes place in an arc formed between an anode and a pool of mercury. The mercury pool is the cathode. The gas formed when the arc strikes is mercury vapour. A distinction is drawn between the mercury-arc rectifier, in which "keep-alive" electrodes must be used, to establish the arc each half-cycle of alternation of the current rectified, and the Ignitron, in which the process of maintaining the arc is automatic (see IGNITRON).

The mercury-arc rectifier is one of the oldest forms of rectifier, and it has been used in one or another application for over thirty years. Later developments have given it its chief application in converting alternating to unidirectional current for large power systems; capacities up to several thousands of kilowatts are available today.

The basic design provides a pool of mercury and one or more anodes enclosed in an evacuated chamber. If the current-handling capacity of the rectifier is less than about 50 amperes, the bulb may be of glass; otherwise, metal tanks are used, metal-tank rectifiers having ratings of up to 30,000 volts. The residual gas must be reduced to a pressure of the order of 0·0001 mm. of mercury and the temperature must be kept below 50 deg. C. to prevent the pressure of the gas rising. Water-cooling jackets or air-blowing fans may be used for cooling.

Polyphase rectification is made possible by the provision of suitable numbers of anodes, two for full-wave and six for three-phase rectification.

Fig. 24 shows a mercury-arc rectifier in a glass bulb. The glass dome of the rectifier condenses the vapour, and mercury drains back into the pool.

Assuming that an arc has been started, by means to be explained, then when the current ceases the arc will cease. Thus it is necessary to provide means both to start the arc and, once started, to maintain it. The circuit of Fig. 25 serves to explain how this is done.

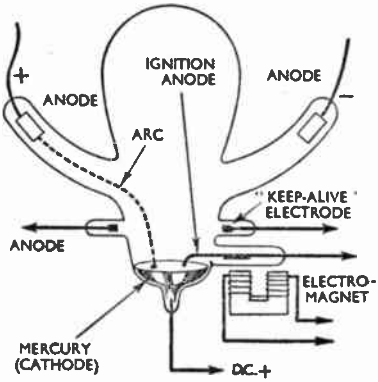


Fig. 24. Mercury-arc rectifier which has a magnetically controlled ignition anode and a "keep-alive" electrode.

The subsidiary pool is not in contact with the main pool until the tube is mechanically tipped so that contact between the pools is made. This contact is then broken as the tube is restored to its vertical position. In breaking contact, an arc is formed. The arc jumps to the anodes and is maintained between the pool and either of these, as one or the other is positive with respect to the pool and according to the phase of the current flowing in the primary of the transformer. Power is wasted in this process but, relatively, not much.

Owing to the continuous ionization of the gas in the "keep-alive" system (Fig. 24) rectification through the main anodes to the cathodes is made possible. The action of the rectifier, considered solely from the point of view of the action of the main anodes is concerned with what is called the cathode spot formed on the surface of the pool by the arc. This spot becomes a source of electrons and is equivalent to the cathode of a hard valve. The mercury atoms also are liberated and form the vapour in the tube. The electrons shoot towards the anode and in their passage ionize the vapour.

The positive ions then move towards the negative pool and thus cancel the space charge otherwise formed by the electrons. As in all gas-filled tubes, it is this cancellation of the space charge which causes them, when used as rectifiers, to have a relatively low internal impedance and gives them the high efficiency which makes their use so valuable where large power conversions are in process.

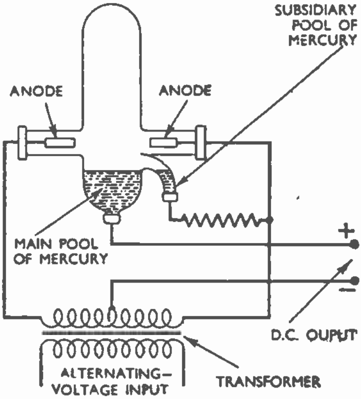


Fig. 25. Mercury-arc-rectifier circuit for full-wave single-phase rectification. The bulb is mounted on a rocking cradle, and the starting arc is obtained by tilting the bulb so that mercury in the subsidiary pool first contacts and then parts from the mercury that is contained in the main reservoir.

The difficulties experienced in producing stable and efficient operation of mercury-arc rectifiers are (1) a tendency for effects associated with arc-back; (2) the consequent need to provide means to cool the tank or tube (see ARC-BACK) and hence to absorb power in doing so, and (3) the need for auxiliary "keep-alive" circuits also representing a reduction in overall efficiency. See, however, IGNITRON.

Mercury-arc rectifiers may be supplied with auxiliary grid electrodes. These do not control the current flow in the way associated with a hard valve, but they can be made to determine the anode voltage at which conduction starts.

The tendency appears to be to substitute the ignitron for the mercury-arc rectifier, since it dispenses with the need for special "keep-alive" circuits and its tendency to arc-back is less.

For small-power rectifier systems, the vacuum-valve rectifier has the notable advantage of robustness in operation, and is relatively independent of the nature of the external circuit load. But its efficiency is relatively poor, making it unsuitable where a large power is rectified. See MERCURY-VAPOUR (HOT-CATHODE) RECTIFIER, RECTIFICATION.

MERCURY-POOL RECTIFIER. Synonym for the MERCURY-ARC RECTIFIER and the IGNITRON. The term fails to distinguish between these two types of mercury-arc rectifier.

MERCURY-VAPOUR (HOT-CATHODE) RECTIFIER. Term describing a widely used rectifier in which the cathode is heated by the passage of a current, and the gas is ionized mercury vapour. The mercury-vapour (hot-cathode) rectifier is essentially a high-vacuum valve which contains mercury vapour in equilibrium with liquid mercury. The basic difference between this type of rectifier and that in which there is relatively no gas (see VACUUM-VALVE RECTIFIER) is that full conduction between anode and cathode takes place when only 15 to 20 volts is applied (positive to anode).

This effect is due to the presence of positive ions of the mercury vapour which cancel the space charge otherwise present (see GAS-FILLED VALVE).

Thus the mercury-vapour valve, in common with all gas-filled valves, has a relatively low internal resistance when used as a rectifier.

The ionization is set up when the plate is at least about 10·4 volts with respect to the cathode. At 15 volts the ionization is more pronounced, and the electrons, travelling from cathode to anode, knock many electrons out of the mercury-vapour molecules, and these, released, also travel to the plate. The increase of current thus caused is negligible, the gas being at a low pressure.

The positive ions are, however, numerous and move, relatively very slowly, towards the cathode. A condition is produced in which there are nearly as many positive ions as electrons. The positive ions, therefore, cancel the space charge, giving a resultant space charge that is virtually zero.

The bombardment of the cathode by the positive ions is not deleterious unless the potential gradient through which they fall exceeds 22 volts. If, therefore, the anode potential relative to the cathode never exceeds this critical value, the cathode does not disintegrate.

The important parameters concerned in the operation of mercury-vapour (hot-cathode) rectifiers are (1) the maximum peak plate current; (2) the maximum permissible average plate current, and (3) the maximum permissible peak inverse voltage. The quantities (1) and (2) are determined by the available emission from the cathode and the heating of the anode, respectively. The peak inverse voltage is determined by the voltage at which sparks take place between the electrodes; owing to the vapour in the valve, this is lower in the mercury-vapour (hot-cathode) type of rectifier than in the hard-valve type.

A great deal more care must be taken to maintain the temperature of the mercury-vapour valve between certain limits than when the hard valve is employed because the temperature determines the vapour pressure. If the temperature is too low, the anode voltage to produce conduction may exceed that at which cathode disintegration takes place; if too high, flash-over may occur.

When mercury-vapour (hot-cathode) valves are operated in parallel, the anode current to each must be led through an inductor to ensure that each valve, though having slightly different characteristics, shall take substantially the same current, otherwise the one having the smallest voltage drop may carry nearly all the current, and this must, at all costs, be avoided.

Low-voltage heater elements are used because the voltage-drop must be of the order of 15 volts, and the heater voltage must be small compared with this; 2·5- to 5-volt heaters are generally used. In applications to high power (of the order of a few kilowatts), the cathodes are usually of the heater type and consist of a cup containing vanes or discs coated with oxide. Such a cathode is heated from a central heater and is surrounded by a shield or shields polished to reduce heat radiation.

In common with gas-filled tubes or valves, the mercury-vapour (hot-cathode) rectifier scores as to power efficiency and low internal impedance, but does so only at the expense of an instability which makes it unsuitable where the load and the operating conditions are variable, and when any accidental short circuits would result in the total destruction of the valve. See GAS-FILLED VALVE, RECTIFICATION, RECTIFIER.

MERCURY-VAPOUR RECTIFIER. Generalized term describing any rectifier in which the gas in the valve or tube is mercury vapour.

MESH. Of a network, that part of a network bounded by any simple closed conducting path. See NETWORK.

MESH CONTOUR. Boundary of a mesh. See MESH, NETWORK.

METAL-CLAD SWITCHGEAR. Power-supply switchgear in which each component is covered by a heavy metal protective casing connected to earth. It is used in permanent installations, such as radio senders, where the power supply to be controlled is more than about 3 kW.

METALLIC CIRCUIT. Circuit formed by a continuous conductive piece of metal. The term is useful in distinguishing a circuit which does not include a capacitor from one which does. For instance, a metallic circuit is formed by a resistor, rectifier and inductor; but not by an inductor, resistor and capacitor.

METALLIZED-PAPER CAPACITOR. Form of fixed capacitor constructed from paper having an extremely thin metallic coating applied by means of an evaporation process. See FIXED CAPACITOR.

METALLIZED-PAPER CONDENSER. Synonym for METALLIZED-PAPER CAPACITOR.

METALLIZED RESISTOR. Form of fixed resistor in which the resistive element consists of a thin film of metal deposited on the surface of a ceramic or glass rod. The term is often applied to similar resistors in which the thin resistive film consists of carbon. It is also applied, somewhat loosely, to composition or "paste" resistors in which the resistive element is formed of a rod moulded from a thermosetting plastic mixture containing powdered carbon or graphite.

Metallized resistors have comparitively small dimensions and can be made to have very high values of resistance. They have a negligible amount of self-inductance and self-capacitance and are suitable for use at radio frequencies. See COLOUR CODE, FIXED RESISTOR.

METALLIZED VALVE. Valve with a glass bulb covered by a sprayed-on metal which closely adheres to the glass. The metallized envelope forms an electrostatic shield around the electrodes. This may be advantageous

METAL RECTIFIERS (WESTINGHOUSE)—HALF-WAVE CLASS

Type	*Circuit*	*Max. Peak Voltage*	*Max. Current Output (Micro-amperes)*
W.1	Half-wave	6	250
W.2	,,	12	250
W.3	,,	18	250
W.4	,,	24	250
W.5	,,	30	250
W.6	,,	36	250
WX.1	,,	6	100
WX.2	,,	12	100
WX.3	,,	18	100
WX.4	,,	24	100
WX.5	,,	30	100
WX.6	,,	36	100

METAL RECTIFIERS

Type	*Nominal Output*		*Maximum Input (Volts)*
	Volts	Max. current mA	
HT.43	600	120	275
HT.44	400	120	210
*HT.44	400	75	210
HT.45	300	75	170
HT.46	240	120	250†
HT.47	260	60	250†
HT.48	260	30	250†
HT.49	120	20	108
HT.50	320	40	300–0–300
HT.51	400	100	350–0–350
HT.52	400	200	350–0–350
HT.53	600	200	500–0–500
HT.54	120	60	110

**Alternative output.*

METAL RECTIFIERS (WESTINGHOUSE)—L.T. TYPES

Type	*Output*		*Nominal A.C. input (Volts)*	*Circuit*
	Volts	*Amp.*		
LT.51	2	0·5	3·6	Half-wave
LT.52	12	1·5	15·6	Full-wave bridge
LT.53	12	3·0	15·6	,, ,, ,,
LT.54	12	5·0	15·6	,, ,, ,,
LT.56	24	1·5	31	,, ,, ,,
LT.57	24	3·0	31	,, ,, ,,
LT.58	24	5·0	31	,, ,, ,,

in preventing stray couplings between circuits, but an external shield surrounding an ordinary glass bulb can be equally effective. The covering of a metallized valve is often connected electrically to the cathode electrode by means of an internal connexion. See SCREENING.

METAL RECTIFIER. Rectifier in which the rectifying action takes place between the inner surface of a coating on a metal and the metal itself. In the copper-oxide metal rectifier, the rectification is between an oxide of copper and the pure metal; in the selenium rectifier, it is between a special alloy coated on the selenium and the selenium itself.

The advantages of the metal rectifier are that no chemical action takes

(WESTINGHOUSE)—HIGH-TENSION TYPES

Circuit	*Capacitors*			*Remarks*	*Type*
	No. req'd	Cap. μF	Wkg. voltage D.C.		
Voltage-doubler	2	16	450	A.C. receivers	HT.43
,, ,,	2	16	350	,, ,,	HT.44
,, ,,	2	8	350	,, ,,	*HT.44
,, ,,	2	8	350	,, ,,	HT.45
Half-wave	1	16	350	A.C./D.C. receivers	HT.46
,, ,,	1	16	350	,, ,,	HT.47
,, ,,	1	8	350	,, ,,	HT.48
,, ,,	1	8	150	Battery eliminators	HT.49
Full-wave centre-tap	1	4	350	Valve-replacement rectifier	HT.50
,, ,,	1	16	500	,, ,,	HT.51
,, ,,	1	32	500	,, ,,	HT.52
,, ,,	1	32	750	,, ,,	HT.53
Half-wave	1	16	350	Midget receivers (A.C./D.C.)	HT.54

†*A.C. or D.C.*

place and no disintegration of the material is essential to the process, its life is relatively unlimited and the maintenance required is negligible.

Metal rectifiers are used fairly extensively for power conversion from alternating to direct current. The internal resistance of the rectifier is generally higher than that of a valve. On the other hand, efficiencies up to 90 per cent are obtainable, and the great reliability and long life of metal rectifiers make them highly suitable for medium-power installations, especially where wide variations in loading are not likely to be encountered.

The metal rectifier is frequently used as a voltage-doubler because it is better adapted to this purpose than rectifier valves, two of which must be used since the cathodes cannot be connected together (see VOLTAGE-DOUBLER).

Another application of metal rectifiers is their use as electronic switches, notably in the ring modulator. Moving-coil instruments are used in conjunction with metal rectifiers to measure alternating currents and voltages. See MEASURING INSTRUMENTS, RING MODULATOR.

The accompanying tables give details of the ratings of various types of metal rectifier available for radio and television applications.

METAL VALVE. Valve with a bulb made of metal. There is no basic reason why the bulb of a valve should be made of glass, and several years ago it seemed as if the metal envelope would be universally adopted; but it is not necessarily true that the metal bulb is stronger than the glass bulb and, although a metal valve may not break when dropped, the electrode structure may well be rendered useless.

METER. General term applied to any electrical measuring device in which a pointer moves over a calibrated scale. See AMMETER, VOLTMETER.

METRE. Unit of length in the metric system, equal to 39·370113 in.

METAL RECTIFIERS (WESTINGHOUSE)

Rectifier Type Number	*Nominal Output with Sinusoidal Input (Half-wave)*	
	Volts	*mA**
36K1	35	0·1
36K2	70	0·1
38K3	105	0·1
36K4	140	0·1
36K5	175	0·1
36K6	210	0·1
36K8	280	0·1
36K10	350	0·1
36K12	420	0·1
36K14	490	0·1
36EHT10	350	0·1
36EHT20	700	0·1
36EHT25	875	0·1
36EHT30	1,050	0·1
36EHT35	1,225	0·1
36EHT40	1,400	0·1
36EHT45	1,575	0·1
36EHT50	1,750	0·1
36EHT60	2,100	0·1
36EHT70	2,450	0·1
36EHT80	2,800	0·1
36EHT90	3,150	0·1
36EHT100	3,500	0·1
36EHT115	4,020	0·1
36EHT130	4,550	0·1
36EHT145	5,080	0·1
36EHT160	5,600	0·1
36EHT180	6,300	0·1
36EHT200	7,000	0·1
36EHT220	7,700	0·1
36EHT240	8,400	0·1
Westeht	5,000†	0·15
,,	3,000†	0·15
,,	1,700†	0·15
Pulse-multiplier Unit..	—	—

* *The maximum*

—E.H.T. TYPES (RATINGS FOR TELEVISION APPLICATIONS)

Nominal Output with Pulse Input						*Max. Input Voltage (Sinusoidal Input)*	*Max. Input Voltage (Pulse Input)*
Half-wave		*Doubler (two Rectifiers)*		*Tripler (three Rectifiers)*			
Volts	*mA*	*Volts*	*mA*	*Volts*	*mA*		
—		—		—		27	—
—		—		—		54	—
—		—		—		81	—
—		—		—		108	—
—		—		—		135	—
—		—		—		162	—
—		—		—		216	—
—		—		—		270	—
—		—		—		324	—
—		—		—		378	—
—		—		—		270	—
1,310	0·1	2,340	0·1	3,340	0·1	540	1,450
1,640	0·1	2,930	0·1	4,180	0·1	675	1,810
1,960	0·1	3,520	0·1	5,000	0·1	810	2,180
2,190	0·1	4,100	0·1	5,850	0·1	945	2,540
2,620	0·1	4,680	0·1	6,570	0·1	1,080	2,900
2,950	0·1	5,280	0·1	7,520	0·1	1,220	3,470
3,280	0·1	5,850	0·1	8,350	0·1	1,350	3,630
3,930	0·1	7,020	0·1	10,000	0·1	1,620	4,350
4,580	0·1	8,200	0·1	11,700	0·1	1,890	5,080
5,240	0·1	9,380	0·1	13,300	0·1	2,160	5,800
5,900	0·1	10,300	0·1	15,000	0·1	2,430	6,520
6,550	0·1	11,700	0·1	16,700	0·1	2,700	7,250
7,520	0·1	13,400	0·1	19,200	0·1	3,100	8,300
8,500	0·1	15,200	0·1	21,700	0·1	3,520	9,420
9,500	0·1	17,000	0·1	24,200	0·1	3,900	10,500
10,400	0·1	18,700	0·1	26,700	0·1	4,320	11,600
11,800	0·1	21,100	0·1	30,000	0·1	4,850	13,000
13,000	0·1	23,400	0·1	33,400	0·1	5,400	14,500
14,400	0·1	25,700	0·1	36,700	0·1	5,940	16,000
15,700	0·1	28,000	0·1	40,000	0·1	6,480	17,400
—	—	—	—	—	—	350–0–350	—
—	—	—	—	—	—	350–0–350	—
—	—	—	—	—	—	350–0–350	—
—	—	—	—	6,000	0·15	—	2,540

current rating for the 36K and 36EHT rectifiers is 2mA. † *Full-wave input.*

METRE-AMPERE. Measure of the field intensity produced by a sending aerial; a metre-ampere postulates a radio-frequency current of one ampere flowing in one metre of vertical conductor.

METRIC WAVE. Radio-wave of 1–10 metres in wavelength, that is, within a frequency range of 30–300 Mc/s. See VERY HIGH-FREQUENCY WAVE.

MICA CAPACITOR. Form of capacitor having mica as the dielectric. See FIXED CAPACITOR, TRIMMER.

MICA CONDENSER. Synonym for MICA CAPACITOR.

MICRO. Prefix meaning one-millionth. The abbreviation is μ. For examples, see MICRO-AMPERE, MICROHENRY.

MICRO-AMMETER. Electric current-measuring device calibrated in micro-amperes (one micro-ampere equals 10^{-6} ampere). See AMMETER.

MICRO-AMPERE. Millionth part of an ampere, representing an extremely small current. The abbreviation of micro-ampere is μA.

MICROHENRY. Millionth part of a henry; its abbreviation is μH. See HENRY.

MICROMICROFARAD. Billionth (12^{-9}) of a farad; an exceedingly small capacitance, such as might exist between a few inches of wire running close to another in the wiring of a receiver. The abbreviation for micromicrofarad is $\mu\mu$F. The micromicrofarad is also known as the picofarad (abbreviated pF.). See FARAD.

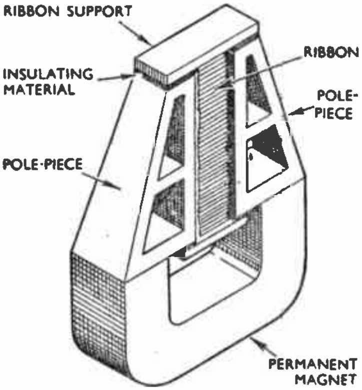


Fig. 26. Typical form of construction of the velocity ribbon microphone.

MICRON. Thousandth part of a millimetre.

MICROPHONE. Device for converting sound into electrical energy, the electrical output varying in time in a manner similar to the pressure amplitude of any sound wave which strikes it. Generally the acoustic-electrical conversion does not take place directly; the sound waves impinge on a diaphragm and cause it to vibrate, giving rise to mechanical energy, and the resulting movement is communicated to some form of generator. These two energy transformations take place simultaneously, and there is no time lag between sound wave and electrical output.

Although the acoustical-mechanical conversion is nearly always achieved by means of a diaphragm, there are a number of alternative methods of transforming the mechanical into electrical energy.

The movement of the diaphragm may be used to vary the impedance of an electrical circuit, as in the carbon granule and capacitive microphones; it may cause a conductor to move in a magnetic field so that e.m.f.s are induced in it, as in the moving-coil and ribbon microphones; or the movement may be communicated to a Rochelle salt crystal, across which e.m.f.s are generated by piezo-electric action.

The frequency response of a microphone is influenced considerably by the mechanical resonance of the diaphragm. In the Post Office type of carbon granule microphone, the diaphragm resonates within the audio-frequency range at approximately the frequency at which the ear is most sensitive, giving high efficiency.

In broadcasting and recording, however, where high quality is essential, it is necessary to secure a level frequency response, and it is customary to place resonances, as far as possible, outside the audio range. In capacitive microphones, for example, a high frequency of mechanical resonance is achieved by clamping the diaphragm under very great tension by a ring.

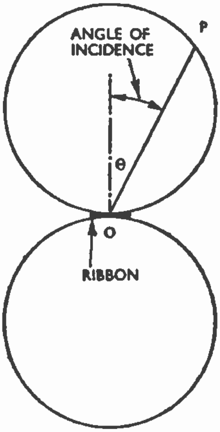


Fig. 27. Figure-of-eight polar diagram illustrating the variation in sensitivity of a velocity ribbon microphone with the angle of incidence. The length of any line such as *OP* measures sensitivity to sounds having an angle of incidence of θ to the ribbon.

Although it is possible to raise the mechanical resonant frequency to 8,000 c/s by this method, it reduces the sensitivity considerably.

In velocity ribbon microphones a low frequency of mechanical resonance is essential to secure a level frequency response; the ribbon is very lightly tensioned, and so requires protection from draughts or winds by one or more acoustic screens.

In some microphones, such as those of the moving-coil type, the diaphragm is exposed to the sound waves on one face only, the other being boxed in. Any movement which occurs in the diaphragm in these circumstances is determined solely by the pressure of the sound wave, and microphones for which this is true are termed pressure-operated instruments.

In other microphones both faces of the diaphragm are exposed to the sound wave and the movement of the diaphragm is a function of the difference in air pressure between the two faces. In this mode of operation, the movement of the diaphragm is directly proportional to the particle velocity of the wave. For this reason microphones using this principle are termed "velocity" instruments.

In a velocity microphone the difference in air path between the two faces of the diaphragm is a very important dimension, since the upper frequency limit of the microphone is inversely proportional to it. As a rough approximation, the upper frequency limit of the microphone may be taken as that value for which the path difference is equal to half the wavelength. The path difference must be less than one inch in a high-quality instrument. This can be obtained fairly easily by using the type of construction indicated in Fig. 26, which illustrates a velocity ribbon microphone.

Velocity microphones are clearly double-sided; in fact, their output for a given sound wave is directly proportional to the cosine of the angle of incidence, so that the polar diagram has the figure-of-eight shape shown in Fig. 27. From this it can be shown that the output of the microphone is constant within ±2 db. within an arc subtending 100 deg. on each face of the diaphragm.

In a pressure microphone one factor which determines the degree of coupling between the acoustic and mechanical systems is the size of the diaphragm, and the properties of any microphone of this type are dependent to a considerable extent on these dimensions.

If, for example, the diaphragm is large compared with the wavelength of the sound wave striking it, the wave is obstructed in the same manner as sea waves by a breakwater, and reflection occurs, giving an increase in the pressure exerted by the wave on the diaphragm and a corresponding increase in the output voltage. As reflection can cause the pressure to reach only double its normal value, the output can rise by only 6 db. above normal. This rise in output is important only at high frequencies where wavelengths are short, and, since the wavelength corresponding to 10,000 c/s is only 1·3 in., it is clear that a high-grade instrument must have a very small diaphragm and a correspondingly small output voltage.

If a sound wave is incident in the plane of a flat diaphragm of large dimensions, the diaphragm is subjected to compression at some points in its surface and rarefaction at others. The net effect of this is that the output of the microphone is less than normal. This effect, too, being a function of the wavelength of the sound wave, is more pronounced at the higher frequencies.

The extent of the high-frequency loss depends on the angle of incidence. At normal incidence there is actually a high-frequency boost because of the obstruction effect described. If the diaphragm is large (say 3 in. in diameter), the response curve of the microphone varies considerably with the angle of incidence of the sound and, to minimize the variation, it is generally recommended that performers should be grouped within an arc subtending 60 deg. at the diaphragm, this being less than one-third of the useful arc available from a velocity ribbon microphone.

At low frequencies, when the wavelength is large compared with the dimensions of the microphone, the output of a microphone is independent of the angle of incidence, so that the polar diagram is a circle with the microphone as centre. As frequency increases and wavelength decreases, the microphone becomes progressively more directional, since the wavelength becomes comparable with microphone dimensions and the polar diagram develops into an ellipse situated at the front of the diaphragm.

Research is continually striving to produce a unidirectional microphone, that is, one having a useful arc of 180 deg., being live on one side and dead on the other. An approximation to this ideal can be made by combining the outputs of a pressure and a velocity microphone situated as close to each other as possible. The polar diagram obtained from such an arrangement is of cardioid shape at low frequencies, but departs from it at high frequencies.

The sensitivity of a microphone is usually expressed in decibels as the open-circuit voltage (one volt being taken as zero) for an acoustic pressure of one dyne per square centimetre applied to the diaphragm. It is not unusual in modern microphones to

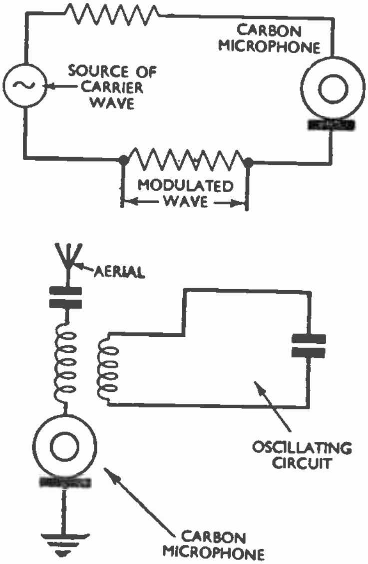


Fig. 28. The upper diagram is the circuit of a microphone modulator which produces amplitude modulation; the lower circuit shows how a carbon microphone can be used to modulate aerial currents in a low-power radio sender

have a sensitivity as low as —90 db., for any improvement in the frequency response is invariably accompanied by a loss in sensitivity.

MICROPHONE AMPLIFIER. Amplifier which raises the level of the output from a microphone to a value suitable for volume-range compression or for mixing. See LINE AMPLIFIER, MICROPHONE.

MICROPHONE BOOM. Long arm carrying a microphone used in broadcasting, film and television studios. It is usually extensible, and can be swung about a pivot to any required position.

MICROPHONE MODULATOR. In *amplitude* modulation, a modulator in which the carrier wave is passed through a variable-resistance microphone. In *frequency* modulation, a microphone modulator is one in which a capacitive microphone forms part of the oscillating circuit of the oscillator generating the carrier wave. Fig. 28 shows a carbon-granule microphone modulator for amplitude modulation. The resistance of the microphone is varied by sound waves and so the carrier wave is amplitude-modulated. This form of modulation was used for radio telephony before the invention of the valve.

Fig. 29 shows a capacitive microphone used for frequency modulation. Sound waves vary the capacitance of the microphone and hence the frequency of the carrier wave. The arrangement is impractical because slow changes in microphone capacitance cause the carrier-wave frequency to drift. In both cases the necessity of using a microphone that is directly connected to the circuits of a sender makes the schemes impracticable for broadcasting and public communications. See FREQUENCY MODULATOR, VARIABLE-RESISTANCE MODULATION.

MICROPHONE RESPONSE. Relationship, usually exhibited in graph form, between the magnitude of the electrical output of a microphone and the amplitude of the sound input. The microphone output is generally expressed in decibels relative to the output at a frequency in the centre of the frequency range, such as 1,000 c/s. A high-quality microphone has a substantially level response between 50 c/s and 10,000 c/s. See MICROPHONE.

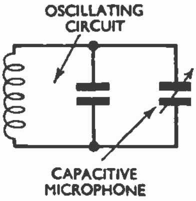


Fig. 29. Microphone modulator for frequency modulation; variations in the capacitance of the microphone cause variations in the resonant frequency of the oscillatory circuit.

MICROPHONIC EFFECT. Synonym for MICROPHONY.

MICROPHONICITY. Synonym for MICROPHONY.

MICROPHONIC NOISE. Synonym for MICROPHONY.

MICROPHONY. Production of variations in electrode currents of a valve due to mechanical movements of the electrodes. The colloquialism "ponging" is sometimes used instead of microphony, as it describes the "pong" that is heard in a loudspeaker or headphone connected to the output of a sensitive audio-frequency amplifier when the valves in the early stages of the amplifier are tapped mechanically.

Microphony is due to mechanical vibrations of the electrode structure which cause modulations of (notably) the anode current. Some valves are more microphonic than others. Naturally, the effect is more pronounced as the over-all gain of the amplifier becomes greater. A cathode-follower amplifier valve in the early stages of an amplifier is remarkably microphonic.

Microphony is so bad in certain cases that sound waves impinging on the valve will cause it to ring or "pong." In public-address systems, a retroactive effect may take place, the sound output from the loudspeaker setting up vibrations in the valves which produce sounds, which react round the positive feedback loop so produced.

Methods of reducing microphony include the insulation of the valve from sound by wrapping it in soft material; the use of special valve holders with spring suspensions; or the mounting of ordinary ones on stretched rubber. See VALVE HOLDER.

MICRORAY. Path traversed by an electromagnetic wave form having a wavelength of less than 20 cm.

MICROVOLT. Millionth part of a volt; abbreviated μV.

MICROVOLTS PER METRE. Unit employed in evaluating the intensity of the field set up by a distant radio sender. Assuming vertically polarized waves, the rating in microvolts per metre (abbreviated, μV/m) denotes the voltage difference per metre of height along the lines of electric force.

MICROWATT. Millionth part of a watt. The microwatt is too small a unit of power to be often used. The abbreviation of microwatt is μW.

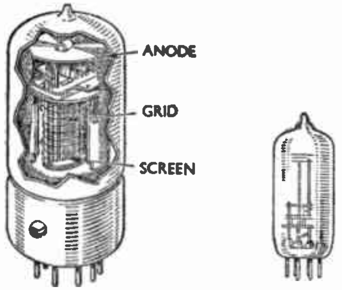


Fig. 30. Miniature valves reproduced at about half actual size: the more modern is the all-glass type (*right*), which saves the height hitherto necessitated by the foot of the valve.

MICROWAVE. Radio-wave of less than 20 cm. wavelength. See CENTIMETRIC WAVE.

MIL. Unit of length equal to one-thousandth of an inch.

MILLER EFFECT. Phenomenon in triodes which causes an alteration of input admittance in consequence of some change in anode-circuit impedance; the effect follows from the fact that the anode/grid capacitance of such valves represents a path through which a fraction of the alternating component of the anode current can flow.

MILLI. Prefix meaning one-thousandth; the abbreviation is m.

MILLIAMMETER. Electric current-measuring device calibrated in milliamperes (one milliampere equals 10^{-3} ampere). See AMMETER.

MILLIAMPERE. Thousandth part of an ampere. This is a conveniently small unit of current for expressing the value of anode currents of valves, and hence much used in radio. The abbreviation is mA.

MILLIMICROFARAD. Unit of capacitance equal to one thousand-millionth (10^{-9}) of a farad.

MILLIVOLT. Thousandth part of a volt. Abbreviation, mV.

MILLIVOLT-AMPERE. Thousandth of a volt-ampere. Abbreviation, mVA.

MILLIVOLTS PER METRE. See MICROVOLTS PER METRE.

MILLIWATT. Unit of electrical power equal to one-thousandth (10^{-3}) of a watt. A milliwatt (abbreviated mW) is often taken as a zero reference level for expressing levels in terms of the decibel scale. See DECIBEL, ACTUAL LEVEL, WATT.

MINIATURE VALVE. Valve in which the dimensions have been reduced from an accepted normal. There are two uses for miniature valves: where the bulk of apparatus must be reduced to a minimum, as in a deaf-aid amplifier; and in cases where inter-electrode capacitance must be reduced to a minimum.

Apart from difficulties of heat dissipation at electrodes, the only factor which prevents the use of smaller valves and yet smaller valves is the difficulty in manufacturing them. Thus the fundamental quantities—amplification factor, mutual-conductance and anode slope-resistance—remain unaltered as the dimensions of a valve are decreased. Naturally, the power that can be safely dissipated at the anode is reduced as the size of the anode is reduced. Nevertheless a miniature valve, one-tenth the volume of an ordinary valve, will handle several watts, counting heater power.

Television demands amplifiers giving substantially level response graphs up to 4 Mc/s. Other aspects of technology, notably that of measurement, demand even wider frequency bands. The opening up of the centimetric band also requires valves that can overcome the difficulties of electrode impedances which are less than circuit impedances connected to them. The smaller miniature valve illustrated in Fig. 30 is approximately 2 in. by ⅞ in. So far as portable apparatus and deaf-aid equipment are concerned, "miniaturization" is a necessity. See ELECTRODE CAPACITANCE, ELECTRODE IMPEDANCE.

MINIMUM CLEARING. Operation of adjusting or process of modifying a direction-finding apparatus to obtain more distinct or more accurate indications. The name derives from the fact that most direction-finders require the operator to locate a minimum-signal setting.

MIRROR DRUM. Method of mechanical scanning, used in early television systems, in which a light spot is made to traverse the picture area in lines by means of reflection from a number of mirrors placed round the circumference of a revolving drum. Each mirror represents one scanning line, so that a 30-mirror drum would provide 30-line pictures.

The light spot is modulated in accordance with the received television signal, and the mirrors are so set at an angle with the drum that the light is not only reflected on to a screen to trace a line as each mirror moves, but successive mirrors are slightly offset so that the path of the spot is moved horizontally a distance equal to the diameter of the spot at each successive line.

Mirror drums were originally used for 30-line television and vertical line scanning was employed. The drum was driven by an electric motor and synchronization was carried out by electromagnetic control of a phonic wheel placed on the motor shaft (see DRUM SCANNER).

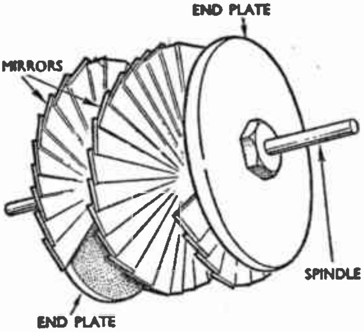


Fig. 31. In the mirror screw, formed by a number of metal plates spirally mounted on a spindle as shown, the edge of each plate is highly polished to provide a rectangular reflecting face.

Difficulty in setting the mirrors accurately preclude the use of the device for high-definition television, apart from the technical difficulties in providing light modulation at the high frequencies required.

MIRROR SCREW. A mechanical television scanning device consisting of a spiral made up of a number of rectangular pieces of metal, threaded on to a spindle and clamped between two end plates. The edges of the pieces of metal are highly polished to form mirrors, and each piece is slightly twisted on the spindle in relation to the one next to it, as shown in Fig. 31.

One piece of metal, that is to say, one mirror, is required for each line of the picture, and the angle between each piece is $\frac{360}{N}$ deg., where N is the number of lines per picture. The width of the picture is determined by the number and thickness of the mirrors, and the illuminating source has to be of a length equal to the picture width.

Owing to the angular displacement between successive mirrors, rotation of the screw provides complete line scanning, and on completion of the picture, repetition of the frame is automatic as the screw continues to rotate.

As in the case of the mirror drum (see DRUM SCANNER), the mirror screw suffers from defects that make it unsuitable for high-definition television. The metal mirrors are not easy to fit, modulation of the light is difficult, and synchronization of the rotating mechanism needs a synchronizing impulse of considerable power. Compared with the cathode-ray tube, all mechanical devices suffer from the same major defect—the considerable inertia of the device which makes synchronizing difficult.

MISMATCHING FACTOR. Ratio of the load current without matching to the load current with matching. The mismatching factor is concerned with the ratio $\frac{Z_s}{Z_L}$, where Z_s is the internal impedance of the generator and Z_L the load impedance. The factor is given by:

$$k = \frac{\sqrt{\frac{4Z_s}{Z_L}}}{1+\frac{Z_s}{Z_L}}$$

Note that, if Z_s and Z_L are equal, and equal to R (condition of load resistance being equal to generator resistance), then $k = \frac{\sqrt{4}}{2} = 1$; also that any other value of $\frac{Z_s}{Z_L}$, both Z_s and Z_L being resistive, makes k less than unity; for example, if $\frac{Z_s}{Z_L} = 4$, $k = \frac{\sqrt{4\times4}}{1+4} = \frac{4}{5}$, which is less than unity.

With the theoretical condition that the internal impedance is a reactor of equal value and opposite sign to that of the reactor forming the external impedance, then $\frac{Z_s}{Z_L} = -1$ and k is infinity; thus the load current with such mismatching is infinite. This is the condition of resonance, where there is no resistance in the circuit. See MATCHING, MATCHING TRANSFORMER.

MIXED COUPLING. Coupling between two circuits caused by common or mutual inductance and capacitance. See CAPACITIVE COUPLING, INDUCTIVE COUPLING.

MIXER. Synonym for MIXER VALVE. See FREQUENCY-CHANGER.

MIXER VALVE. Valve in which the signal wave and oscillator wave are added in a superheterodyne receiver. The mixer valve is generally combined with the oscillator valve in a single envelope to form a frequency-changer. See FREQUENCY-CHANGER.

M.K.S. UNITS. Abbreviation for metre-kilogram-second system of units.

M.K.S. μ UNITS. Abbreviation for metre-kilogram-second electromagnetic system of units.

MODULATED AMPLIFIER. Carrier-wave amplifier in an anode-modulation circuit. The modulated amplifier is essentially a class-C amplifier valve, adjusted so that the output from the valve is proportional to the voltage applied to the anode-circuit terminals. See AMPLITUDE MODULATION, ANODE MODULATOR.

MODULATED TELEGRAPHY. See TYPE A2 WAVE.

MODULATED WAVE. Wave produced by the process of modulation. A distinction may be made between three waves in a modulation system: first, the carrier wave, of which some characteristic, such as amplitude, frequency, phase or time of duration, is varied by the modulating wave; second, the modulating wave which, in carrier-wave transmission, represents the intelligence being transmitted; and third, the modulated wave which is the wave resulting from modulation. See CARRIER WAVE, MODULATING WAVE, MODULATION, MODULATOR.

MODULATING WAVE. The wave in a modulator which changes some characteristic of the carrier wave. In carrier-wave transmission, it is the wave which represents the intelligence being transmitted. See CARRIER WAVE, MODULATED WAVE, MODULATION, MODULATOR.

MODULATING-WAVE AMPLIFIER. Amplifier which may be considered part of a modulator, and which amplifies the modulating wave before passing it to the modulating-wave terminals of a modulator. See ANODE MODULATOR, MODULATED AMPLIFIER, MODULATING WAVE, MODULATOR, MODULATOR VALVE.

MODULATION. Variation of a characteristic of one wave according to the instantaneous amplitude of another wave; or, in carrier-wave transmissions, the variation of a characteristic of a carrier wave in accordance with the instantaneous amplitude of the complete modulating wave. The modulating wave represents the intelligence being transmitted.

In the latter case, the process of modulation has tremendous importance in all communications. The

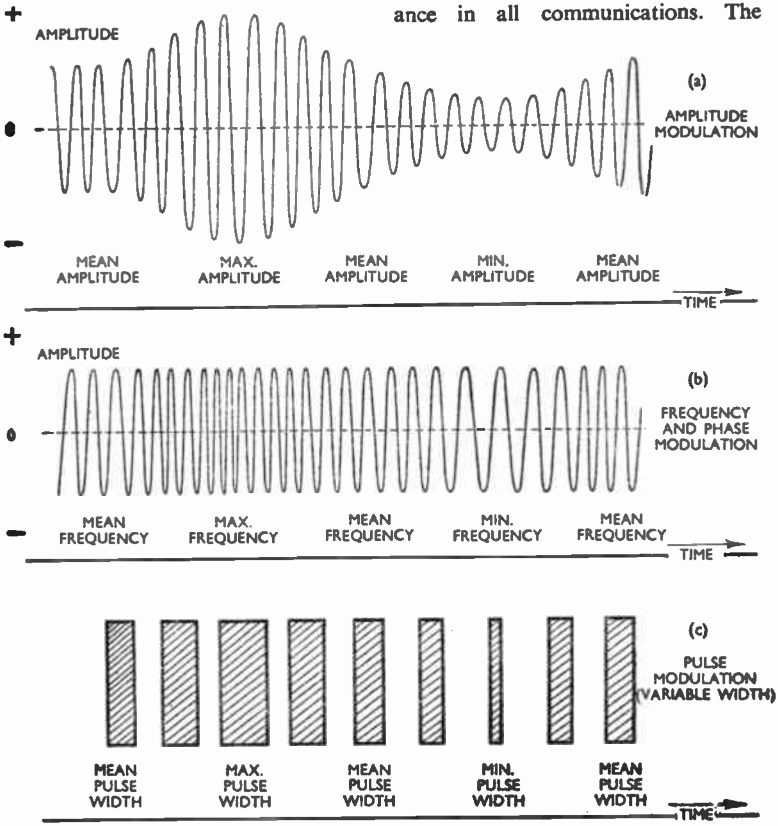


Fig. 32. Diagrammatic representation of the effects upon a sinusoidal wave of the three forms of modulation: (*a*) the amplitude of the wave varies; (*b*) its frequency and phase vary; (c) the wave is broken up into pulses of varying duration.

definition concerns not only radiotelephony, it also embraces telegraphy and line telephony in its simplest form. In telegraphy, the modulating wave is formed by the key sender; in ordinary line telephony on short lines, the carrier wave is of zero frequency and steady amplitude, and is modulated in amplitude by the carbon microphone. A moving-coil microphone would be equivalent to a suppressed-carrier modulator if the carrier wave were of zero frequency. However, this description is concerned with the association of modulation and radio.

The definition says that a characteristic of the carrier wave is varied. There are four characteristics of a sinusoidal wave: (1) amplitude; (2) frequency; (3) phase, and (4) time of duration. Any one of these characteristics can be varied by the modulating wave, to get amplitude, frequency, phase and pulse modulation (see AMPLITUDE MODULATION, FREQUENCY MODULATION, PHASE MODULATION, PULSE MODULATION). These are illustrated in Fig. 32.

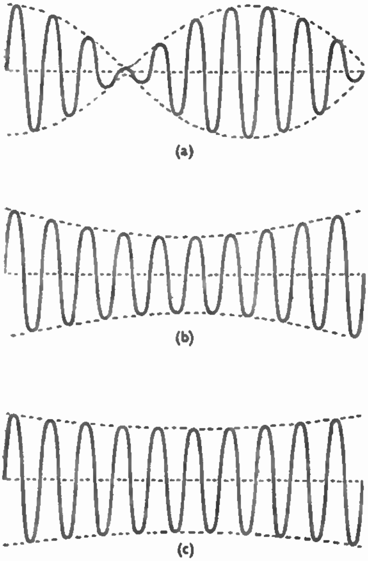


Fig. 33. Comparison in the modulation depths of three amplitude-modulated waves; in (*a*) the depth is maximum, in (*b*) much less, and in (*c*) very small.

There are clearly three waves to be considered: the carrier wave, some characteristic of which is varied; the modulating wave, which causes the characteristic of the wave to vary; and the modulated wave, which is the end-product of the process (see CARRIER WAVE, MODULATED WAVE, MODULATING WAVE, WAVE). A modulator is essential to modulation; a modulator has three pairs of terminals. The carrier wave is applied to one pair, the modulating wave to a second pair and the modulated wave is obtained from the third pair (see MODULATOR).

An examination of the characteristics of the modulated wave shows it to be composed of a wave of the same frequency as the carrier wave before modulation and a number of new waves. The latter waves appear in pairs, one of each pair having a frequency as much greater than the carrier wave as the other is less. These waves are called sideband waves and the difference between carrier- and sideband-wave frequency is equal to the frequency of any sinusoidal component of the modulating wave and, in frequency, phase and pulse modulation, integral multiples of this difference (see SIDEBAND, SIDEBAND WAVE).

The general definition of modulation applies equally to the use of modulation for frequency-changing. Thus, if a sinusoidal wave of frequency f_1 is amplitude-modulated by another of frequency f_2, the modulated wave obtained contains sideband waves of frequencies $f_1 + f_2$ and $f_1 - f_2$ (or $f_2 - f_1$). The sideband waves are frequency-changed waves (see FREQUENCY-CHANGING). The suppressed-carrier modulator is frequently used as a frequency-changer.

MODULATION CONDITION. In a sender generating waves that are modulated to a specified depth, the values of voltages and currents in the

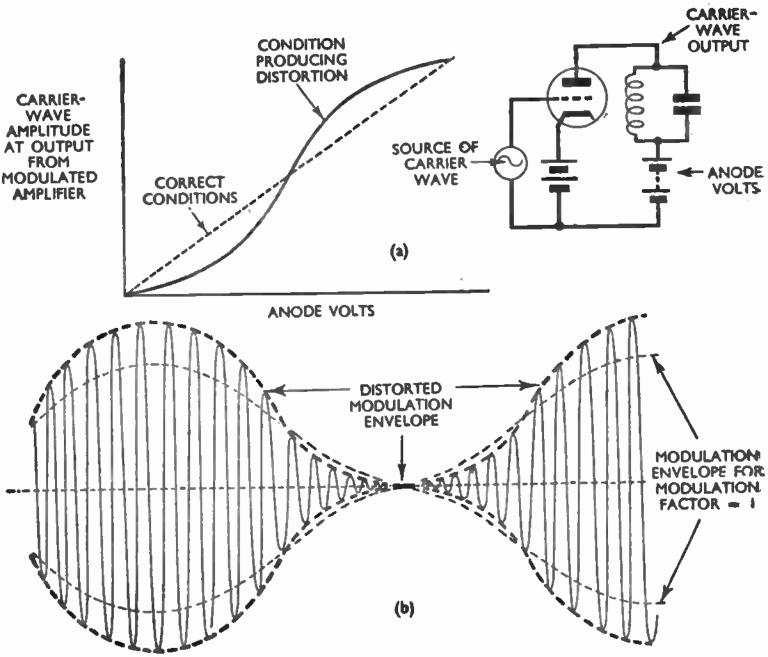


Fig. 34. Cause and effect of modulation distortion in amplitude modulation: (*a*) in anode modulation, distortion may be produced if the graph relating the carrier-wave output and the anode-voltage supply is not linear; (*b*) example of a wave form in which there is distortion caused by over-modulation.

final stages which handle the modulated waves.

MODULATION DEPTH. Qualitative term indicating the degree of variation of, for example, the amplitude of an amplitude-modulated wave. The term could also be used, but seldom is used, for any form of modulation. Fig. 33 shows amplitude-modulated waves in which the modulation depth is large, medium and small. The quantitative expression of depth of modulation is given by the modulation factor. See MODULATION DISTORTION, MODULATION FACTOR, MODULATION PERCENTAGE.

MODULATION DISTORTION. Distortion of the modulated wave due to lack of proportionality between the amplitude of the modulating wave and the value of the characteristic of the carrier wave varied by the modulating wave. Modulation distortion in amplitude modulation occurs when the modulation envelope is not an exact copy of the form of the modulating wave (Fig. 34).

Modulation distortion in frequency or phase modulation occurs when the instantaneous frequency or phase of the carrier wave is not proportional to the instantaneous amplitude of the modulating wave.

Modulation distortion may be produced by filters which fail to transmit sideband waves with equal amplitude, or transmit them at different wave velocities. This form of distortion becomes less as the ratio of carrier-wave to sideband amplitude becomes greater. In single-sideband systems, the carrier wave is introduced in demodulation and has a large amplitude compared with the sideband waves, thus minimizing distortion. See AMPLITUDE MODULATION, FREQUENCY MODULATION, MODULATION ENVELOPE, SIDEBAND WAVE.

MODULATION ENVELOPE. Line drawn through the peak amplitudes of the graph showing an amplitude-modulated wave. The modulation envelope should be an exact copy of the form of the modulating wave (see MODULATION DISTORTION). The detection or demodulation of the modulated wave produces a wave of the same form as the modulation envelope. See AMPLITUDE MODULATION, MODULATION FACTOR.

MODULATION FACTOR. Quantitative expression of the modulation depth (see MODULATION DEPTH). It is the ratio of half the difference between maximum and minimum peak-amplitudes of the modulated wave to the steady (or unmodulated) peak amplitude of the carrier wave. In frequency modulation, the modulation factor is half the difference between the maximum and minimum frequencies of the modulated wave divided by the frequency of the unmodulated carrier wave. Fig. 35 gives an example of the term as applied to amplitude modulation; if the steady peak amplitude of a carrier wave is 5 volts, and, with a sinusoidal-modulating wave, the maximum peak amplitude of the modulated wave 10 volts, and the minimum 0 volts, the modulation factor is $\frac{\frac{1}{2}(10-0)}{5} = 1{\cdot}0$.

If the peak amplitudes were 7·5 and 2·5, the modulation factor would be $\frac{\frac{1}{2}(7{\cdot}5 - 2{\cdot}5)}{5} = 0{\cdot}5$. A further example (not illustrated in Fig. 35) is a peak amplitude of 5·2 and a minimum amplitude of 4·8 when the modulation factor is $\frac{\frac{1}{2}(5{\cdot}2 - 4{\cdot}8)}{5} = 0{\cdot}04$. Expressed as percentages, these are 100, 50 and 4 per cent. Thus the modulation percentages are 100, 50, and 4 (see MODULATION PERCENTAGE).

The modulation factor could be expressed for a sinusoidal modulating wave and absence of modulation distortion as the ratio of twice the peak amplitude of the (equal-amplitude) sideband waves to the peak amplitude of the carrier wave (of constant amplitude). See AMPLITUDE MODULATION, SIDEBAND WAVE.

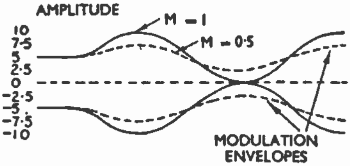


Fig. 35. Examples of values of the modulation factor in amplitude modulation; they are represented graphically in terms of the modulation envelope of two modulated waves.

The modulation factor is not much used in frequency modulation, the modulation index being more useful. See CARRIER WAVE, MODULATED WAVE, MODULATING WAVE.

MODULATION FREQUENCY. Frequency of a MODULATING WAVE.

MODULATION INDEX. In frequency modulation, the ratio of the frequency swing to the frequency of the modulating wave. The modulation index is a number which compares the conditions of all frequency-modulated waves on a common basis. The frequency swing is proportional to the amplitude of the modulating wave, and if the ratio of the amplitude to the frequency of the modulating wave is kept constant, the modulating index is constant. But the modulating index expresses the maximum phase difference between the modulated wave and the carrier wave in a frequency-modulated wave; thus, if the amplitude of the modulating wave is proportional to its frequency, and if it is used in a frequency modulator, the modulated wave that results is equivalent to a phase-modulated wave.

The modulation index in a phase-modulated wave is the ratio of the phase change of the modulated wave to the frequency of the modulating wave. From this it can be shown that, if the amplitude of the modulating wave is inversely proportional to its frequency, and is applied to a phase modulator, the modulated wave is a frequency-modulated wave. See FREQUENCY MODULATION, PHASE MODULATION.

MODULATION METER. Meter which indicates the instantaneous power level in a communications system. Such a meter is placed in shunt with the channel and is calibrated either in modulation percentage or in decibels.

MODULATION MONITOR. Device which permits the supervision of modulation in a sending system. It may be a MODULATION METER (q.v.) or an OSCILLOSCOPE (q.v.).

MODULATION PERCENTAGE. Number equal to one hundred times the MODULATION FACTOR (q.v.).

MODULATOR. Device having three pairs of terminals which produces a modulated wave from two other waves. In carrier-wave transmission, the carrier wave is applied to one pair of terminals, the modulating wave (representing, in carrier-wave transmission, the intelligence to be transmitted) to another; the modulated wave appears at the third pair of terminals. Used as a demodulator, the modulated wave is applied to one pair of terminals, the local oscillator wave to another (this oscillator having the same frequency and phase as the carrier wave in the modulated wave) and the modulating wave is extracted from the third pair of terminals.

Used for frequency-changing, the wave whose frequency is to be changed is applied to one pair of terminals, the output of the local oscillator to another and the waves of changed frequency appear at the third pair of terminals. The generalization describing a modulator as a "device with three pairs of terminals" covers all forms of modulators, whether they are for amplitude, frequency, phase or pulse modulation. See CARRIER WAVE, DEMODULATION, MODULATED WAVE, MODULATING WAVE, MODULATION.

MODULATOR ELECTRODE. In a cathode-ray tube, the electrode which controls the magnitude of the electron-beam current. If more than one such electrode is used, they are numbered consecutively outwards from the cathode. The electrode is sometimes referred to as a control electrode, but this term should be applied only in connexion with valves. See CATHODE-RAY TUBE.

MODULATOR VALVE. In a circuit for anode modulation, the final valve in the modulating-wave amplifier, the alternating anode potential of which is applied to the anode of the modulated amplifier. See ANODE MODULATOR.

MOLECULE. Smallest particle of an element or compound which can lead a separate existence. A molecule of a compound would, on subdivision, cease to have the same chemical properties because it would then be broken down into the dissimilar atoms from which the molecule was built up. The molecule of an element is, of course, made up of atoms of that element only.

MONITOR. Device for reproducing any kind of transmission or recording and which does not appreciably affect the transmission or recording. A monitor enables the quality of the transmission or recording to be checked and breakdowns to be rapidly detected. See MONITORING AMPLIFIER, MONITORING CIRCUIT.

MONITORING AMPLIFIER. In general, an amplifier forming part of a monitor; in particular, an amplifier which is connected across a telephone channel for monitoring purposes and which absorbs negligible power from the channel. See BRIDGING AMPLIFIER, MONITORING CIRCUIT.

MONITORING CIRCUIT. Any circuit used for checking the performance of a transmission system. The more reliable a communication system, the more valuable it is to its users. The maintainance of a service is greatly facilitated by the provision of measures to check the performance of an equipment while it is working. This checking is called monitoring.

There are two classifications of monitoring, the qualitative and the quantitative; in broadcasting, for example, one maintenance engineer may judge quality, background noise and so on, in a general way; while another is constantly checking the feed currents of valves, the actual or test levels on various points of the lines, the instantaneous modulation depth, and so forth. The former is a qualitative, the latter a quantitative, form of monitoring. Although checks and tests may be made when the system is not in service, this is classifiable as testing rather than monitoring.

Apart from broadcasting, all communication services are provided with monitoring circuits. It could also be said that other types of apparatus, such as the more complex types of measuring apparatus, are provided with monitoring circuits. Thus a panel may be provided to check voltages and feed currents; frequencies may also be checked to be sure the scales are reading correctly. Such processes may be described as monitoring, and the circuits employed, monitoring circuits. See BROADCASTING.

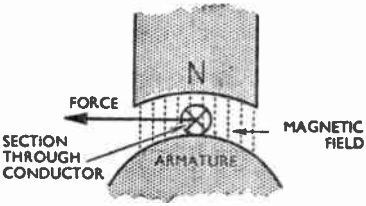


Fig. 36. When a conductor in a magnetic field carries current, it experiences a force which acts at right-angles to the axis of the conductor.

MONITORING RECEIVER. Receiver tuned to a radio sender so as to enable a maintenance engineer to check the quality of the transmission. See MONITORING CIRCUIT.

MONITOR VALVE. Valve used for monitoring purposes. See MONITORING CIRCUIT.

MORSE CODE. In signalling, the representation of letters and numerals in the form of dots and dashes, as follows:

A	·–	J	·–––	S	···	1	·––––
B	–···	K	–·–	T	–	2	··–––
C	–·–·	L	·–··	U	··–	3	···––
D	–··	M	––	V	···–	4	····–
E	·	N	–·	W	·––	5	·····
F	··–·	O	–––	X	–··–	6	–····
G	––·	P	·––·	Y	–·––	7	––···
H	····	Q	––·–	Z	––··	8	–––··
I	··	R	·–·	0	–––––	9	––––·

MORSE TELEGRAPHY. Transmission of intelligence by means of the Morse code.

MOSAIC. Name given to the photosensitive screen of the storage camera on which the image of the picture to be televised is focused. The mosaic consists of a mica plate on which there is a surface composed of minute, isolated globules. These are photo-sensitive and consist of caesium so deposited that each globule is insulated from the next.

On the side of the mica sheet remote from the caesium coating is a sheet of metal. There is, therefore, a very great number of minute photocells, each formed by a globule on the one side and the metal plate on the other side of the mica. The operation of the mosaic depends on the fact that each globule forms a small capacitor with respect to the back plate. When the image is focused on the mosaic, electrons are lost by photo-electric emission, the number of electrons so lost being dependent on the intensity of the light on the globule concerned, and on the length of time the light is applied to it.

Thus, each tiny capacitor charges up at a rate proportional to the intensity of the light, the globule becoming positively charged in regard to the metal plate.

The mosiac is scanned by a cathode-ray beam (see STORAGE CAMERA) which discharges the tiny capacitors. It should be noted that the current passing through the output load resistance is comparatively large, because the charge in each minute capacitor is proportional to the total photo-electric emission of each cell since the previous scanning.

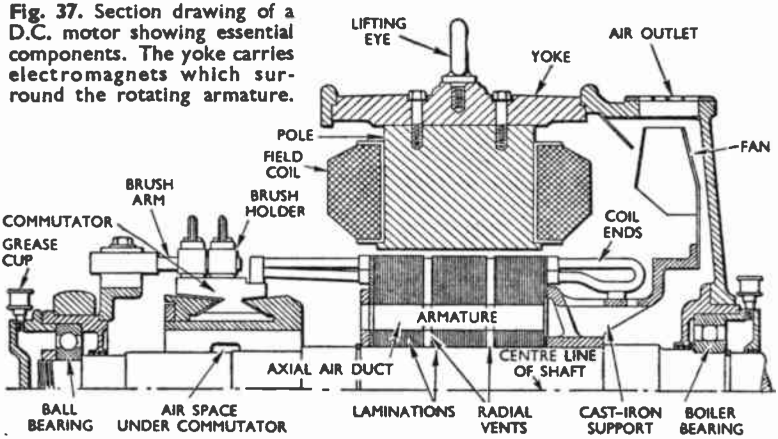


Fig. 37. Section drawing of a D.C. motor showing essential components. The yoke carries electromagnets which surround the rotating armature.

The total emission during the time of one picture frame (in the B.B.C. television system, one twenty-fifth of a second) is thus used, and not the emission during the instant the spot is being scanned. In other words, the mosaic is a storage device, and the output is dependent on the length of time between scans.

The output depends, also, upon the speed of the scanning beam, for the faster the movement of the beam, the less complete will be the discharge of each capacitor; and the less each capacitor is discharged, the less sensitive will it be to any change in light intensity. Thus, too rapid a scanning speed will cause insensitivity of the device and a general "flatness" or lack of contrast between the light and shade of the picture image.

MOSAIC ELECTRODE. Metal plate behind the mica sheet on which are deposited the caesium globules of the mosaic used in the storage camera. See MOSAIC, STORAGE CAMERA.

MOTOR. Machine for the continuous conversion of electric energy into mechanical energy. This conversion is made possible by the fact that a conductor carrying current in a magnetic field experiences a force which acts at right-angles to the axis of the conductor, as illustrated in Fig. 36. The force is proportional to the strength of the field, the current carried, and the length of conductor within the influence of the field.

The essential components of a *direct-current motor* are illustrated in Fig. 37. They consist of a stationary iron or steel yoke carrying electromagnets, and a rotating armature mounted on a shaft which is supported in bearings.

The armature, whose purpose it is to carry the magnetic flux across the large space between the poles and to support the current-carrying conductors, consists of a large number of soft-iron laminations which are lightly insulated from one another. These are keyed to the shaft and are firmly held between strong end plates. It will be seen from Fig. 37 that they are separated into three packets by ventilation spacers, and that axial holes are provided to carry air through the armature for the purpose of cooling it.

The armature windings, of copper strip or wire, are carried in slots on the outer periphery of the armature, and are held in position by steel wire binders; the outer ends are attached to a cast-iron support (which also carries the cooling fan) and the inner ends are connected to a commutator. This consists of a number of copper bars (one for each pair of armature conductors) which are insulated from one another by mica and are strongly clamped in position to withstand the centrifugal force caused by rotation at speed.

The commutator is connected to the electricity supply by means of carbon brushes which are carried by brush holders mounted upon brush arms.

A somewhat different construction of armature, which is used for large machines, is illustrated in Fig. 38. In this the laminations are carried on a cast-iron "spider" consisting of a central hub, which is keyed to the shaft, several radial arms and an outer rim to which the laminations are keyed.

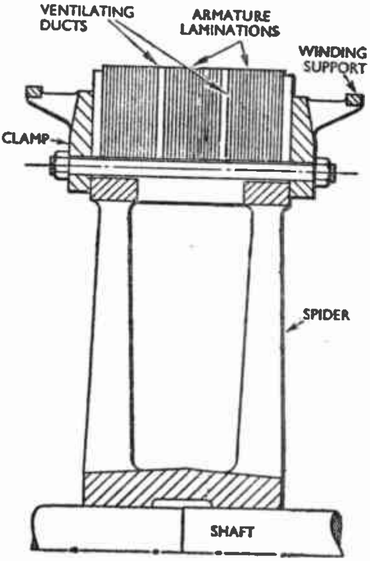


Fig. 38. The armature laminations of a large direct-current motor may be carried on the outer rim of a cast-iron "spider" which is keyed to the shaft.

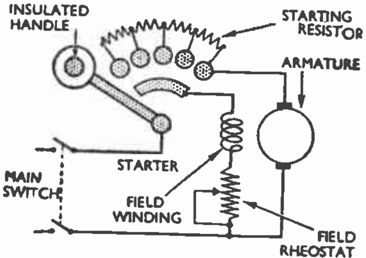


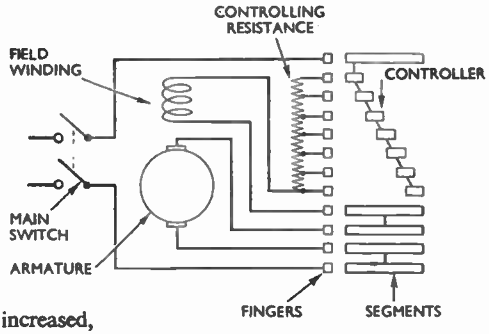
Fig. 39. Diagram of the connexions for a shunt-wound type of D.C. motor with the main switch and starter.

The windings of the field magnets may be connected in parallel with the armature so as to receive the full supply voltage, or they may be in series with the armature. In the former case, the coils consist of a large number of turns of fine wire and, in the latter, a few turns of heavy wire or strip. Sometimes both kinds of winding are used and the motor is then referred to as a compound machine.

To assist in the commutation, or reversal of current in a coil as its commutator bar passes under a brush, additional magnets carrying the armature currents are often arranged between the main poles. These are referred to as interpoles.

The speed characteristics of motors are dependent upon the methods of connecting the field, and the machines are classified as shunt-, series-, or compound-wound. The connexions of a shunt-wound machine, often abbreviated and referred to as shunt motor, are shown in Fig. 39. As the field winding is connected across the mains, the strength of the field is not affected by the load on the motor, except that a de-magnetizing effect

Fig. 40. Connexion diagram for a series-wound D.C. motor with main switch and controller.



caused by the current in the armature conductors has greater influence as the load increases. When unloaded, the motor runs at a fixed speed which depends upon the setting of the field rheostat and, as the load is increased, the speed falls to a slight extent.

The connexions for a series motor are shown in Fig. 40. In this machine the field current depends upon the load on the machine and, since the speed is inversely proportional to the field strength, the motor runs slowly on heavy load and faster on light loads. If the motor were run without any load, it would develop a dangerous speed and, therefore, this type is used only in cases where the load is always connected and where the change of speed with load is no disadvantage. The principal application is for traction purposes.

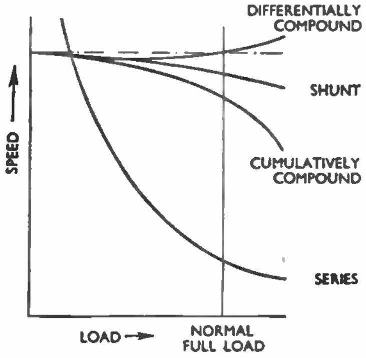


Fig. 41. Speed/load characteristics of the four types of D.C. motor.

In compound machines, the series winding can be arranged to assist or to oppose the shunt winding, and in the first instance, the "cumulatively" compounded machine, the speed falls as the load is increased. This characteristic is useful in cases where sudden heavy loads are likely to be applied as, if a flywheel is attached to the motor, this takes up some of the load as the motor speed falls, and absorbs energy again as the speed rises, thus relieving both the motor and the supply mains of heavy surges.

The "differentially" compounded machine may be used when constant speed is a desirable characteristic, because the amount of compounding can be arranged to compensate for the small drop in speed which occurs on a plain shunt motor as the load is increased (Fig. 41).

There are three main types of *alternating-current motor*, known respectively as synchronous motors, induction motors, and commutator motors; but numerous variations and combinations of these machines are used for different purposes. The synchronous motor, as its name implies, runs at a constant speed depending upon the frequency of the supply, while the induction motor runs at a little less than synchronous speed, the "slip," or difference between running speed and synchronous speed, increasing somewhat as the load is increased (see SYNCHRONOUS MOTOR).

The commutator motor is a variable-speed machine. One type, the series motor, has a speed characteristic similar to the D.C. series motor, while others have slightly drooping characteristics but may be adjusted in speed and can run above or below synchronous speed.

The induction motor is primarily a three-phase machine, although, by the use of special devices, satisfactory single-phase induction motors can also be produced. In large machines the rotor windings are insulated and the ends are taken to slip-rings by which means resistance may be inserted in the rotor circuit during starting. This resistance has the effect of reducing the amount of starting current drawn from the three-phase supply mains, and also of increasing the starting torque.

A cheaper construction is obtained by threading plain copper bars through holes in the rotor laminations and connecting up the ends to form what is known as a squirrel cage. This type of motor has a low starting torque and takes a heavy starting current from the mains.

MOTOR-BOATING. Slow self-oscillation of an amplifying system which produces a steady *pop-pop-pop-pop* sound from the loudspeaker. The sound may also be produced by the squegging, at a similar slow rate, of higher-frequency self-oscillation. See SQUEGGING OSCILLATOR.

MOTOR CONVERTER. Combination of wound-rotor induction motor and D.C. generator used to convert A.C. to D.C. and vice versa. Connexions are made between the induction-motor rotor winding and points in the D.C. armature winding.

Although the machine takes up more floor space than a rotary converter, it can be used without transformers and has certain other advantages, such as the following:

It can be started up simply as an induction motor without the special equipment required for this in the case of a rotary converter.

Voltage regulation on the D.C. side is obtained without the complicated provisions required with a rotary converter.

It has high efficiency and a good power factor.

Sparkless commutation is easily obtained as the frequency of the injected alternating current is low.

MOTOR GENERATOR. Simplest form of converting machinery, consisting of a motor and generator coupled together. This combination of machines can, obviously, be used for any converting purpose, for example, to obtain D.C. from an A.C. supply, or A.C. from a D.C. supply; to obtain high-voltage D.C. from a low-voltage D.C. supply, and also to change the frequency and voltage of an A.C. supply. This combination, however, takes up more space, and is more costly in most instances than certain machines designed especially for conversion. See DYNAMOTOR, MOTOR CONVERTER, ROTARY CONVERTER.

MOULLIN VOLTMETER. Valve voltmeter operating on the anode-bend principle (see VALVE VOLTMETER); the anode is connected to one end of the filament, the p.d. across which provides the H.T. supply.

MOVING-COIL INSTRUMENT. Electrical instrument, the action of which depends on the fact that a current-carrying coil, suitably placed in a magnetic field, will be caused to move, the force causing this movement being directly proportional to the current passing through the coil. See AMMETER, MEASURING INSTRUMENTS, MOVING-COIL LOUDSPEAKER, MOVING-COIL MICROPHONE.

MOVING-COIL LOUDSPEAKER. Loudspeaker in which the diaphragm is conical and attached to, and actuated by, a speech coil. The coil former surrounds the central limb of an E-shaped magnet, as shown in Fig. 42; application of speech currents to the coil causes it to be displaced in either direction along the axis of the centre limb. The frequency of alternation corresponds with that of the speech currents. Sound waves are produced by the cone vibrating at the same frequency as the coil which drives it.

The magnet may be permanent or energized. If energized, a separate coil is connected to a source of D.C. supply (sometimes the amplifier H.T.). The speech coil has a low impedance (2-20 ohms) and is connected to the driving valve via a matching transformer. The flexible edge of the cone is clamped around its periphery. In some types, the cone is corrugated to increase its flexibility.

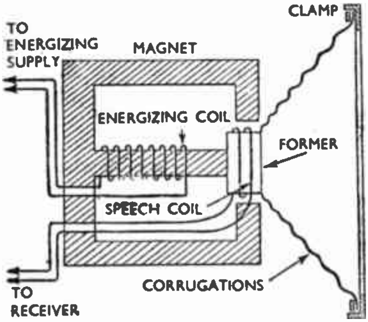


Fig. 42. Section diagram showing the principle of the moving-coil loudspeaker. Speech currents from the receiver pass through the speech coil which, situated in the field of the magnet, is horizontally displaced by electromagnetic action.

MOVING-COIL MICROPHONE. Microphone in which sound vibrations impinging upon its diaphragm cause a coil, wound on a former, as shown in Fig. 43, to move like a piston in the annular gap of a permanent magnet similar to but smaller than that of a moving-coil loudspeaker. The coil thus cuts the lines of force from the magnet and speech voltages are induced in the coil, the frequency and amplitude corresponding to the frequency and amplitude of diaphragm vibration.

MOVING-COIL PICK-UP. Pick-up used for reproducing gramophone records or direct-recorded discs and working on principles similar to those of the moving-coil microphone. The reproducing needle is attached to the coil former. When tracing the modulated groove, the vibrating needle imparts alternating movements to the coil, producing alternating voltages, the frequency of which corresponds with that of the modulated groove.

The instrument is delicate in construction, has low impedance and low sensitivity. In modern types frequency response is good and harmonic distortion low. See GRAMOPHONE PICK-UP, MOVING-COIL INSTRUMENT.

MOVING-IRON INSTRUMENT. Electrical instrument, the action of which depends on the force existing between a current-carrying ooil and magnetic material. See MEASURING INSTRUMENTS, MOVING-IRON LOUDSPEAKER, MOVING-IRON MICROPHONE.

MOVING-IRON LOUDSPEAKER. Loudspeaker in which the cone is attached to a soft-iron armature pivoted and placed, as shown in Fig. 44, in the magnetic field provided by a permanent magnet. Speech currents applied to the coil surrounding the armature cause the armature to vibrate at the frequency of the currents. These vibrations are imparted to the cone which sets up pressure variations producing sound waves.

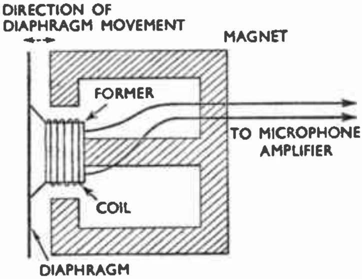


Fig. 43. Diagrammatic section through a moving-coil microphone. Sound waves impinging on the diaphragm cause the coil and former to move horizontally in the magnetic field; e.m.f.s are thus induced in the coil at the frequency of the sound wave.

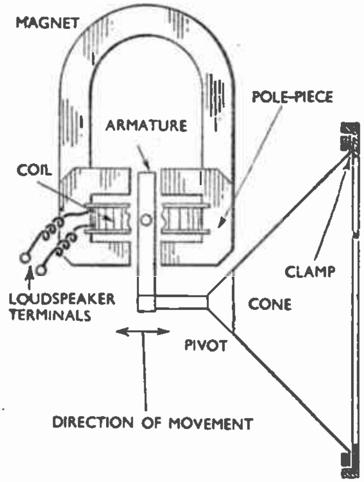


Fig. 44. Principle of the moving-iron loudspeaker. An armature is pivoted at the centre of a coil situated in the field of a magnet. Speech currents from receiver or amplifier cause the armature, and consequently the cone (attached to it by a rod), to vibrate and produce corresponding sound waves.

MOVING-IRON MICROPHONE. Microphone, the construction of which is on the same principle as that of the moving-iron loudspeaker (Fig. 44). When sound waves strike the diaphragm, it vibrates and the movement is communicated to the soft-iron armature, which oscillates at the frequency of the incident sound wave. In oscillating, the armature offers a low-reluctance path to magnetic flux between the soft-iron pole-pieces in the manner described under GRAMOPHONE PICK-UP. In cutting the many turns of the stationary coil ,surrounding the armature, this flux sets up alternating voltages in the coil, and these voltages, having the frequency of the initial sound wave, constitute the output of the microphone. See MICROPHONE.

MOVING-IRON PICK-UP. See GRAMOPHONE PICK-UP.

MU. Word representing μ, the Greek letter, which is used as a symbol for the amplification factor of a valve. Hence the term variable-mu valve. See AMPLIFICATION FACTOR, SYMBOLS, VARIABLE-MU VALVE.

M.U.F. Abbreviation for MAXIMUM USABLE FREQUENCY.

MULTI-CAVITY MAGNETRON. Magnetron with a solid cylindrical anode surrounding a cylindrical cathode; there are a number of symmetrically disposed cavities known as resonators, or RHUMBATRONS (q.v.), which are cut from the inner surface of the annular space between the anode and the cathode. The fields set up by the currents circulating in the resonators cause the electrons in the annular space between anode and cylindrical cathode to form a spoke-shaped concentration of electrons, which rotates like a wheel about the "axle" formed by the cathode. The electron concentrations maintain oscillations in the cavities or rhumbatrons, and these oscillations maintain the rotation of the spoke-shaped concentration. Thus the retroactive process that is, of course, essential to an oscillator is set up.

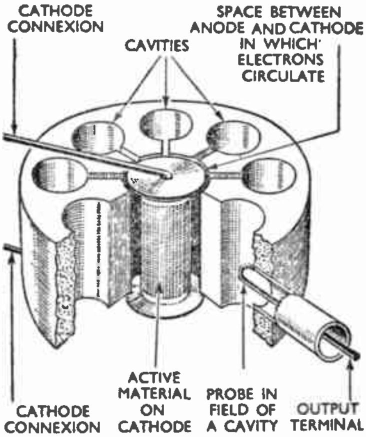


Fig. 45. Multi-cavity magnetron partly cut away to reveal internal details; the magnet is not shown. This magnetron is representative of the type used at frequencies of the order of 1,000 Mc/s.

The multi-cavity magnetron valve owes its inception to work carried out in Great Britain during the Second World War; it was further developed in America. The device is used in radar for the generation of centimetric waves. It is mainly used in sending pulses. Instantaneous pulse power of the order of 3 MW has been produced at wavelengths of 10 cm., and about 100 kW for waves of 1–2 cm. in length.

When used for producing pulses, the H.T. voltage may be as high as 40 kV. The time-length of the pulse is of the order of a microsecond and its frequency 1,000 c/s. The device may be tuned over a small range of frequencies by an adjusting screw. The average size of the valves handling instantaneously this astonishing amount of power is no bigger than a man's fist.

The basic features of the valve are shown in Fig. 45. The valve is essentially a diode and a MAGNETRON (q.v.). Under the influence of radial electric fields and axial magnetic fields, the electrons emitted by the axial cathode rotate around the cathode and are eventually collected by the anode. In passing the mouths of the cavities, the non-uniform conditions cause the majority of electrons to give up energy, so producing oscillations in the cavities. The fields consequently created around the mouths of the cavities tend to concentrate the electrons into "spokes" (Fig. 46). This concentration rotates around the cathode and causes the oscillations to be maintained.

Cathodes are of special construction and are indirectly heated. The cylindrical nickel cathode may be covered with a pure nickel powder which is mixed with the active material and sintered on to the cylinder. The instantaneous-emission current may be of the order of thousands of amperes. See OSCILLATOR, RADAR.

MULTI-CHANNEL SYSTEM. In television, a system of transmission in which the required frequency spectrum is split up into a number of separate bands by means of frequency-discriminating networks, each band being transmitted over a separate system. At the receiver, the bands are combined to cover the whole spectrum, producing a complete picture.

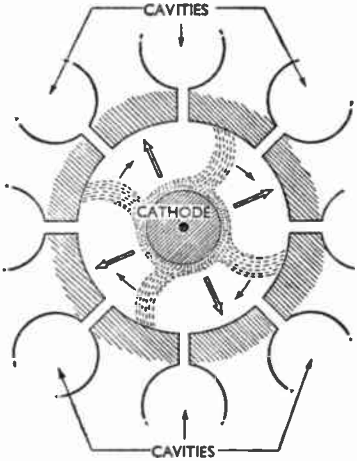


Fig. 46. Plan view of a multi-cavity magnetron; the spoke-like electron concentration, rotating in the space between anode and cathode, is maintained by the radial electric field (broad arrows) and axial magnetic field.

MULTI-CHANNEL TELEGRAPHY. Employment of a dozen or more voice-frequency telegraph channels over a single audio-frequency system, each channel working on a selected frequency band.

MULTI-FREQUENCY GENERATOR. Synchronous alternating-current generator designed for operation at more than one frequency. Since the frequency depends upon the speed of rotation and the number of poles, variation in either of these varies the frequency.

MULTI-LAYER WINDING. Method of winding a coil, usually on a cylindrical or rectangular former, in which the turns of wire are laid side by side to form a single layer of close turns on which is wound a second layer, and so on. This type of winding is simple and straightforward, but it produces a coil of high self-capacitance. Its use is limited to carrier-, audio- and power-frequency inductors and transformers.

Sometimes a layer of paper is interposed between the layers of wire, either for the purpose of making the coil self-supporting, or to reduce the capacitance between layers (as is necessary in some carrier- and audio-frequency applications), or to improve the insulation (in power transformers). See WAVE-WINDING.

MULTI-MU VALVE. Synonym for VARIABLE-MU VALVE.

MULTIPHASE. Synonym for POLYPHASE.

MULTIPLE RECEPTION. System of simultaneous reception of several sets of signals on equipment in which some major item serves a common purpose. An example is the use of one aerial to provide the input to two or more receivers.

MULTIPLE SCANNING. In a television system, the repeated scanning of the scene to be transmitted by two or more beams. See SCANNING.

MULTIPLE-SPARK SYSTEM. In radio telegraphy, a quenched spark system in which the spark-gap consists of a number of closely spaced metal plates. See QUENCHED SPARK-GAP, QUENCHED SPARK SYSTEM.

MULTIPLE-TUNED AERIAL. Aerial tuned section-by-section, each section connected to earth through a separate tuned circuit, normally consisting of a fixed inductor and variable capacitor. The type is sometimes used for the lower frequencies.

MULTIPLE-TWIN CABLE. Group of four wires consisting of two twisted pairs, the two pairs being twisted over each other. Multiple-twin cable is used in quadripole circuits. See QUADRIPOLE.

MULTIPLE VALVE. Term which may be used to describe a valve with separate electrode structures all enclosed in one bulb. In a multiple valve, these electrodes are used simultaneously for different functions. Examples of multiple valves, which are much better described by these more exact terms, are the triode-hexode frequency-changer and the double-diode-triode. See FREQUENCY-CHANGER VALVE.

MULTIPLE-WAY SYSTEM. Telegraph system in which two or more messages are sent over the same wire simultaneously, either where each way has whole-time connexion to the line, or where each way is allocated exclusive use of the line in rapid succession. See DUPLEX SYSTEM, MULTIPLEX SYSTEM.

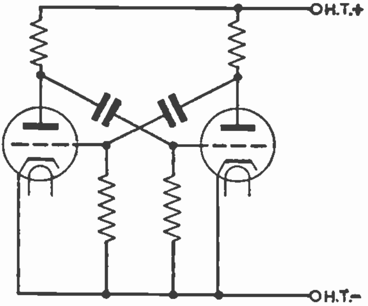


Fig. 47. Elementary form of multivibrator using a resistance-capacitance-coupled amplifier.

MULTIPLEX SYSTEM. Multiple-way system of telegraphy in which two or more messages are sent over the same wire simultaneously by allocating the exclusive use of the line to each way in rapid succession. See MULTIPLE-WAY SYSTEM.

MULTIPLIER. See FREQUENCY-MULTIPLIER.

MULTI-POLE SWITCH. Switch for simultaneously making or breaking two or more separate paths of a circuit. The term "double-pole" or "triple-pole" may also be used. See SWITCH.

MULTI-SPARK SYSTEM. In radio telegraphy, any spark system in which more than one discharge occurs across the gap for each discharge of the capacitor. See SPARK FREQUENCY, SPARK SENDER.

MULTIVIBRATOR. Arrangement of valves, usually a resistance-capacitance-coupled amplifier, in which the output is connected to the input to provide positive feedback; it is sometimes referred to as a flip-flop arrangement. The circuit generates relaxation oscillations the frequency of which readily takes the value of any stable drive connected to the input.

The output comprises a wave containing many components with frequencies equal to whole-number multiples of the lowest frequency. If a wave of frequency f is applied to certain terminals of the multivibrator, the output contains waves of frequency

$n_1f, n_2f, n_3f \ldots$ and of $\frac{1}{n_1}\cdot f, \frac{1}{n_2}\cdot f, \frac{1}{n_3}\cdot f \ldots$, n_1, n_2 and n_3 being whole numbers. The multivibrator can thus be used as a frequency-multiplier or a frequency-divider.

The multivibrator is shown in its elementary form in Fig. 47. The amplifier is of the resistance-capacitance type and the anode of the output valve is coupled to the grid of the input valve. The output waves contain harmonic waves in great profusion. Fig. 48 indicates how a wave from an outside source may be used to control the oscillations of the multivibrator. In this case, the output from the multivibrator contains waves that have both n times and $\frac{1}{n}$ times the frequency of the applied wave.

The maximum frequency of the wave produced by a multivibrator of the resistance-capacitance type is of the order of 100 kc/s, but other types using tuned circuits and frequency-changer valves can be used at very high frequencies. See FREQUENCY DIVISION, FREQUENCY MEASUREMENT, FREQUENCY MULTIPLICATION.

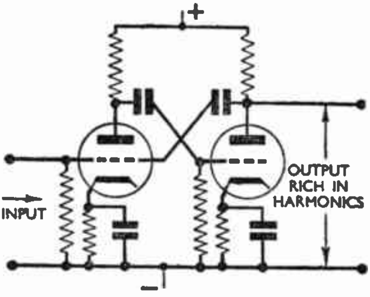


Fig. 48. Circuit for the application of waves from an outside source to control oscillations of the multivibrator.

MULTI-WAY SWITCH. Switch for selectively connecting two or more alternative current paths. See SWITCH.

MUSA RECEIVER. Receiver employing a *M*ultiple-*U*nit *S*teerable *A*ntenna, a form of aerial constructed in unit form and capable of rotation. The effect is to change the total polar diagram of the system, by changing the relative phases of the individual sections of the diagram produced by the separate elements.

MUSICAL SPARK SYSTEM. Synonym for SINGING SPARK SYSTEM.

MUTUAL-CAPACITANCE ATTENUATOR. Type of variable attenuator in which energy is transferred from input to output by way of a series capacitor consisting of a fixed and a movable plate, the distance between which can be varied to control the output. Fig. 49 illustrates a mutual-capacitance attenuator of the type sometimes used to control the output of a signal generator.

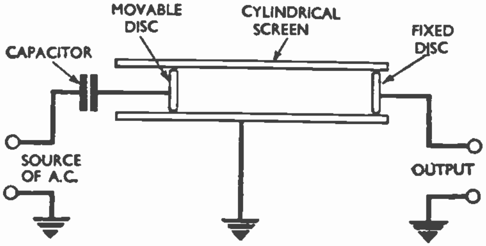


Fig. 49. Diagram showing the principle of a mutual-capacitance attenuator.

MUTUAL CONDUCTANCE. Ratio of a small change of anode current to the small change of control-grid voltage producing it, the anode voltage remaining constant. Mutual conductance is one of the three important and related parameters of a hard-vacuum valve, the other two being anode slope-resistance and amplification factor. Fig. 50 shows a typical grid-volts/anode-current characteristic of a valve and, inset, a circuit which can be used to plot the graph experimentally. At some point in the graph, such as P, the negative grid volts are E_g, and the resulting anode current, I_a. Suppose E_g to be given a greater negative value by a small amount, ΔE_g (ΔE_g being very small compared with E_g).

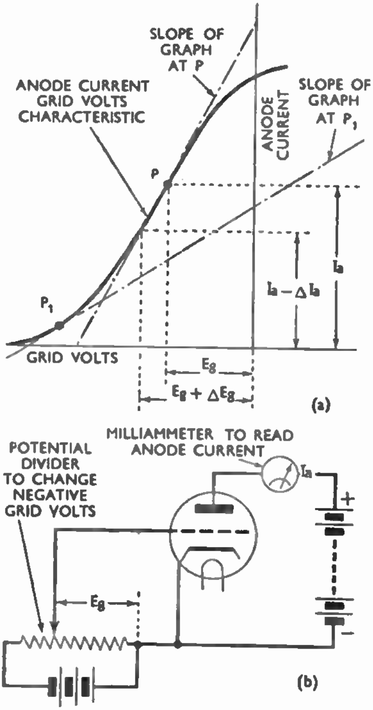


Fig. 50. Grid-volts/anode-current characteristic (*a*) plotted experimentally by using the circuit shown at (*b*). The mutual conductance of the valve at, for example, points *P* and *P*₁ respectively may be calculated from the slope of the graph at those points.

The negative grid volts are now $E_g + \Delta E_g$. The anode current is decreased by an amount ΔI_a, and becomes $I_a - \Delta I_a$. Mutual conductance is given by dividing ΔI_a by ΔE_g.

The reason for making small changes is that there may not be a linear relationship between I_a and E_g. Fig. 50 shows a graph of a non-linear relationship. Considering the point P_1, then by making ΔE_g, and consequently ΔI_a, infinitesimally small, the ratio of the two quantities is still finite and measures the slope of the curve at the point P_1. The slope varies with E_g. Thus, in specifying mutual conductance, the values of the anode current, grid voltage and anode voltage must be stated, since mutual conductance changes with these.

The ratio is a conductance, that is, the inverse of a resistance, since it is a current divided by a voltage (see OHM'S LAW). It is usually expressed as so many milliamperes per volt. This is a measure of the slope of the grid-volts/anode-current characteristic at a point. Mutual conductance can be expressed in mhos or millimhos.

The relationship between mutual conductance, g_m, anode slope resistance, r_a, and amplification factor, μ, is that $\mu = g_m r_a$, or $g_m = \frac{\mu}{r_a}$. Thus, for a given mutual conductance, the amplification factor can be increased if the slope resistance is equally increased. The value of g_m may be the same for either triode or pentode, but μ and r_a are both much greater in a pentode than in a triode. See AMPLIFICATION FACTOR, ANODE SLOPE-RESISTANCE, GRID-VOLTS/ANODE-CURRENT CHARACTERISTIC, SLOPE RESISTANCE, VOLTAGE FACTOR.

MUTUAL COUPLING. Synonym for TRANSFORMER COUPLING.

MUTUAL IMPEDANCE. Synonym for TRANSFER IMPEDANCE.

MUTUAL INDUCTANCE. Property of two circuits which causes the phenomenon of mutual induction. Mutual inductance is proportional to the rate at which the magnetic field of force through one of the circuits changes when the current in the other circuit is varying; it is a measure of what (in radio) is commonly called the magnetic coupling between the circuits.

MUTUAL-INDUCTANCE COUPLING. Synonym, occasionally employed, for INDUCTIVE COUPLING.

MUTUAL INDUCTION. Process in which an increase or decrease in the current conditions in an inductor causes a corresponding change in the magnetic field of force which is cutting through another inductor and so induces a voltage in the latter. The process is one of electromagnetic induction between two adjacent inductors. See ELECTROMAGNETIC INDUCTION.

MYRIAMETRIC WAVE. Electromagnetic wave having a wavelength greater than 10,000 metres; i.e., having a frequency less than 30 kc/s.

N

NARROW-BAND AMPLIFIER. Apparatus designed to respond only to a limited frequency range; for example, an intermediate-frequency amplifier having extremely sharp-peaked resonances in its inter-valve couplings, such as might be used for radiocommunication purposes.

NATURAL FREQUENCY. Frequency at which an aerial or other oscillatory circuit will ring when excited by a momentary impulse. The term also implies the *lowest* frequency at which an aerial will oscillate freely. See FREE OSCILLATIONS, OSCILLATORY DISCHARGE, RINGING.

NATURAL MODE. Method of oscillation in which an aerial or other oscillatory device resonates at its natural frequency rather than at some harmonic thereof.

NATURAL OSCILLATIONS. See FREE OSCILLATIONS.

NATURAL WAVELENGTH. Wavelength equivalent to the NATURAL FREQUENCY (q.v.).

NAVIGATIONAL AID. Radio and radar device which enables an aircraft or a ship to fix its position or to make an accurate approach to a particular spot. Of the position-fixing methods, one of the earliest and most easily understood involves the use of direction-finding stations. If two such stations accurately determine the direction from which they receive signals sent from a ship or aircraft, the position of the sender can easily be fixed. Two lines drawn upon a chart, starting from each of the direction-finding (D.F.) stations and running in the measured direction, intersect at the required spot (Fig. 1). Altern-

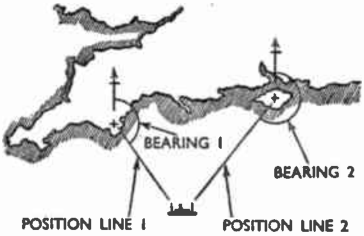


Fig. 1. Old-established form of navigational aid in which the position of a ship or aircraft can be fixed if two direction-finding stations measure the bearings on which they receive its signals. Each station thus produces a position line, the point of intersection of the lines providing a "fix."

atively, the process can be reversed; the bearings of two distant senders of known position can be determined at the craft itself and its position can be established from charts.

The former method is still widely used. It has the advantage that the ship or aircraft can make use of its normal communication apparatus to obtain bearings, but the degree of accuracy is less than that of some of the later systems; an additional disadvantage is that, if the shore stations are to measure the bearings, the craft must risk giving away its position to an enemy in time of war. If the craft is to determine its position by its own gear, this must be of specialized type as the normal communications apparatus is unsuitable.

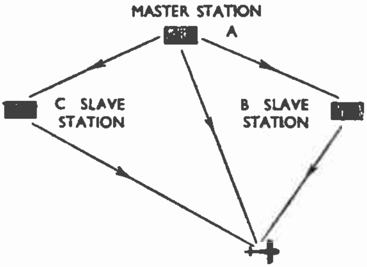


Fig. 2. Elements of a Gee system. The pulses originate from the master station, travelling direct to aircraft or ship; the pulses are also picked up by the slave stations, each of which, after an accurately measured time-delay, sends out its own pulses.

Of the later systems, Gee is one of the most accurate. Gee enables positions to be determined to within a few hundred yards under favourable conditions. Introduced by the R.A.F. during the Second World War, this ground-based system does not require the aircraft or ship to send signals or communicate with the ground stations. A skilled navigator can fix his position in under a minute.

Gee employs a technique akin to that of radar. A chain of suitably spaced stations emits short pulses of energy, and the relative time-intervals between the arrival at the craft of the pulses from the various stations is measured at the distant point (Fig. 2). These intervals indicate the difference in length of the paths by which the pulses have travelled to the receiver. For example, if the pulse from Station *B* arrives 20 microseconds later than that from Station *A*, it must have travelled 6 km. farther. It is assumed that both pulses started at the same instant, and that the velocity of the waves is 300,000 km/s.

In practice, the pulses do not start at precisely the same instant, but the initial time-interval is known and the principle is thus unaffected. If a series of such points are drawn and connected, the resultant line is then a hyperbola representing the loci of a point of constant difference in distance from Stations *A* and *B*.

The navigator of the craft knows that, at all points along such a line, Station *B* is 6 km. farther away than Station *A*. This does not, in itself, constitute a "fix"; but if the navigator now measures the arrival-interval of a pair of pulses from Station *A* and another Station *C*, he will be able to get a fix, because this second measurement will place him on another position line intersecting the first; the point of intersection representing his position.

In practice, no calculations are

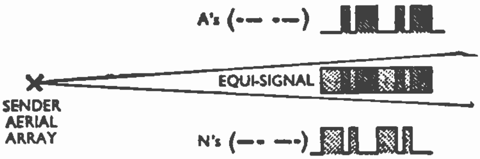


Fig. 3. Directional beam made up of keyed A and N signals in Morse code. When travelling along the centre line of the beam, the combined signal is received as a single continuous note.

required. The navigator measures the time intervals on a cathode-ray tube, electronically calibrated in special units, then turns to his Gee chart—an ordinary Admiralty chart overprinted with the Gee "lattice"—to locate the appropriate pair of lines, and notes their point of intersection.

Identical in general principle, the American system Loran is also widely used. Gee works on frequencies between 20–80 Mc/s and gives high accuracy over distances limited to optical ranges of the order of 150–200 miles for an aircraft at medium height; Loran uses lower frequencies of about 2 Mc/s and gives somewhat lower accuracy but increased range, especially at night.

Still lower frequencies, and continuous instead of pulsed radiation, characterize the Decca Navigator system. The working principle here depends on the fact that the waves from two senders working on rigidly controlled frequencies (identical, or bearing a simple arithmetical ratio to each other) set up in space a fixed phase-pattern which can be detected by a suitable receiver.

The receiver of the Decca Navigator installation detects these variations in the phase-pattern as it is borne through them on ship or aircraft, and displays the resulting navigational data by means of moving pointers on calibrated dials. Readings can be taken almost at a glance, and it only remains for the navigator to apply the figures to the Decca chart to obtain his position.

Radio systems enabling an aircraft to fly along a line, usually that of direct approach to its destination, commonly take the form of a composite beam. In such a beam the narrow central zone, along which the pilot should fly, gives a characteristic sound in his telephone receivers, while if he deviates to one side or the other he hears a different signal which tells him whether he has strayed to port or starboard. It is customary so to key the signals that a Morse letter A (· –) is heard to one side of the beam and an N (– ·) to the other. In the centre of the beam the two signals overlap to give a steady note (Fig. 3).

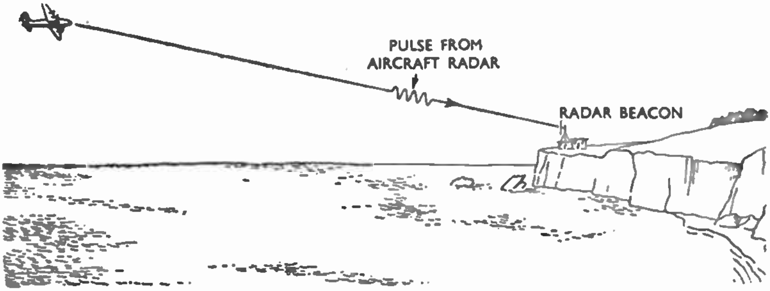


Fig. 4. Navigational aid employing radar. When the beacon is triggered by a pulse from the aircraft's radar gear, it emits a pulse in return, enabling the navigator to determine the range as well as the direction of the beacon.

These systems, of which there are many forms, have the advantage that the pilot himself can operate them, and that only the ordinary communications receiver is required. They suffer, on the other hand, from the fact that they cover a single route per beam, and that a pilot who deviates from the fixed route, possibly to avoid a storm, receives no further help unless he wastes time getting back into the beam.

Radio beacons form a separate class of navigational aid, some giving only a direction and some a position. The former type, sometimes called a radio lighthouse, in its simple form, employs a rotating beam and radiates a different characteristic signal every few degrees of sweep. By noting which of these signals is the loudest, the navigator can decide his bearing from the beacon. If he can repeat the process on another beacon, he can obviously get an actual fix. The range of most radio beacons is quite short; but a system called consol, similar to the radio lighthouse, has a range of some hundreds of miles, and gives a definite and accurate fix.

The later type of radar beacon enables the navigator to find his distance from the device, as well as to direct his ship or aircraft towards it. In effect, therefore, it gives him an approximate fix, as well as permitting homing on to the beacon. For this purpose a form of radar equipment is used by the craft, the impact of each pulse from the craft causing the beacon to emit a pulse in reply. The radar equipment then determines the range in the usual manner, and indicates when the aircraft is heading straight for the beacon (Fig. 4).

The type of radar device originally known as H_2S., and subsequently made in a variety of forms, can be regarded as a navigational aid, because in effect it gives a view of the ship's or aircraft's surroundings to greater distances than the eye can cover, and continues to do so at night or in fog. See BEACON DIRECTION-FINDER, BEAM, CATHODE-RAY TUBE, DIRECTION-FINDER, HOMING SYSTEM, PHASE, RADAR.

NEEDLE-ARMATURE PICK-UP. See GRAMOPHONE PICK-UP.

NEGATIVE. Condition of being charged with electrons, of being more highly charged with electrons than some reference point, or of being at a lower electrical potential than some other point in a circuit.

NEGATIVE CONDUCTANCE. Property which causes current to decrease when voltage increases. The term is the reciprocal of negative resistance. A device possessing negative conductance is capable of maintaining oscillations in a tuned circuit to which it is connected. See DYNATRON.

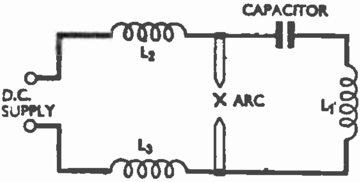


Fig. 5. Example of a device having the property of negative resistance; known as the singing arc, it has often been used in the past to maintain the oscillations in a tuned circuit.

NEGATIVE ELECTRON. See ELECTRON.

NEGATIVE FEEDBACK. Interconnexion of the input and output terminals of an amplifier in such a way that the output signal opposes the input signal in phase. This results in a decrease in apparent amplification but an improvement in linearity. See CURRENT FEEDBACK, NEUTRALIZATION, VOLTAGE FEEDBACK.

NEGATIVE-FEEDBACK AMPLIFIER. Amplifier in which a considerable part of the inherent gain is sacrificed, by negative feedback, in order to improve fidelity of reproduction, stability of gain, and so forth. See NEGATIVE FEEDBACK, STABILIZED-FEEDBACK AMPLIFIER.

NEGATIVE IMAGE. Television image in which the light portions of the original scene are dark, and the dark parts light. It is produced when a picture is received under conditions of reversed phase. Instead of the cathode-ray tube being modulated correctly so that light parts of the original picture cause increase of brilliance, the lighter portions produce less brilliance, and vice versa. Positive voltage modulation has been replaced by negative modulation so that the received picture looks like the negative of an ordinary photograph instead of the positive.

This can be caused in the receiver by

using incorrect connexions to the cathode-ray tube or the wrong number of vision-frequency amplifier stages, for each stage brings about a reversal of phase, except in the case of cathode followers.

NEGATIVE PHASE-SEQUENCE. Non-standard sequence of phases in a three-phase A.C. system (in the standard system, the phases reach their successive maximum values in the order: red, yellow, blue).

NEGATIVE PLATE. Plate of a secondary cell having a potential which is negative with respect to the other electrode of such a cell. See POSITIVE PLATE, VOLTAIC CELL.

NEGATIVE RESISTANCE. Property which causes current to decrease when the applied voltage increases. It is possessed by some forms of gas discharge, the carbon arc, and by some types of thermionic tubes. Some of the earliest radio senders of continuous waves employed the arc as a generator; any negative-resistance device is potentially capable of maintaining oscillations in a tuned circuit connected to it, and the singing arc was once widely used for the purpose (Fig. 5).

NEGATIVE SHIELD. Electrode forming part of the electron gun of a cathode-ray tube. It is often in the shape of a hollow cylinder concentric with the cathode. The electron beam passes along the axis of the cylinder and, by giving the latter a suitable bias negative with respect to the cathode, the density of the electron stream, and hence the mean brightness of the trace on the screen, may be controlled.

The function of the negative shield may thus be compared with that of the control grid of a valve. The negative shield was originally known as the Wehnelt cylinder and is also referred to as the grid or the modulating electrode.

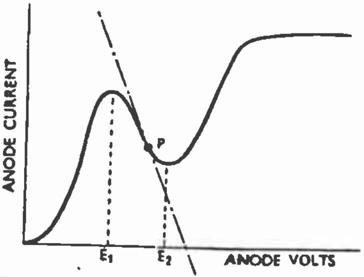


Fig. 6. Graph illustrating the shape of the anode-volts/anode-current characteristic of a tetrode when secondary emission takes place at the anode. At P, and regions between E_1 and E_2, the slope of the graph is negative, indicating a negative slope-resistance.

NEGATIVE SLOPE-RESISTANCE. Slope resistance of a conductor when an increase of voltage acting across the conductor produces a decrease of current (Fig. 6). See NEGATIVE RESISTANCE, SLOPE RESISTANCE.

NEGATIVE TRANSCONDUCTANCE. Transconductance in which positive increase in an electrode voltage produces a reduction in the electrode current of another electrode. See DYNATRON, KINKLESS TETRODE, TRANSCONDUCTANCE.

NEGATIVE TRANSMISSION. In television, a system of transmission in which the carrier-wave amplitude is inversely proportional to the instantaneous light values of the scene being televised.

NEGATIVE VIDEO SIGNAL. Vision signal whose peak voltage is negative instead of positive. Such a signal brings about a negative picture when applied between cathode and modulator of the cathode-ray tube. It is essential that all vision signals, except the synchronizing signals, shall be positive in respect to their zero. In this connexion, it must be realized that the signal applied to the modulator of the cathode-ray tube is D.C.-restored (see VISION MODULATION).

NEGATRON. Valve (other than a tetrode) designed to give a negative-resistance characteristic. Fig. 7 shows the principle of the negatron. There are two anodes; the current in anode 1 is determined by the control-grid poten-

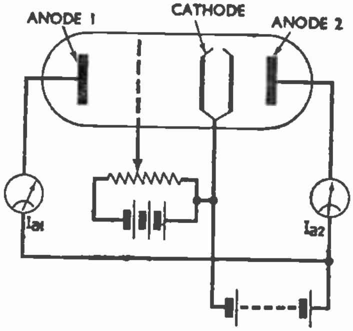


Fig. 7. Circuit of a negatron. As the grid is made more positive in respect of the cathode, I_{a1} increases but I_{a2} decreases; as the grid is made more negative the current changes are reversed.

tial in the sense that, as this grid is more positive, so the anode-1 current increases. But it is also arranged that, as the current to anode 1 increases, it takes electrons from the stream flowing to anode 2. As the grid is made more positive, so the anode-2 current decreases. Thus a negative mutual conductance is established between control grid and one of the anodes. See NEGATIVE RESISTANCE, NEGATIVE SLOPE-RESISTANCE, NEGATIVE TRANSCONDUCTANCE.

NEON GLOW-TUBE. Glow-tube in which the gas is neon. See GLOW-TUBE.

NEON TUBE. See NEON GLOW-TUBE.

NEON TUNING-INDICATOR. Neon glow-tube used to indicate relative amplitude of radio-frequency voltages in a circuit. By observing the brightness of the glow the lamp can be used to determine the location of a tuning point. It is often employed in tuning a sender.

NEON VALVE. See NEON GLOW-TUBE.

NEPER. Natural logarithm of the ratio of two currents. The neper, unlike the bel and decibel, is a unit which is not concerned with power; it simply compares two currents regardless of the resistances of the circuits in which the currents flow. When the two resistances are equal, and when the decibel may therefore be used to express their ratio, the value of nepers and decibels may be related. In such circumstances, it can be shown that there are 8·68 decibels to the neper. See BEL, DECIBEL.

NETWORK. Assembly of components, such as resistors, inductors, capacitors or rectifiers, connected together in any way. The term is general; but from this general conception come certain other, more precise, terms: a *linear* network, for instance, is one in which the network constants have the same value, regardless of the current passing through them; thus, a network containing a rectifier is not a linear network. Again, a *passive* network is one which has no sources of energy in it; a network containing valve amplifiers is not, therefore, a passive network.

There are *two-terminal* and *four-terminal* networks. A four-terminal network may be considered as having one pair of input terminals and one pair of output terminals. The two-terminal network is more a theoretical conception than a reality, because in nearly all cases it can be seen to be a four-terminal network. A *quadripole* is a four-terminal network having two pairs of terminals; it may be balanced or unbalanced, symmetrical or asymmetrical. The term "network" has a very wide meaning, and is useful in analysing or explaining transmission in its several aspects.

See C-NETWORK, H-NETWORK, L-NETWORK, LATTICE NETWORK, LINEAR NETWORK, O-NETWORK, PASSIVE NETWORK, PI (π)-NETWORK, QUADRIPOLE, T-NETWORK.

NETWORK BRANCH. Junction in a network where currents can divide. See NETWORK.

NETWORK CONSTANT. See NETWORK PARAMETER.

NETWORK PARAMETER. Element of a network, defined by its character and its magnitude. Thus a network parameter might be described, when its character was in question, as "inductance," or as an inductor when the physical component was meant. A network parameter may be called a network constant. See NETWORK.

NEUTRAL. Fourth wire of a three-phase transmission system. It carries no current if the loads on the three phases are balanced. See MAINS.

NEUTRALIZATION. Method of stabilizing a triode radio-frequency amplifier by means of negative feedback to balance the positive feedback through the anode/grid capacitances of the valves. Special methods of stabilizing became necessary as soon as the design of triodes began to yield reasonably steep slopes; such valves were normally unstable when they were used with efficient, low-loss tuned circuits, and their full gain could not be exploited unless some special device was used to prevent self-oscillation.

Numerous methods were devised for neutralizing the energy fed back through the inter-electrode capacitances of the valve; one of the simplest and most effective was to couple a small pick-up winding to the tuning inductor of the anode circuit and feed the small voltages therefrom through a variable capacitor to the grid. Fig. 8 shows two of the common systems.

Neutralizing became unnecessary in receiver circuits with the introduction of valves having inter-electrode screens (see PENTODE, TETRODE), but it is still used in high-power senders where triodes are employed as power-amplifier valves. See BRIDGE NEUTRALIZING, POWER AMPLIFIER.

NEUTRAL POINT. In a three-phase power-distribution system, the terminal of a star transformer which is at a constant (usually zero) potential. In a D.C. machine, in which the potential of one terminal is raised and of the other lowered in respect of earth, the neutral point is the mean potential. This is usually zero. See EARTH, EARTHY.

NEUTRAL RELAY. Polarized telegraph relay constructed or adjusted so that, in the de-energized condition, the contact-bearing armature normally lies in a central position between, and not touching, the two fixed contacts. The passage of a current through the controlling winding causes the armature to move towards one or other of the contacts according to the direction of the current. See ELECTROMAGNETIC RELAY.

NEUTRODYNE. Particular form of neutralizing circuit developed by the American pioneer, Hazeltine. See NEUTRALIZATION.

NEUTRON. Neutral particle (one without electrical charge) of the same mass as a proton. The neutron is postulated as one of the constituent particles of the atomic nucleus.

NEUTROSONIC RECEIVER. Special type of superheterodyne receiver, now obsolete, in which neutralized triodes were used as intermediate-frequency amplifiers. This arrangement enabled somewhat higher gain to be got from the I.F. stages. It has been superseded by amplifiers using screened-grid valves. See NEUTRODYNE.

NIGHT EFFECT. See NIGHT ERROR.

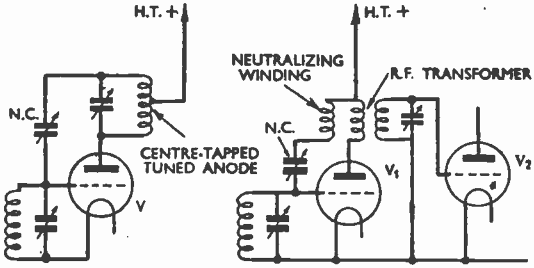


Fig. 8. Two of the many ways of neutralizing a triode R.F.-amplifying stage, *N.C.* being the neutralizing capacitor in each case. This provides sufficient negative feedback to balance the positive feedback occurring through the anode/grid capacitance.

NIGHT ERROR. Polarization error in loop direction-finders which may be apparent at any time, but is most prominent at night. The bearings obtained from a vertical loop direction-finder rotated about a vertical axis will be correct if the radio-waves are vertically polarized. Should there be a horizontally polarized down-coming component present in the wave, the horizontal members of the loop will have voltages induced in them; thus zero output voltage is not obtained when the plane of the loop is perpendicular to the bearing of the wave. A vertically polarized downcoming wave produces the same effect as any other vertically polarized wave and so causes no trouble.

It is therefore apparent that difficulty will be encountered if direction-finding is attempted where the ionospheric ray is present as well as the ground ray. Ionospheric rays are almost invariably elliptically or circularly polarized, and as such must have a horizontal component. When the wave possesses both a vertically polarized and a horizontally polarized component, the result is either that the loop indicates an erroneous bearing, or that it is impossible to obtain a zero response for any loop position.

Near a sending station, the ionospheric rays are weak or non-existent on all frequencies, and reliable bearings can be obtained. On low and medium frequencies, the ionospheric ray, although weak during the day, becomes important at night and forms a large percentage of the signal received; the reliable range may be as small as 25 miles. In the received signal, it is the ratio of the intensity of the ionospheric ray to the ground ray which determines the liability to error, since this is greater at night for the usual direction-finding frequencies and distances. The name "night error" was given to this phenomenon. Bearing errors may, on occasions, be as high as 30 deg.

The Adcock direction-finder aims at reducing night errors by removing the top horizontal sides of the loop, and by screening the lower horizontal leads to the receiver, so that no voltages can be induced in the horizontal members. This type of direction-finder can therefore be used on high frequencies at long range where reception is solely by means of the ionospheric ray. See ADCOCK DIRECTION-FINDER, DIRECTION-FINDING, IONOSPHERIC RAY, LOOP DIRECTION-FINDER, POLARIZATION.

NIPKOW DISC. Simplest form of mechanical scanner for television. It is a disc perforated with a number of holes and was invented by Nipkow in the latter part of the nineteenth century. See DISC SCANNER.

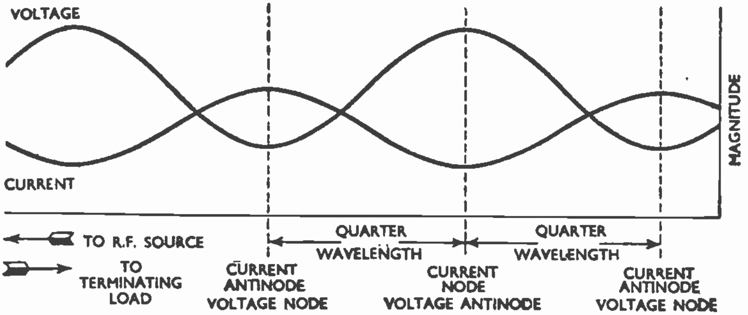


Fig. 9. Current and voltage distribution along a transmission line with mismatched termination when zero attenuation is assumed; current antinodes coincide with voltage nodes, and current nodes with voltage antinodes.

NODAL POINT. Synonym for node. See NODES AND ANTINODES.

NODE. Any point, in a system having a non-uniform distribution of current (or voltage), at which the current (or voltage) has minimum r.m.s. value. See NODES AND ANTINODES.

NODES AND ANTINODES. Points, in a system having non-uniform distribution of current (or voltage), at which the current has minimum and maximum r.m.s. values respectively.

Suppose a source of radio-frequency power is connected to a distant load by means of a transmission line. If the load is matched to the line, the energy, which is conveyed to the load in the form of current and voltage waves, is absorbed by the load. At any point in the line the current and voltage are in phase with each other and, if the line were loss-free, the values of current and voltage would be constant all along the line.

In practice, a transmission line must have some loss, and there must be some decrease in the magnitudes of the current and voltage as the waves travel along the line. In a low-loss line that is not exceptionally long, the attenuation will be small, however, and, to a first approximation, it can be assumed that the values of both current and voltage are constant along the line, there being only a progressive phase retardation as the waves travel from source to load.

When there is a mismatch between the load and the line, the energy arriving at the load is not entirely dissipated therein. Part is absorbed by the load, and the remainder is reflected back into the line in the form of current and voltage waves which travel back along the line to the source.

Conditions in the line are now complicated. The current and the voltage at any point on the line are the resultants of forward-travelling and backward-travelling wave components.

If there is an impedance mismatch between the generating source and the line, as well as between the load and the line, there will be reflections at both ends of the line. In this case there will be an infinite series of forward-travelling and an infinite series of backward-travelling wave components. Each series, however, can be regarded as making up a single forward-travelling (or backward-travelling) component.

The magnitude of the current, or voltage, at any point in the line is dependent upon the magnitudes of and the phase relationship between the forward-travelling and backward-travelling components of current (or voltage).

Since the forward-travelling components undergo progressive phase retardation as they travel from source to load, while the backward-travelling components undergo progressive phase retardation as they travel from load to source, it follows that the phase difference between the two current (or voltage) components will show cyclic variation along the line.

At those points where there is zero phase difference between the two current components the value of current will be at a maximum; at those points where there is a phase difference of 180 deg. the value of current will then be minimum. Points of alternate minimum and maximum current magnitude, known as current nodes and antinodes respectively, will be spaced along the line at quarter-wavelength intervals.

Similar conditions apply in respect of the voltage, but an antinode of voltage is coincident with a node of current, and a node of voltage with an antinode of current.

Fig. 9 shows graphically the variations of current and voltage magnitude along a transmission line that is terminated by a load impedance which does not match the line. The line itself is assumed to be loss-free. The curves form what is frequently referred to as the standing-wave pattern.

By virtue of its distributed capacitance and inductance, a transmission

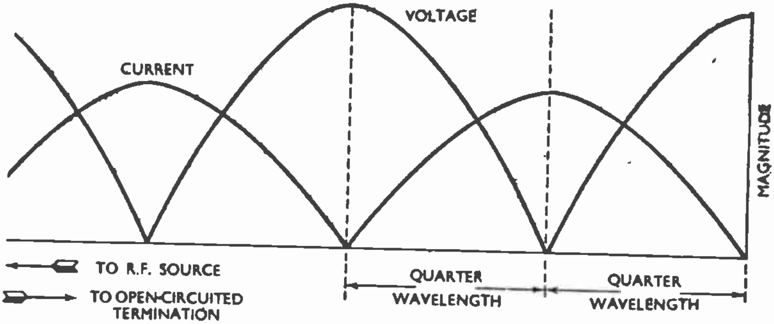


Fig. 10. Standing-wave pattern of current and voltage along an open-circuited transmission line assumed to be loss-free; the nodal values of both are zero.

line can carry radio-frequency currents even though it be open-circuited at the end. With no terminating load, all the energy reaching the end of the line is reflected back. Nodes and antinodes of current and voltage are, therefore, set up along the line. With a loss-free line the nodal values of current and voltage are zero. The open end of the line is an antinode of voltage and a node of current. The standing-wave pattern is shown in Fig. 10.

An open-wire aerial possesses distributed capacitance and inductance and behaves in some respects as an open-circuited transmission line. The distribution of current in the aerial is non-uniform and nodes and antinodes of current and voltage are set up.

An earthed quarter-wave, vertical, wire aerial has a node of current and an antinode of voltage at the top, and an antinode of current and a node of voltage at the base. A half-wave dipole has a node of current and an antinode of voltage at each end, and an antinode of current and a node of voltage at the centre.

NOISE. Unwanted energy or voltages present in a signalling system, especially those of a random character. For details of the various types of noise received by an aerial, see ATMOSPHERICS, INTERFERENCE. For noise produced in amplifiers and receivers, see SET NOISE. Reference may also be made to HUM, LINE NOISE, NOISE FACTOR, NOISE SUPPRESSION, RANDOM NOISE, SIGNAL-TO-NOISE RATIO.

NOISE FACTOR. Measure of the sensitivity of receivers in which the limit is determined by noise rather than by available gain. It is the factor by which the signal-to-noise ratio is worsened between input and output, that is, $N = \frac{P_{no}}{P_{so}} \times \frac{P_{si}}{P_{ni}}$, where N is the noise factor; P_{ni} is the noise power, within the energy band width of the receiver, available at the aerial terminals of the receiver; P_{si} is the signal power available at the aerial terminals of the receiver; P_{no} is the noise power available at the detector, and P_{so} is the signal power available at the detector.

The expression "power available" means the power which would be given to a perfectly matched load. It is equal to $E^2/4R$, where E and R are the generator e.m.f. and internal resistance respectively. See NOISE, SENSITIVITY, SIGNAL-TO-NOISE RATIO.

NOISE LIMITER. Circuit used extensively in communications and television receivers for reducing the effects of static and impulse interference; in television, particularly the interference produced by motor-car ignition systems. A typical example of such a circuit is given in Fig. 11; there are, however, many different types.

The example chosen takes the form of an additional diode in series with the output from the diode detector and connected to the H.T. supply through a high-value resistor. The noise-limiting diode is thus normally conductive, and the anode potential is arranged to be sufficiently positive for the diode to remain conductive for all normal values of vision-signal amplitude applied to the cathode. Thus the diode merely acts as a low-value series resistor and introduces negligible attenuation to the wanted signal. If, however, an interfering voltage at the detector output exceeds a predetermined value, the cathode potential of the noise-limiting diode exceeds the anode potential and the diode becomes non-conductive, greatly attenuating the interfering and vision signals and considerably reducing the effect of the interfering impulses.

The performance of the circuit can be improved by paying careful attention to the values of the detector components to obtain a good response to the transient voltages caused by the interfering signal.

In some receivers the degree of noise suppression can be varied by a control knob which, when interference is troublesome, should be adjusted to give maximum suppression consistent with the maintenance of a good picture or good-quality sound reproduction. The control should be used with great care because if it is advanced too far the noise suppressor will operate on the peaks of the wanted vision signal, thus upsetting the relative tone values of the white parts of the picture and impairing reproduction.

NOISE SUPPRESSION. Action of a device which automatically suppresses the output of the receiver until a predetermined input level is reached. Such a device is called a muting circuit or quiet automatic gain-control. High-gain receivers employing automatic gain-control tend to be excessively noisy while the tuning control is being operated because, between stations, the gain is at its maximum, there being no carrier wave to reduce it. Set noise and interference heard in this way is called inter-station noise.

For noise suppression in its general sense, see INTERFERENCE.

NOISE VOLTAGE. See NOISE.

NO-LOAD. Condition existing when the terminals of a source of electricity are open-circuited and the source has no load. No-load voltage is a synonym for open-circuit voltage. See LOAD.

NON-INDUCTIVE. Quality of being completely or substantially devoid of inductance. The condition is found only in components which have been specially designed for the purpose of presenting to alternating currents an impedance which is as nearly as possible equal to the D.C. resistance.

NON-INDUCTIVE RESISTOR. Resistor having negligible self-inductance. See FIXED RESISTOR.

NON-LINEAR DISTORTION. General term covering all forms of distortion due to non-linearity in the input/output-signal amplitude characteristic of a system. For example, the anode-current/grid-voltage characteristic of a valve is never perfectly linear, so that valve amplifiers inevit-

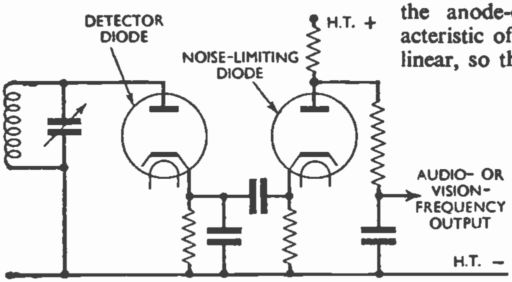


Fig. 11. Circuit details of one of the many forms of noise limiter. It is used in television receivers and comprises an additional diode connected to the H.T. supply through a high resistance.

ably give rise to non-linear distortion. Such distortion can, however, be reduced to a negligible proportion by the suitable choice of working point for the valve, the limitation of signal amplitude, and the use of negative feedback.

Distortion is caused also by mechanical non-linearity, as in microphone diaphragms and loudspeaker coil suspensions.

Details of the separate forms of non-linear distortion are given elsewhere (see AMPLITUDE DISTORTION, HARMONIC DISTORTION, INTERMODULATION DISTORTION). See also LINEAR AMPLIFICATION, NEGATIVE-FEEDBACK AMPLIFIER.

NON-LINEAR MODULATION. Amplitude modulation by a process in which are added the amplitudes of two waves to form a third which is then rectified. One of the components of the rectified wave is an amplitude-modulated wave. Although it may seem impossible to obtain linear modulation by the use of a non-linear device, the rectification of the complex wave and the selection of a band of waves from this does, in fact, give the required result, as shown in Fig. 12.

In adding together the amplitudes of two waves, a wave is obtained which contains only the two component waves; but if one wave controls the amplitude of another, new waves (sideband waves) are produced. The wave obtained by adding two waves must be rectified before the carrier and sideband waves (representing an amplitude-modulated wave) are produced; even then, these must be

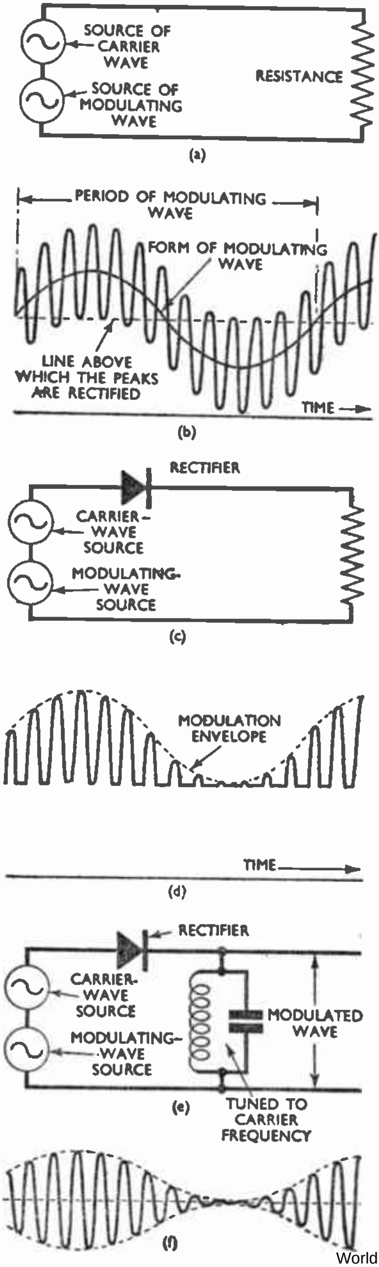


Fig. 12. Diagrams showing the principle of non-linear modulation: circuit (*a*) produces a wave as shown at (*b*) and, when this is rectified by circuit (*c*), it produces the wave (*d*); to derive the modulated wave uniting carrier and first-order sideband waves a filter, shown in (e) as a tuned circuit, must be used to eliminate other sideband waves, the modulated wave (*f*) being that finally produced.

selected from a host of other waves by a filter before the true amplitude-modulated wave can be offered to the transmission channel.

The circuits in Fig. 12 are basically similar to that used to produce beating. The difference between non-linear amplitude modulation and the production of beats lies in the relative frequencies of the two waves added together, as well as that selected by the filter.

For all non-linear modulation, the carrier and modulating waves are of widely different frequency and the filter selects the waves having frequencies f_c of the carrier wave and $f_c + f_m$ and $f_c - f_m$ of the sideband waves (see AMPLITUDE MODULATION, SIDEBAND). In beating, if the waves added together have frequencies f_1 and f_2 (where $f_1 - f_2$ is much less than either f_1 or f_2) the beat frequency selected by the filter is $f_1 - f_2$. See BEATING, LINEAR MODULATION, SIDEBAND WAVE.

NON-LINEAR RESISTANCE. Property of exhibiting different values of resistance according to the voltage applied to or current passed through a resistor. Current through a resistor, instead of giving a straight line against voltage, gives a graph with one or more changes of slope (Fig. 13). Non-linear resistance devices are used, among other purposes, for rectification. See RECTIFICATION, THERMISTOR.

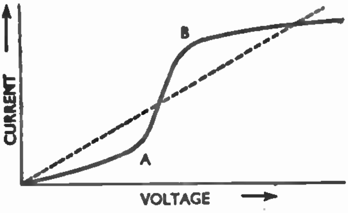


Fig. 13. Graph showing the linear relationship (dotted) between the current flowing through a normal resistor and the voltage applied to it. Non-linear resistance gives a graph with changes in slope such as *A* and *B*.

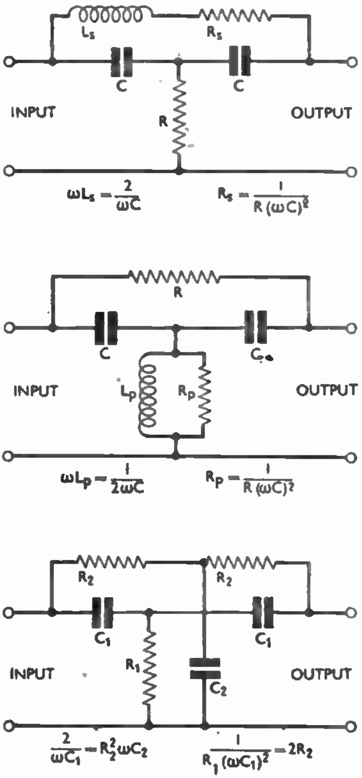


Fig. 14. Three forms of network which, at a certain wave frequency $\omega/2\pi$, give zero voltage at the output terminals, and are therefore null networks. The expressions give the relationships necessary in each for zero output.

NON-POLARIZED RELAY. Relay whose operation is independent of the direction of flow of current through the winding of the electromagnet. See ELECTROMAGNETIC RELAY.

NON-REACTIVE RESISTOR. Component, having neither inductance nor capacitance, designed to present a purely resistive effect at all frequencies.

NORMALLY POLARIZED WAVE. Radio-wave whose plane of polarization is either vertical or horizontal, depending upon the plane of the aerial-system. See HORIZONTALLY POLARIZED WAVE, POLARIZATION, VERTICALLY POLARIZED WAVE.

NOTE FREQUENCY. See AUDIO FREQUENCY, BEAT FREQUENCY.

NOTE MAGNIFIER. Obsolete term for an A.F. amplifying valve. See AUDIO-FREQUENCY AMPLIFIER.

NOTE TUNING. Arrangement of audio-frequency circuits to resonate more or less sharply to a particular frequency, hence to amplify that frequency selectively and assist in discrimination between it and interfering signals. See RESONANCE.

NUCLEUS. Central particle of the atom. It is positively charged, and built of such particles as neutrons, protons and electrons. The atomic number is the algebraic total of the charges on these particles.

NULL NETWORK. Network which gives zero voltage at its output terminals when its input terminals are energized from a wave of a specific frequency. This condition of zero transmission occurs essentially at one frequency. A null network, usually made up of resistors and capacitors, is different from a band-stop filter in that, in its practical form, it does in fact give a zero output voltage, whereas the voltage output from a band-stop filter built of manufactured components is always finite. The null network, examples of which are illustrated in Fig. 14, gives zero output voltage at a certain frequency because two waves travel by different paths to the output terminals, where the waves have equal amplitude and a 180-deg. phase difference, and so cancel out. See BAND-STOP FILTER, PHASE.

O

OBJECTIVE NOISE-METER. Noise-meter in which the noise-level under test operates a microphone, amplifier and measuring instrument calibrated in phons.

OBSERVED BEARING. Bearing as read directly from the scale of a direction-finder, and before any corrections have been applied.

OCTANTAL ERROR. Direction-finding error which rises to a maximum eight times in passing round the complete 360 deg. of coverage.

OCTODE. Valve having eight electrodes. It is used as a frequency-changer valve. An octode is usually considered to be a heptode with a suppressor grid added between the main anode and the screen grid. See FREQUENCY-CHANGER VALVE.

OERSTED. Rarely used unit of magnetizing force on the electromagnetic centimetre-gramme-second system.

OFFSET TONE-ARM. Arm of a gramophone pick-up in which either the pick-up is offset on the arm, or the arm itself is bent to cause the pick-up tracking to be more nearly radial. The normal gramophone pick-up arm traverses the disc in an arc, whereas the recording head, when forming the grooves, traverses the disc along a radius, and the object of using an offset tone-arm is to minimize needle and disc wear and to improve response.

OHM. Practical unit of resistance, linked by definition with the other practical units, the volt, ampere and watt, in that a pressure of one volt will send a current of one ampere through a resistance of one ohm. For purposes of standardization, the ohm is taken to be a resistance of a column of mercury weighing 14·5421 gm. and 106·3 cm. long, at 0 deg. C. The abbreviation for ohm is Ω.

OHMMETER. Electrical device, calibrated in ohms or in multiples or sub-multiples of ohms, for the direct measurement of resistance. In Fig. 1 is illustrated the working principle of a simple ohmmeter. A battery passes current through coils L_1 and L_2 placed at right-angles to each other, and a soft-iron pointer is placed at the intersection of their axes. The circuit includes a resistor of known value.

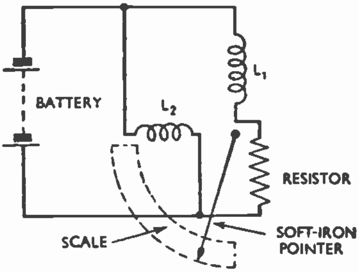


Fig. 1. Working principle of the ohmmeter; the pointer is pivoted at the point of intersection of the axes of the two coils, L_1 and L_2.

Assuming the battery to have constant voltage, the magnetic field of the coil L_2 will be constant and, consequently, the induced magnetism in the pointer, due to L_2, will also be constant. That induced in the pointer by L_1 will vary with the current passing through L_1, that is, with the value of the resistor. The position finally taken up by the pointer will, therefore, be dependent upon the resultant induced magnetism from L_1 and L_2, the pointer lying parallel with the axis of L_2 when the value of the resistor is infinite, and swinging downwards towards the vertical as the resistance is decreased.

By taking various known values of resistance and noting the deflection of the pointer, it is thus possible to calibrate a scale in ohms and multiples or sub-multiples of ohms.

In practice, the "Megger" and bridge "Megger" testers are commonly used forms of this instrument. The "Megger" incorporates a circuit operating on principles similar to those illustrated and a small hand-operated magneto-generator which provides about 500 volts. This, in replacing the battery, gives higher efficiency in measurement owing to the fact that the voltage is more constant, and it also provides more force for the movement of the pointer, which is essential when high-resistance measurements are taken. See BRIDGE MEGGER TESTER.

OHM'S LAW. Law, named after its enunciator, which states that conductors have a property, RESISTANCE, which is independent of the voltage acting across them and the current flowing through them, provided the conductor is kept at a constant temperature (Fig. 2). In its most useful form the law states that the current in a circuit is equal to the voltage divided by the resistance. In symbols, $I = \frac{E}{R}$, when I is the current in amperes, E the voltage in volts and R is the resistance in ohms. (In all cases it is assumed that D.C. is concerned. Calculations on A.C. circuits must take reactances, as well as the ohmic resistance, into account.)

When the current and resistance are known, the voltage can be worked out from another form of the law: $E = IR$. If current and voltage are known, resistance can be found with the aid of a third form: $R = \frac{E}{I}$. From these three simple expressions,

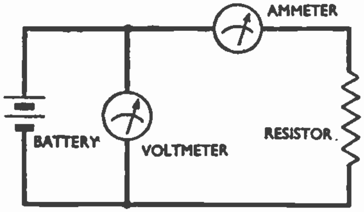


Fig. 2. Ohm's law relates the current, voltage and resistance in a circuit; if any two of the quantities are known the third can be calculated.

a wide range of electrical problems can be worked out. For example, suppose that it is desired to find the value of resistance which will allow a 6-volt accumulator to be charged at 2 amp. from a charging circuit which gives 10 volts. The 6 volts of the battery are opposed by the 10 volts of the charger, so the voltage to be "lost" across the charging resistor is 4. What we have to find is the value of resistance which will pass 2 amp. at 4 volts. Using the formula $R = \frac{E}{I}$, the resistance is found to be 2 ohms.

Again, to find the voltage reaching the anode of a valve which is fed through an anode resistor of 25,000 ohms, the anode current being known to be 5 mA, the formula $E = IR$ is used; the voltage across the resistor is $\frac{5}{1{,}000} \times 25{,}000$, or 125 volts. The voltage reaching the valve anode will therefore be the high-tension voltage minus 125 volts.

OMNI-AERIAL. Aerial which radiates to or receives from all points of the compass with equal efficiency. In its usual form, the omni-aerial consists of a single vertical conductor used as a Marconi aerial. Other examples are the vertical half-wave dipole and the umbrella. The term is an abbreviation of omni-directional aerial. See HALF-WAVE DIPOLE, MARCONI AERIAL, UMBRELLA AERIAL.

OMNIBUS TELEGRAPH SYSTEM. System in which a number of telegraph stations are interconnected so that signals transmitted by any one station are received by all the others in the group. If some of the stations are not equipped with senders, the system is called a *partial* omnibus; if the stations are interconnected through a central switchboard, a central station may transmit to any one, or to all the stations in the group, and the system is called a *switched* omnibus.

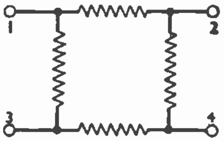


Fig. 3. Fundamental form of the O-network.

OMNI-DIRECTIONAL AERIAL. Synonym for OMNI-AERIAL.

OMNI-DIRECTIONAL RADIO BEACON. Radio sender using an omni-aerial to radiate signals in all directions for the navigational assistance of ships or aircraft. It may, for instance, emit continuously a characteristic and easily recognized signal for the use of craft which carry direction-finding gear.

O-NETWORK. Balanced form of a PI (π)-NETWORK (q.v.). Fig. 3 shows an O-network.

ONE-WAY SWITCH. Switch having only one current path. See SWITCH.

OPEN AERIAL. Aerial in which the oscillatory circuit is completed only by the distributed capacitance of the conductor or conductors, as distinct from the loop aerial, wherein the circuit is closed by a variable capacitor or other tuning device.

OPEN CIRCUIT. Circuit which is broken at some point so that no current can pass through it. See OPEN-CIRCUIT CHARACTERISTIC, OPEN-CIRCUIT VOLTAGE.

OPEN-CIRCUIT ADMITTANCE. Reciprocal of OPEN-CIRCUIT IMPEDANCE (q.v.).

OPEN-CIRCUIT CHARACTERISTIC. Voltage-frequency characteristic of a source of electricity such as a generator, valve amplifier or transformer, when the input voltage is kept constant and the output terminals are open-circuited. See OPEN CIRCUIT.

OPEN-CIRCUIT IMPEDANCE. Term used to describe the sending end impedance of a transmission line, when the receiving end of the line is open-circuited. See OPEN CIRCUIT.

OPEN-CIRCUIT SYSTEM. In telegraphy, a system in which no current flows in the circuit except when a signal is being sent.

OPEN-CIRCUIT VOLTAGE. Voltage at the terminals of a source of electricity when no current is taken from such terminals. See INTERNAL IMPEDANCE, NO-LOAD, OPEN CIRCUIT.

OPEN-CIRCUIT WORKING. Fire-alarm system in which a line, passing through each of the call points, is normally disconnected from earth (i.e. open-circuited) but which is connected to earth when the handle is operated at a call point, causing a signal at the fire station. See OPEN-CIRCUIT SYSTEM.

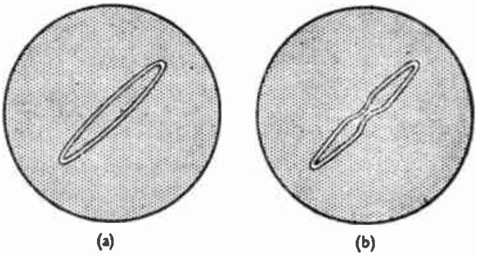

(a) (b)

Fig. 4. Example of the effect of origin distortion: a trace which should appear on the screen of a cathode-ray tube as at (*a*) is modified as shown at (*b*).

OPEN-DIAPHRAGM LOUDSPEAKER. Loudspeaker in which the vibrating diaphragm is not loaded by a cone or horn, the diaphragm itself forming the sound-radiating agent; the principle of working is thus similar to that of a headphone. See HEADPHONE, LOUDSPEAKER.

OPEN-WIRE FEEDER. Connexion used between an aerial and the corresponding sender or receiver and consisting of two parallel wires insulated from one another and from earth. See FEEDER.

OPEN-WIRE LINE. Transmission line in which the conductors are carried on insulators mounted on poles, the two wires being a few inches apart. See TRANSMISSION LINE.

OPERATING TIME. In telephony or telegraphy, the time occupied in establishing and closing-down the communication channel, as distinct from the time occupied for the transmission of the communication itself. In an echo-suppressor, it is the time which elapses between the instant of application of the signal and the instant of 6 db. suppression; it varies as signal magnitude varies.

OPTICAL-MECHANICAL TELEVISION SYSTEM. Any television system in which scanning is carried out by mechanical means. See DRUM SCANNER, MECHANICAL SCANNING, MIRROR SCREW, SCANNING.

ORBITAL-BEAM VALVE. Valve in which use is made of secondary emission from the anode to produce a valve with a high mutual conductance. The use of an orbital-beam is not fundamental to the operation of the valve, but has the practical advantage that material evaporated from the cathode shall not be deposited on the anode and so decrease its property of emitting a profusion of secondary electrons. Reduced to its basic simplicity, the principle of the orbital-beam valve is akin to that of an electron multiplier.

The primary electrons are made to strike an anode which is designed to give strong secondary emission, and these secondary electrons are attracted to a second anode. Thus the mutual conductance between control grid and the second anode is high. See ELECTRON MULTIPLIER, SECONDARY EMISSION.

ORIGIN DISTORTION. Distortion of a cathode-ray tube trace near the origin, peculiar to gas-focused tubes with electrostatic deflection; an example is given at Fig. 4. It is caused by a space-charge effect which reduces the sensitivity at low values of deflecting voltage.

The effect is eliminated in some tubes by means of splitting one deflector plate of each pair into two halves which are connected to equal positive and negative potentials (Fig. 5). Either of these potentials alone would be

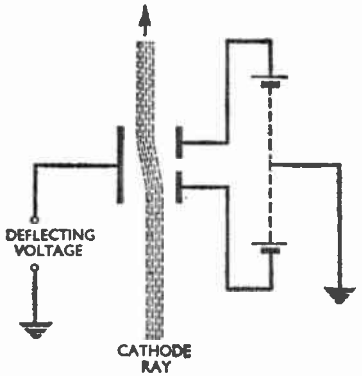


Fig. 5. Manner in which connexions may be made to the deflector plates of a cathode-ray tube in order to overcome the effects of origin distortion.

sufficient to deflect the beam off the screen, but as regards its final deflection the two cancel out. So long as the spot remains on the screen, the deflecting voltage never falls to zero, thus origin distortion does not take place. See GAS FOCUSING.

OSCILLATING CURRENT. Alternating current, the frequency of which is determined by constants of the circuit generating the current.

OSCILLATION. In mechanics, rhythmic motion of a mass on either side of a central point, as with a pendulum; in radio engineering, the generation of alternating currents of specified frequency in a circuit containing inductance or resistance and capacitance.

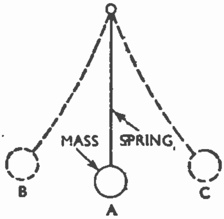


Fig. 6. Mechanical oscillation between points *B* and *C* of a mass, mounted at the end of a blade spring, when it is displaced from its rest position *A*.

The principles of electrical oscillation are better understood when the reader is familiar with mechanical oscillation. Imagine a mass suspended on a spring (Fig. 6). If the mass is displaced from its rest position *A* and held at position *B*, the tensioned spring will form a source of *potential* energy; if the mass is released, this energy will cause it to return to position *A*, at which point the potential energy will be zero.

By virtue of its inertia, the mass will continue its movement through *A* to some point *C*, the potential energy of the spring being transferred to the moving mass in the form of *kinetic* energy. At *C* the mass comes to rest and energy is once more stored in the spring, forcing the mass back to *A*. Thus there is a sequence of changes in the form of energy, alternating between potential and kinetic.

The complete movement of the mass from *A* through *B* and *C* and back to *A* is called a cycle and can be shown graphically as in Fig. 7. The number of such cycles occurring in unit time is called the frequency of oscillation. The frequency is determined by the value of the mass and the length and stiffness of the spring; it is greater for a small mass or for a short, stiff spring than for a large mass or a long, weak spring.

In the example given, a proportion of potential energy is dissipated in each cycle through air resistance and friction in the spring; hence the extent of the swing decreases with each successive cycle. The effect is illustrated in Fig. 8; such wave-trains are called *damped* oscillations.

If an independent source of energy could be applied to counteract the resistance losses referred to, then the extent of the swing or *amplitude* of successive cycles could be maintained constant, as shown in Fig. 9. These are known as *continuous oscillations*, for, with such a system, the oscillations will continue at constant amplitude so long as the source of external energy is applied.

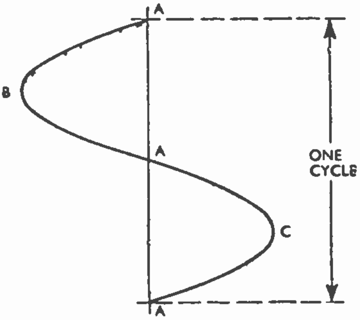


Fig. 7. How one cycle of an oscillation may be expressed graphically. Points *A, B, C* correspond with those in Fig. 6.

In electrical oscillation, the fundamental factors are inductance, capacitance, voltage and current. These can be compared with mechanical oscillation factors, inductance, capacitance, voltage and current being equivalent to mass, spring, spring tension and velocity of mass respectively.

A circuit containing inductance and capacitance is shown in Fig. 10. A voltage charges the capacitor at regular intervals. Consider one cycle of oscillation. When the capacitor is charged, its plates will have positive and negative charges.

Assume the spark-gap to have such a width that, at maximum charge on the capacitor, the air resistance of the gap breaks down; the gap now presents a relatively low resistance to electric current, which will now flow from the capacitor's right-hand plate through the gap and the inductor *L* to the left-hand plate. As the current passes through *L* a magnetic field is set up around the inductor.

When this field reaches maximum intensity, the whole of the potential energy originally stored in the capacitor is transferred to the inductor in the form of kinetic energy. This corresponds to the point *B* in Fig. 6. At this instant, the potential difference (p.d.) across the capacitor is zero and there is no voltage to maintain the current; the current will, however, continue to flow while the magnetic field slowly falls. This falling in the magnetic field sets up an e.m.f. in the inductor, such e.m.f. opposing the reduction of the p.d. across the inductor and tending to maintain the current in the same direction.

The current continues to flow until the magnetic field has died down and the capacitor is charged to maximum, the polarity of the charge on the respective plates now being reversed. This corresponds with point *C* in Fig. 6, where the energy is stored in

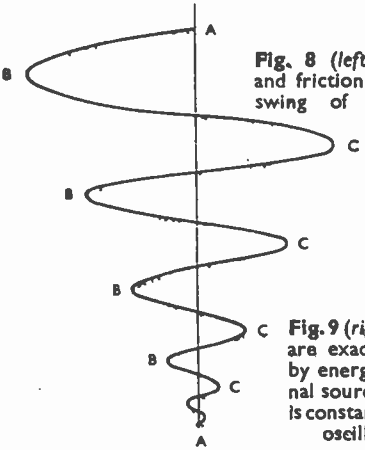


Fig. 8 (*left*). Air-resistance and friction losses cause the swing of the mechanical oscillator (Fig. 6) to decrease progressively; thus the device produces what are known as damped oscillations.

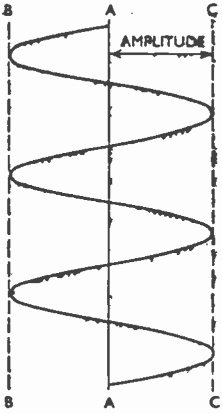


Fig. 9 (*right*). When losses are exactly counteracted by energy from an external source, the amplitude is constant and continuous oscillation results.

the spring. The p.d. across the capacitor now starts a current in the opposite direction, the gap breaks down, and a magnetic field is once more set up in the inductor.

Thus there is a further transference of energy from capacitor to inductor and, as the field collapses, current is maintained around the circuit in a direction which causes the capacitor to be charged at the same polarity as on the initial charge, and a complete cycle of oscillation has taken place.

In normal oscillatory circuits, the spark-gap shown in Fig. 10 is replaced by a resistance, which may be the resistance of the inductor itself or supplementary to it; in either case the principles are the same.

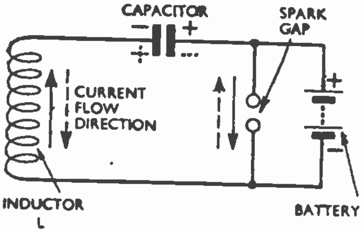


Fig. 10. Fundamental circuit for production of electrical oscillations; the direction of current flowing in the circuit is reversed every half-cycle.

As in the mechanical case, the number of cycles occurring in unit time is termed the frequency of oscillation and is usually expressed in cycles per second (c/s), kilocycles per second (kc/s) or megacycles per second (Mc/s). The frequency is determined by the oscillation constants of the components forming the circuit and may be deduced from $f = \frac{1}{2\pi\sqrt{LC}}$, where f = number of cycles per second, L = inductance in henries and C = capacitance in farads. See DAMPED OSCILLATIONS, FREE OSCILLATIONS, OSCILLATORY DISCHARGE.

OSCILLATION CIRCUIT. See OSCILLATORY CIRCUIT.

OSCILLATION CONSTANT. Product of the inductance (L) and the capacitance (C) of a resonant circuit. So long as this product remains constant, irrespective of individual values of L and C, the resonant frequency of the circuit remains constant.

OSCILLATION INTERFERENCE. Interference to neighbouring receivers, due to a receiver in which excessive use of positive feedback or an insufficiently screened local oscillator causes it to radiate. See HOWLING.

OSCILLATION VALVE. Valve the grid and anode of which are connected through an external circuit in such a manner as to produce oscillations; the frequency of the oscillations is determined by the constants of the circuit. See OSCILLATOR.

OSCILLATOR. In a radio sender or receiver, that part of the circuit which generates oscillations. In general, an instrument designed to produce electrical oscillations.

A simple form of oscillator is a single thermionic valve, the grid and anode of which are inter-coupled through an oscillatory circuit. In the circuit illustrated (Fig. 11) the voltage from the battery, applied across the inductor L_1, in series with the valve, produces a current in L_1 and a consequent p.d. across the capacitor. A second inductor L_2 is magnetically coupled to L_1 and has a potential developed across it by induction.

If this potential is applied to the grid of the valve, the grid becomes negative with respect to the cathode, and the current through the valve, and hence through L_1, will decrease; but the magnetic field around L_1 opposes a fall in current and maintains the charge on the capacitor. When the field has collapsed, the capacitor will discharge, producing a current through L_1 in the opposite direction.

An e.m.f. of opposite polarity is now produced in L_1 and, by induction, a positive e.m.f. is applied to the grid,

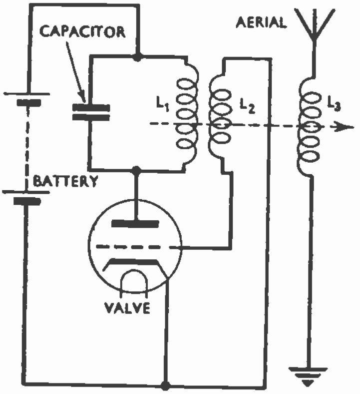


Fig. 11. Simple form of oscillator used in radio; in this an oscillatory circuit forms the coupling between the grid and the anode of a triode, and the closed circuit is inductively coupled to an aerial-earth system.

increasing the current through the valve. When this current is at maximum, the original p.d. across L_1 is restored, and a complete cycle of oscillation has taken place and the sequence is repeated, the circuit continuing to oscillate as long as the voltage from the battery is maintained.

If a third inductor L_3 is coupled to the circuit and terminated with an aerial-earth system, the oscillations produced in the "closed" circuit will produce similar oscillations in the aerial-earth system.

This arrangement forms the basis of radio sending, the oscillations in the aerial-earth system being radiated from it as electromagnetic waves. The frequency of the oscillations is determined by the values of the inductors and the capacitor (see OSCILLATION).

See also oscillators under the headings: AUDIO, BEAT, BEAT-FREQUENCY, CAPACITIVE-FEEDBACK, CRYSTAL, DOUBLE-FREQUENCY, DYNATRON, FREQUENCY-STABILIZED, GANGING, INDUCTIVE-FEEDBACK, INTERMEDIATE-FREQUENCY, LINE-STABILIZED, LOCAL, MASTER, RELAXATION, SELF-EXCITING, SQUEGGING and TUNING-FORK OSCILLATORS.

OSCILLATOR CIRCUIT. Electrical circuits associated with a device producing oscillations; the external circuit of an oscillation valve. See OSCILLATORY CIRCUIT.

OSCILLATOR STABILITY. Closeness with which the frequency of an oscillator adheres to the required value when temperature, H.T. supply voltage or other parameters are varied. See FREQUENCY STABILIZATION.

OSCILLATORY CIRCUIT. Electrical circuit containing inductance and capacitance, usually illustrated as shown in Fig. 12. The frequency of oscillation is dependent upon the oscillation constant LC and is calculated from $f = 1/(2\pi\sqrt{LC})$, where f is the frequency in cycles per second, L the inductance in henries and C the capacitance in farads.

OSCILLATORY CURRENT. Current flowing in an oscillatory circuit.

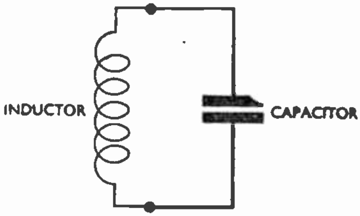


Fig. 12. Universal method of representing by diagram an oscillatory circuit comprising inductance and capacitance.

OSCILLATORY DISCHARGE. Release of energy, existing initially in the form of an electric or a magnetic field, into a circuit where the release results in the production of electric oscillations.

If the energy stored in a charged capacitor is released into a low-resistance circuit containing an inductor, there is a transfer of energy from the capacitor to the inductor. The discharge current rises rapidly to a peak, and energy, originally in the form of an electric field in the capacitor, is transformed to the form of a magnetic field around the inductor.

The magnetic field then collapses on the inductor, maintaining the current flow (but with decreasing value), and the capacitor re-charges in polarity opposite to the original polarity. The capacitor then discharges again, the current reversing. The process is repeated over and over again, the current oscillating to and fro in the circuit.

The transfer of energy, at each half-cycle, from the capacitor to the inductor, and vice versa, is not complete owing to resistance and other sources of loss in the circuit. Consequently, the half-cycles are of diminishing peak value and the oscillations ultimately cease owing to the expenditure of the whole of the initial energy in the circuit losses.

The train of oscillations of current has the form illustrated graphically in Fig. 13. In Fig. 14 the conditions in the circuit are shown, corresponding to the points marked *A*, *B*, *C* and *D* in Fig. 13.

The frequency of oscillation is determined by the constants of the circuit and is equal to $\frac{1}{2\pi}\sqrt{\frac{1}{LC}-\frac{R^2}{4L}}$ cycles per second, where L = inductance (henries), C = capacitance (farads), and R = effective high-frequency resistance of circuit (ohms). This frequency is termed the *natural frequency* of the circuit.

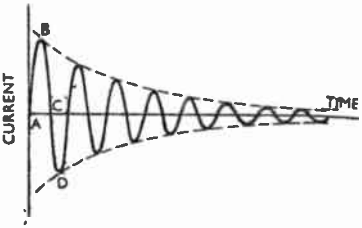


Fig. 13. Form of the wave-train of an oscillatory-discharge current.

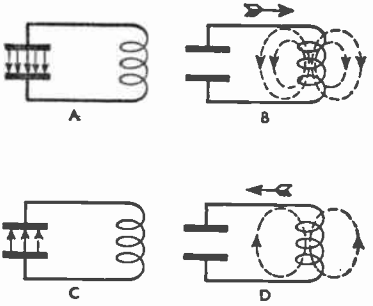


Fig. 14. Circuit conditions, when an oscillatory discharge takes place, corresponding to points *A*, *B*, *C* and *D* on the current/time graph of Fig. 13.

It is a condition for the production of an oscillatory discharge that R shall be less than $2\sqrt{\frac{L}{C}}$; otherwise the discharge will be unidirectional. When R^2 is very small compared with $4L$, the frequency is approximately equal to $\frac{1}{2\pi\sqrt{LC}}$, that is, to the resonant frequency of the circuit. See SPARK SENDING SYSTEM.

OSCILLATORY SCANNING. Methods of television scanning in which alternate lines are scanned in opposite directions, back and forth across the scene. They employ mechanical systems and make use of oscillating or vibrating mirrors. The Priess system is one that is fairly highly developed, employing only one mirror to obtain both vertical and horizontal scanning. Other schemes use one mirror each for the two scans.

In the Priess system, the mirror is mounted on a thin steel wire on which it is caused to swivel by an electromagnet. A frame holding the steel wire at its ends takes care of the slower frame-scan movement by oscillating the mirror in a direction at right-angles to the swivel. Very little power is needed to move the mirror, the natural frequencies of the mechanical arrangements being chosen to suit the oscillation periods.

Light is supplied through a modulating device and the mirror throws this on a screen to form the picture. Specially designed sending apparatus is necessary, of course, because each alternate line is scanned in the opposite direction and no instantaneous fly-back at the end of a line is required.

OSCILLOGRAM. Record of a wave form, as shown by the trace on an oscillograph screen, when the trace has been photographed and printed. See OSCILLOGRAPH.

OSCILLOGRAPH. Instrument for investigating wave forms of alternating voltages, tracing the wave forms on a revolving mirror or a fixed screen and producing a permanent record of the results obtained.

The alternating voltages may not be the primary object of investigation; the instrument is used for examining alternating currents, for mechanical problems and for a wide range of scientific investigations; in every case the oscillograph records voltage wave forms which can be related to the problem being examined.

The wave form may be traced by light reflected from an oscillating mirror, as in the Duddell oscillograph, or by a beam of electrons (see CATHODE-RAY TUBE). The record is usually produced photographically.

An electromagnetic oscillograph ceases to be effective at frequencies above 1,000 c/s; the cathode-ray oscillograph, however, has a very wide frequency range which, with a high-vacuum cathode-ray tube, may extend from zero (D.C.) to radio frequencies of several megacycles per second. For this reason, the cathode-ray oscillograph has almost entirely replaced the electromagnetic type in radio engineering.

Other advantages of the cathode-ray oscillograph are that a finer degree of control and adjustment is possible; and that the load taken from the circuit being tested is negligible and, therefore, does not upset the working conditions of the circuit. The input capacitance of the oscillograph, however, cannot be ignored when connected to radio-frequency circuits.

The cathode-ray tube may have a metal or a glass envelope, and an oscillograph may use either type. The metal tube is used only where an oscillograph forms a permanent laboratory installation. It has two advantages over the glass tube: the electrodes can be replaced if worn or damaged, and the camera and film used for recording the graph can be installed within the tube itself, permitting the

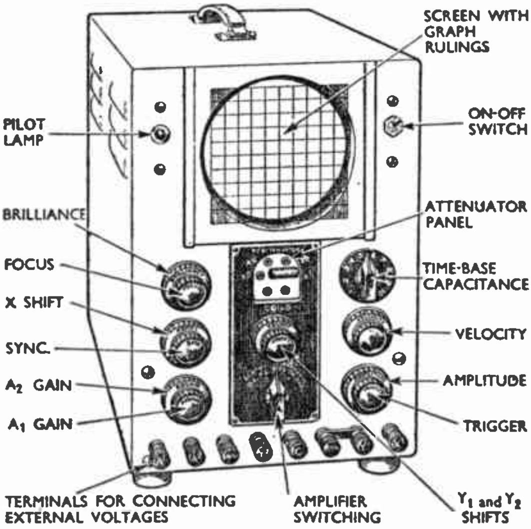


Fig. 15. Cossor portable double-beam oscillograph using a 4½-in. tube; it is suitable for both direct observation and the production of oscillograms by photography.

electron beam to be focused on the film direct, thus producing a more clearly-defined record.

Initial costs and subsequent maintenance are higher for the metal tube, largely because a vacuum pump is an essential accessory; the vacuum is, of course, broken down each time a new film is inserted in the camera, and it is necessary to restore the vacuum before the instrument can again be used.

For general testing purposes in radio engineering, a cathode-ray oscillograph having a glass-envelope is normally used and a typical example is shown in Fig. 15.

Such an instrument has the advantages of being portable and completely self-contained. It may be used for direct observation or for recording the wave form by photographic means. When used for direct observation only, the instrument functions as an oscilloscope and it should be clearly understood that this is the only distinction between an oscilloscope and an oscillograph.

The instrument shown employs a double-beam tube of 4½ in. diameter.

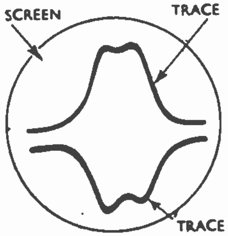


Fig. 16. Example of the traces which appear on the screen of a double-beam tube when the voltage wave forms obtaining at the primary and secondary terminals of an I.F. transformer in a radio receiver are being examined.

The double beam is obtained by placing a metal screen between the Y deflector plates to split the beam as it leaves the final accelerator.

By splitting the beam in this manner, the brilliance of the beam is reduced—but not sufficiently to impair visual examination, although it does lessen the efficiency when the instrument is required for the photographic recording of wave forms at very high frequencies. In the instrument shown, this disadvantage is largely offset by arranging the circuits so that either a double or single beam may be employed.

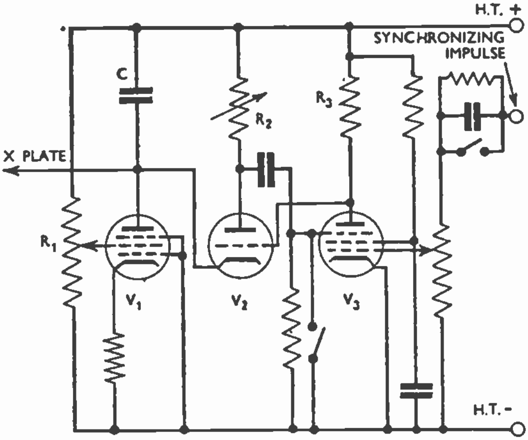
The advantage of the double-beam tube is that two phenomena may be examined simultaneously. For example, a direct comparison between the input and output wave forms of an amplifier may be made. Fig. 16 shows the application of the principle when examining simultaneous voltages across the primary and secondary terminals of a transformer.

The time base provides a saw-toothed wave form, a special feature of the circuit being the use of hard-vacuum valves which permits stable operation over a frequency range of 5–250,000 c/s, a range many times greater than that obtainable from gas-discharge valves, where the frequency range is restricted by the de-ionization time of the gases.

The time-base circuit is shown in simplified form in Fig. 17. The capacitor *C* charges linearly through the valve V_1, causing the cathode of V_2 to become increasingly negative with respect to its anode. The control grid of V_2 is, however, appreciably negative relative to this anode because of the voltage drop across the resistor R_2 in the anode circuit of V_3.

Immediately the cathode of V_2 has become sufficiently negative to approach the potential on its control grid, V_2 will begin to pass current, and a voltage develops across R_2. This swings the suppressor grid of V_3 negative, causing the anode of V_3, and hence the control grid of V_2, to become positive. The action is cumulative, and the capacitor discharges rapidly through V_2; when it becomes discharged, no further current flows through R_2 and the cycle is repeated.

Fig. 17. Simplified circuit of the time base of a cathode-ray oscilloscope or oscillograph. Stable operation at frequencies of up to 250 kc/s is possible because the valves used are all of the hard-vacuum type. The circuit is based on that devised by Puckle.



Since R_2 is in the discharge path, its value affects the fly-back time and, by making this component variable, control over fly-back time is available.

The voltage developed across C, and hence the amplitude of the time-base wave form, depends upon the extent to which the grid of V_2 is maintained negative relative to its anode; since this is dependent upon the voltage drop across R_2, amplitude control is effected by making R_2 variable.

Synchronization between the time base and the working voltage is obtained by injecting a fraction of the working voltage into the control grid of V_3. The frequency of the time-base voltage depends upon the capacitance of C and, in the instrument shown in Fig. 15, nine capacitors of different values are provided for rough adjustment, fine adjustment being obtained by varying the screen volts on V_1.

Wide-range amplifiers are incorporated in the instrument, two conditions of working being available. With a double-beam tube, single-stage amplification for each beam is available with a gain of 28 and a frequency range of 20–100,000 c/s. For single-beam working, using the double-beam tube, two-stage amplification may be used with a gain of 900 for a frequency range of 20–100,000 c/s, or a gain of 106 over the wide frequency range of 20 c/s to 2 Mc/s.

The applications of an oscillograph to radio-frequency engineering are very numerous, and the following are but a few examples:

1. *Voltage Tests.* Normally, the primary function of a cathode-ray oscillograph is the examination of voltage wave forms of an alternating character. The tests may be directly connected with the voltages applied to the instrument, or with some other phenomena which can be caused to produce voltages. In the latter case, the sole limitation is that the problem being investigated must be capable of producing a voltage change of sufficient magnitude to cause deflection of the beam.

To quote examples, an optical problem may be examined by using a photocell to detect changing conditions; a mechanical pressure can be measured by using an electromagnetic pick-up; acoustic problems can be investigated by means of a microphone. In each case, the detecting instrument produces an alternating voltage, which can be applied to the oscillograph for investigation.

2. *Measurement of Current.* The relative value of the current passing through a resistor can usually be measured by ascertaining the voltage developed across the resistor; there-

fore, current measurements can be obtained by applying such a voltage to the deflector plates. In certain cases it is more convenient to measure the current by means of the electromagnetic field produced in deflector coils. Such measurements are, however, subject to error in circumstances where the conditions of the circuit being measured are upset by the inductance and resistance of the deflector coils themselves.

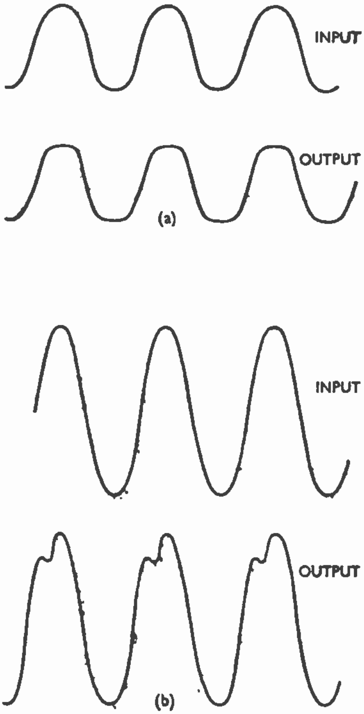


Fig. 18. Traces obtained on a double-beam tube during distortion tests made on an A.F. amplifier by comparing the input and output (voltage) wave forms: (*a*) the output wave form indicates slight distortion which is insufficient for aural detection; (*b*) when the gain of the amplifier is increased, the traces show the increased amplitude of the waves and serious distortion of output.

3. *Distortion Tests.* One of the most useful applications of the oscillograph is the tracing of distortion in receivers and amplifiers. A double-beam cathode-ray tube is particularly useful for this purpose since instantaneous comparison can be made between the wave forms of the input and output voltages.

The trace obtained on the screen when a sinusoidal signal is applied to an amplifier, the input and output of which are connected to an oscillograph, is given at (a) in Fig. 18. This figure assumes the gain control of the amplifier to be set for normal working gain, and the trace obtained indicates little difference between the wave forms of the input and output signals; that is to say, distortion is negligible.

If the gain of the amplifier is increased to a point where serious distortion begins this is indicated on the screen in the form of a distorted trace (Fig. 18b). By gradually reducing the gain of the amplifier until the trace becomes free from distortion, the maximum undistorted gain for a given input signal can be ascertained.

4. *Frequency-response Tests.* The frequency response of an amplifier can be measured on an oscillograph by the use of a calibrated scale. Assume that the horizontal lines over the screeen (Fig. 15) represent, on a vertical scale, steps of 2 decibels. By applying the tests described in relation to Fig. 18a at a frequency of 1,000 c/s, the response of the amplifier at all other frequencies can be measured by simple calculation. Fig. 19 illustrates a condition where the response falls by 4 decibels at 8,000 c/s with reference to 1,000 c/s.

Oscillograms, or permanent records, are produced from an oscillograph by placing a camera near to the screen and photographing the trace. The essential condition for producing an oscillogram is that the trace on the screen has sufficient brilliance and is of a colour suitable for photography.

With a portable oscillograph of the type shown in Fig. 15 accelerator voltages in excess of 1,000 are not desirable but, by using suitable fluorescent-screen material, such an instrument produces a trace which can be photographed successfully. A camera specially designed for use with this oscillograph is shown in Fig. 20.

This camera can be used for producing oscillograms of stationary traces, or for recording non-recurrent wave forms and slow-speed transients. If an oscillograph is to be used frequently for investigating high-speed transients, an instrument specifically designed for photographic application of this kind is desirable.

OSCILLOSCOPE. Term applied to an oscillograph when used for direct observation only, as distinct from the same instrument when used for recording information by producing oscillograms. See OSCILLOGRAPH, OSCILLOGRAM.

OUT OF PHASE. Condition in which two alternating phenomena (for example, a current and a voltage), although of identical frequency, do not pass through their maxima and minima at the same time.

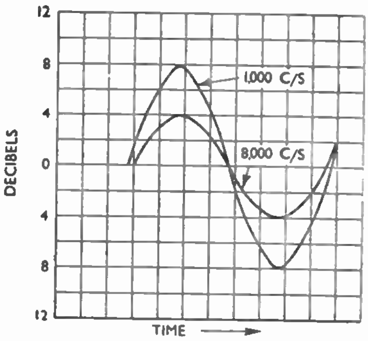


Fig. 19. Frequency-response measurement by use of a suitably calibrated oscillograph. At 1,000 c/s the amplitude reading is 8 db., and at 8,000 c/s 4 db.; this indicates that, taking 1,000 c/s as a datum frequency, the response of the amplifier falls by 4 db. at 8,000 c/s.

OUTPHASING MODULATION. Modulation in which waves having the same frequency as the carrier wave are given a phase difference of just less than 180 deg., the modulating wave being arranged to alter the phase of these waves so that their resultant is an amplitude-modulated wave.

The principle of outphasing modulation is as follows: two waves of equal carrier frequency and amplitude have a certain phase difference, and their resultant is a wave of the same frequency. The modulating wave makes the phase difference vary by equal and opposite amounts in

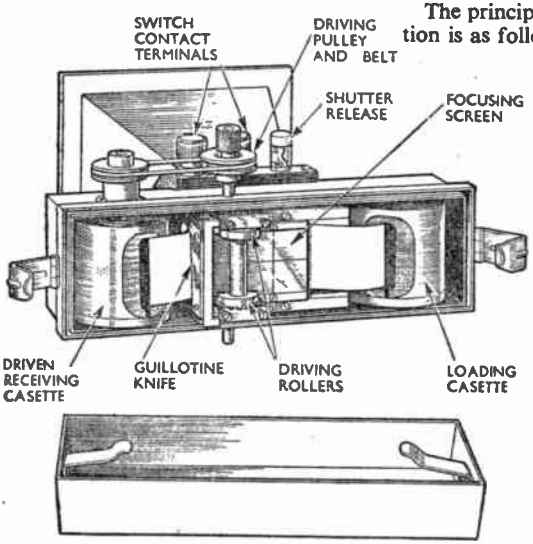


Fig. 20. Cine camera designed specifically for use with the oscillograph shown in Fig. 15. It has a hood attachment which may be fitted into guides on the face of the oscillograph.

the original two waves. This causes the resultant wave to vary in amplitude between certain limits. The original waves may be regarded as phase-modulated, and their resultant as an amplitude-modulated wave. This system was used in the Luxemburg sender. It is economical in power and efficiency is high; for these reasons, outphasing modulation may have a wide use in the future. See AMPLITUDE MODULATION, PHASE MODULATOR.

OUTPUT. Term which denotes the current, power or voltage coming from the terminals of a source of electricity. The full terms are output current, output power and output voltage respectively. The term may also be used to describe the nature of the internal impedance of the source. For example, the output capacitance of a valve is responsible for the capacitive reactance of the internal impedance of a valve considered as a source of electricity. Similarly, values may be assigned to the output capacitance, impedance, inductance and resistance; these values are measured between the output terminals of a receiver, amplifier, or other source of power.

OUTPUT CAPACITANCE, IMPEDANCE, INDUCTANCE, RESISTANCE. Total capacitance, impedance, inductance or resistance between, say, the output electrode and cathode of a valve when all the other electrodes are strapped to the cathode. It may differ appreciably from the output capacitance, impedance, inductance or resistance respectively that is obtained under working conditions because signal-frequency voltages may be present on the other electrodes.

OUTPUT CAPACITY. See OUTPUT CAPACITANCE.

OUTPUT CIRCUIT. Circuit connected between the output terminals of a source of electricity. See OUTPUT.

OUTPUT CURRENT. Current flowing from the output terminals of a source of electricity. See OUTPUT.

OUTPUT IMPEDANCE. See OUTPUT CAPACITANCE, ETC.

OUTPUT INDUCTANCE. See OUTPUT CAPACITANCE, ETC.

OUTPUT LOAD. Load connected between the output terminals of a source of electricity. See OUTPUT.

OUTPUT POWER. Power existing at the output terminals of a source of electricity. See OUTPUT.

OUTPUT RESISTANCE. See OUTPUT CAPACITANCE, ETC.

OUTPUT TERMINALS. Terminals from which electrical power can be drawn. See OUTPUT.

OUTPUT TRANSFORMER. Transformer with its primary connected across the terminals of a source.

OUTPUT VALVE. Final valve of a series, from which the output passes to whatever form of load is in use. For loudspeaker operation, the output valve is of a type capable of delivering considerable power; for some forms of cathode-ray circuit, the need is mostly for high-output voltages and the valve need not be capable of handling much power. In normal circumstances, however, an output valve is one which will deliver a substantial power.

OUTPUT VOLTAGE. Voltage across the output terminals of a source of electricity. See OUTPUT.

OUTSIDE BROADCASTING. Broadcasting in which the programme to be broadcast cannot, by its nature, take place in a broadcasting studio. Broadcast programmes may contain running commentaries on sporting events or ceremonies of a public nature, or speeches at banquets, etc. The link between control room and programme location is therefore extended to bridge the distance between the place where the outside broadcast takes place and the control room.

When the programme item takes place in the studio the link is short, and is often formed by wires run in the same building which contains studios and control rooms. The terms "studio broadcast" and "outside broadcast" are therefore distinctive inasmuch as the former has a permanent link between programme location and control room, while the latter demands a special link.

Outside broadcasts may take place anywhere; the broadcasting organization therefore hires a special line from the Post Office or Telephone Authority for temporary use. Some places at which broadcasts are constantly made may have permanent outside-broadcast lines, but as these are not studio broadcasts they are still referred to as outside broadcasts.

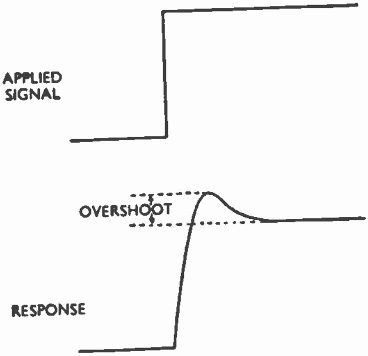


Fig. 21. Response graph exhibiting approximately 25 per cent overshoot.

OVER-ALL FREQUENCY RESPONSE. Frequency response obtained from an electrical communication system (in which equalizers are used) as distinct from the response of individual components in the system. In an ideal communication or recording system, the over-all frequency response is level over the audio range.

OVER-ALL GAIN. Synonym for INSERTION GAIN.

OVER-ALL LOSS. Synonym for INSERTION LOSS.

OVERLOAD. Condition when more power is drawn from a source of power than the source can supply continuously without overheating or distortion or damage. Sources of electricity may, in some circumstances, be overloaded without serious risk of damage to them. For example, the output terminals of a valve amplifier may be loaded to excess without damage to the amplifier. The term does not imply that damage will necessarily result, but rather that the power supplied in the condition of overload is greater than the source was designed to supply. In some circumstances, for example, when cells are short-circuited, irreparable damage may occur. See FACTOR OF SAFETY, LOAD.

OVERMODULATION. Condition of amplitude modulation in which the modulating wave has a greater amplitude than that needed to produce a modulation factor of unity; an overmodulated wave thus has a modulation percentage greater than 100. Fig. 34 on page 397 (MODULATION DISTORTION) shows an overmodulated amplitude-modulated wave. Modulation distortion is produced because the modulation envelope is no longer a faithful copy of the shape of the modulating wave. In broadcasting, overmodulation produces louder signals, but also a distorted output in receivers.

OVERSHOOT. Form of transient distortion in which the response to a signal temporarily exceeds the final value, as indicated in Fig. 21. It is usually expressed as a percentage of the

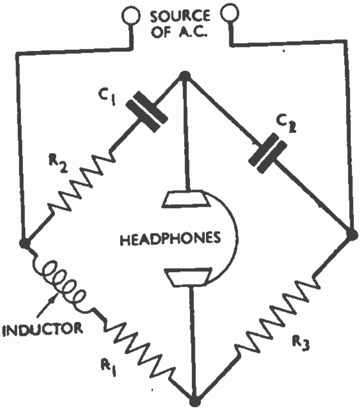


Fig. 22. Form of alternating-current bridge known as the Owen bridge.

final value. See RINGING, TRANSIENT DISTORTION.

OVERTONE. In a complex sound wave, any of the components with a frequency greater than that of the fundamental component. See FOURIER ANALYSIS.

OWEN BRIDGE. A.C. bridge, of the form illustrated in Fig. 22 (appearing at the foot of page 439), in which the inductance can be measured in terms of a known capacitance and two known resistances. When the bridge is balanced, minimum sound is heard in the headphones and the following equations apply.

$$L = R_2 R_3 C_2;\ R_1 = \frac{C_2}{C_1} R_2.$$

OXIDE-COATED CATHODE. Cathode of an indirectly heated valve; it is usually a cylinder and is coated with active material in the form of an oxide. See INDIRECTLY HEATED CATHODE.

OXIDE-COATED FILAMENT. Valve filament which is coated with a mixture of the oxides of the alkali metals and gives adequate thermionic emission at comparatively low temperatures. See FILAMENT, OXIDE-COATED CATHODE.

P

PACK. Abbreviated form of the term POWER PACK (see MAINS UNIT).

PAD. Resistance network comprising, essentially, a series and shunt arm or several series and shunt arms, these arms having fixed values of resistance. The pad is not composed of reactances. A pad may be inserted between the output terminals of a source or network and the input terminals of a network or other apparatus. The object fulfilled by such a connexion is to isolate or decouple networks or apparatus joined by a pad.

A good example of the use of a pad is the joining of the output terminals of a filter to the input terminals of a ring modulator (Fig. 1). The input impedance of the modulator varies sharply as the pairs of rectifiers are made conductive and non-conductive. When terminated by a rapidly changing impedance, the filter may not function so well as when it is terminated in a constant resistance. The pad is used to make connexion between filter and modulator and gives a substantially constant resistive termination for the filter. Obviously, a loss of power results.

A resistance pad has an input resistance which is more and more independent of its terminating resistance as the pad has a greater attenuation. Thus, in the example given, the more complete the decoupling, the greater the loss of power. Sometimes, a pad may be inserted simply for the

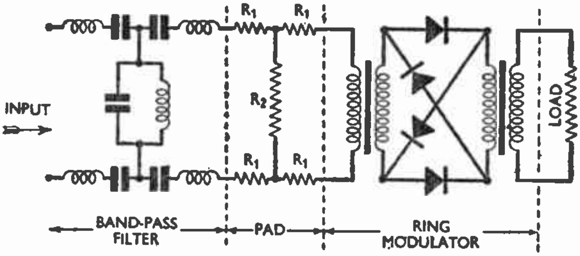


Fig. 1. Diagram showing a pad in use for the purpose of isolating the termination of a filter from the input to a ring modulator.

purpose of reducing the amplitude of a wave. A pad is usually designed on a characteristic-impedance basis. Unlike a variable attenuator, a pad is made up of fixed resistors. See ATTENUATION, ATTENUATOR, FILTER, RING MODULATOR.

PADDER. Synonym for PAD.

PADDING. Use of a PAD (q.v.).

PADDING CAPACITOR. Capacitor brought into circuit when a ganged superheterodyne receiver is switched to a particular wave band, to maintain the correct frequency-difference between the oscillator and the signal-frequency circuits. See GANGING, SUPERHETERODYNE RECEPTION, TRACKING.

PADDING CONDENSER. Synonym for PADDING CAPACITOR.

PANEL. Plate on which apparatus controls and measuring instruments are mounted, such as the front of a radio receiver. Alternatively, a self-contained group of apparatus wired and assembled on a mounting plate for fixing to a rack, having a connexion strip through which all external connexions are made.

PANEL-MOUNTING. Method of construction whereby apparatus is assembled and wired on a series of mounting-plates to form apparatus panels which are fixed to a rack. Panel-mounting is extensively used for aircraft and other radio installations.

PAPER CAPACITOR. Form of fixed capacitor having impregnated paper as the dielectric. See FIXED CAPACITOR.

PAPER CONDENSER. Synonym for PAPER CAPACITOR.

PARABOLIC REFLECTOR. Type of aerial reflector used when working on microwavelengths. Microwaves have characteristics very similar to those of light waves, and the parabolic reflector is an obvious directional device for use at these frequencies. If a dipole is placed at the focal point (*A* of Fig. 2), the parabolic reflector concentrates the radiation into a beam just as a searchlight reflector beams light. The parabola thus converts the spherical waves radiated by the dipole into vertical lines representing the wave front after reflection.

One form of parabolic reflector is known as the rotational parabola; physically, it resembles the narrow end of an eggshell cut in half. Fig. 3 shows a cross-section view of a rotational parabola which is excited by a vertical aerial located at the focal point inside the parabola. A small hemispherical cup is used to direct all the radiation back towards the parabolic surface, thus ensuring that no direct radiation from the aerial takes place, that the reflected beam is sharper, and that a minimum of power is wasted. If the shield were absent, some of the power would not be reflected; this unreflected power would not become part of the main beam and would serve no useful purpose.

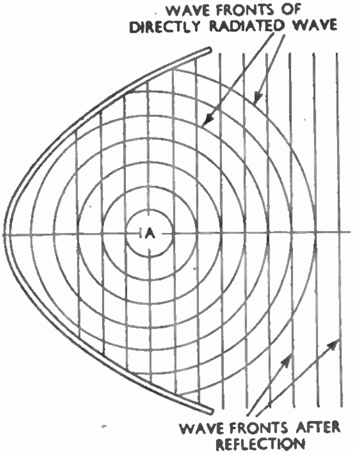


Fig. 2. Radiation of plane waves in the form of a beam when a sender dipole is located at the focal point (represented by *A*) of a parabolic reflector.

Another form of parabolic reflector is the cylindrical parabola with open or closed ends. This type of reflector has a parabolic curvature in one plane, usually the horizontal plane, and is excited by an aerial placed parallel to the cylindrical surface and located at the axis of the parabola. See MICROWAVE, RADIATION.

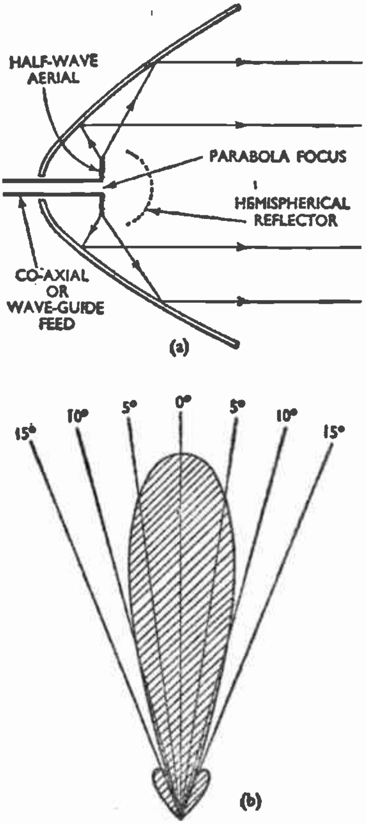


Fig. 3. Diagrams showing (*a*) the cross-section through a rotational parabola, and (*b*) the radiation pattern obtained. The pattern is the same in both the horizontal and vertical planes.

PARAFEED. Trade name for an early type of audio-frequency transformer which was expressly designed for parallel feed. Later, the term became a colloquial abbreviation for a parallel-feed circuit. See PARALLEL FEED.

PARALLEL CONNEXION. Arrangement of circuit elements or circuit parameters such that the voltage applied across each is the same. See SERIES CONNEXION.

PARALLEL FEED. Circuit in which A.C. power is obtained from the anode of a valve by means of a series capacitor, the anode being connected to the H.T. supply by a resistor or inductor. The circuit (Fig. 4) has the advantage of separating the D.C. and A.C. components of the anode current and is used whenever it is undesirable for D.C. to be present in the output circuit. It is sometimes called shunt feed.

PARAMAGNETIC. Possessing a magnetic permeability greater than unity, the value for a vacuum. If a substance responds to a magnetomotive force at all, it can therefore be said to be paramagnetic. See PERMEABILITY.

PARAPHASE. Particular method of phase splitting to produce a resistance-coupled balanced-valve amplifier. See PHASE SPLITTING.

PARASITIC AERIAL. Synonym for PASSIVE AERIAL.

PARASITIC OSCILLATION. Undesired oscillations occurring in a valve circuit having a frequency generally much higher than the normal operating frequencies.

PARASITIC STOPPER. Resistor connected in series with an electrode of a valve to prevent it from generating parasitic oscillation. The resistor should be connected as close to the electrode as practicable, and is commonly of the order of 5,000 ohms for a grid, and 50 ohms for an anode. See PARASITIC OSCILLATION.

PARTIAL. Any one of the single frequencies giving rise to a complex wave form. In complex musical wave forms, most partials are true harmonics of the fundamental. See HARMONIC.

PARTIAL RESTORING TIME. Time taken for the loss in an echo-suppressor to fall to 20 db. after the operating signal ceases. See ECHO-SUPPRESSOR.

PASS BAND. Frequency band lying between the upper and lower cut-off frequencies of a filter.

PASSIVE AERIAL. Element in a directive-aerial system which is not directly connected to sender or receiver, but is excited by induction. A passive element can be either a reflector (Fig. 5) or a director, according to its dimensions and whether it is placed behind or in front of the active aerial.

In a practical case, where the active aerial is a half-wave dipole, a reflector could be placed about a quarter of a wavelength behind, and should be slightly longer than the active element; a director, on the other hand, could be put in front of the active aerial, roughly at the same distance, and should be somewhat shorter. These spacings and dimensions are largely a matter of obtaining correct phase relationships to produce reinforcement of the radiation in a particular direction.

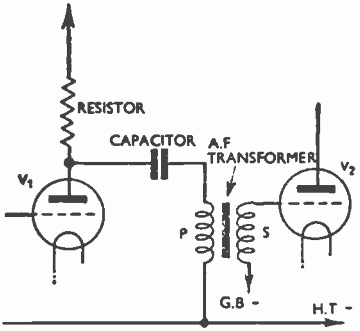


Fig. 4. Simple form of parallel-feed inter-valve coupling for A.F. amplification. The resistor and capacitor divert the A.F. component of the anode current of V_1 to earth through the primary winding (P) of the transformer.

PASSIVE NETWORK. Network in which there are no sources of power. See NETWORK.

p.d. Abbreviation for POTENTIAL DIFFERENCE.

PEAK. Maximum value of some regularly rising and falling quantity, such as an alternating or pulsating current or voltage.

PEAK FACTOR. Ratio between the root-mean-square equivalent of an alternating current or alternating voltage and its maximum value. If the current or voltage follows a sine law the ratio is fixed, but in other cases it depends on the shape of the wave. See ALTERNATING CURRENT, PEAK VALUE.

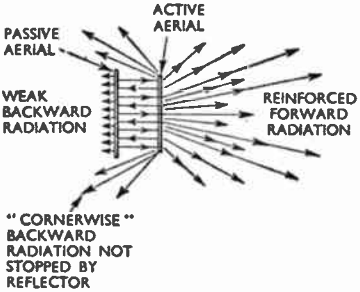


Fig. 5. An attempt to suggest diagrammatically the manner in which a passive aerial, arranged as a reflector behind a half-wave dipole, will affect the radiation in various directions.

PEAK INVERSE ANODE-VOLTAGE. Peak voltage acting across a rectifier when the rectifier is non-conductive. This may be considerably greater than the voltage across the rectifier when it is conductive. Gas rectifiers (for example, all forms of mercury-vapour rectifier) are liable to flash-over as a result of excessive peak inverse anode-voltage. See GAS-FILLED DIODE, MERCURY-VAPOUR RECTIFIER.

PEAK LIMITER. Device for preventing the instantaneous output-signal amplitude of a receiver or sender from exceeding a predetermined value. The device may be regarded as an amplifier so controlled by rectified signal currents that the gain is quickly reduced and then slowly restored to normal when the peak amplitude of signal applied exceeds the predetermined value. See LIMITER.

PEAK REVERSE ANODE-VOLTAGE. See PEAK INVERSE ANODE-VOLTAGE.

PEAK VALUE. Maximum reached by an alternating current or voltage at each successive half-cycle. Fig. 6 illustrates the term in the case of a half-cycle of sine-wave shape.

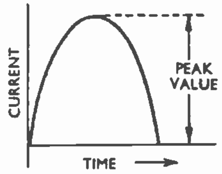


Fig. 6. The peak value of an alternating current or voltage is the momentary maximum occurring at each half-cycle.

PEAK VOLTMETER. Voltmeter for measuring the peak value of an alternating voltage. See VALVE VOLTMETER.

PELTIER EFFECT. Thermo-electric phenomenon associated with junctions of unlike metals, as in a thermocouple. When current passes from one metal to another heat is produced; when heat is applied to such a junction a voltage is produced. The effect is used in instruments for measuring high temperatures and radio-frequency currents.

PENETRATION. Process in which a current spreads into the substance of a conducting material. See DEPTH OF PENETRATION.

PENTAGRID. Synonym for HEPTODE.

PENTODE. Valve with five electrodes: anode, cathode and three grid-type electrodes (Fig. 7). The grid nearest the cathode is the control grid, the next is the screen grid and that nearest the anode is a suppressor grid (see GRID). Had it not been for the effects of anode secondary emission, it is doubtful if the amplifying pentode would have come into use to any considerable extent.

The triode has a limited usefulness, because its grid-to-anode capacitance makes it unsuitable for the amplification of radio-frequency waves. The insertion of the screen grid of the tetrode between anode and control grid reduces the grid-to-anode capacitance, but also introduces a new problem to do with anode secondary emission. One solution of this problem was to form a pentode by adding a third grid to the tetrode. The suppressor grid collects secondary electrons and prevents bombardment of the screen grid by them. The step from triode to tetrode was fundamentally important; that from tetrode to pentode was more expedient, however essential. Now that the problems introduced by secondary emission have been solved by other means, the performance of a tetrode differs but little from that of a pentode; indeed, it is sometimes superior (see BEAM-POWER-VALVE).

In normal use, the control grid of a pentode is negatively biased; the screen grid has a potential usually

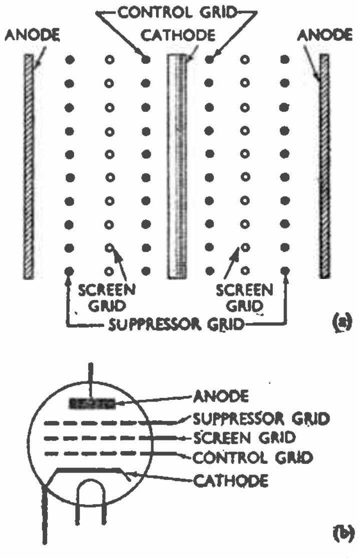


Fig. 7. Diagrams representing: (*a*) section through a pentode, distinguishing the five electrodes; and (*b*) the conventional symbol for a pentode.

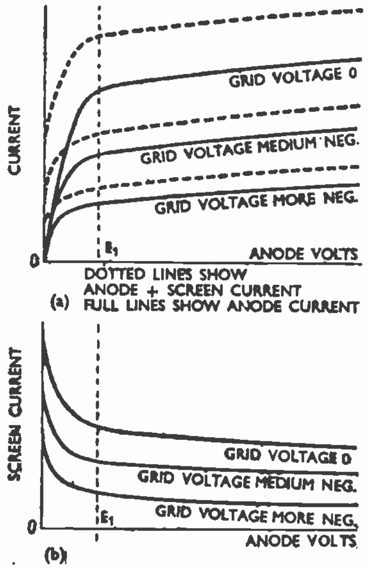


Fig. 8. Graphs indicating that, in a pentode, the total space current (anode current plus screen current) is almost independent of anode voltage when this exceeds a low value. In (*a*) the dotted lines show space current, and the full lines anode current; from (*b*) it is seen that, at low anode voltage (less than E_1), the screen current increases where in (*a*) anode current decreases.

somewhat less than, but of the same order as, that of the anode; while the suppressor is held at cathode potential. The control grid has a fine, and the suppressor grid an open, mesh. The screen-grid mesh is coarser than that of the control grid and finer than that of the suppressor.

Characteristic curves of a pentode of the type described are shown in Fig. 8. The basic principle of the pentode and tetrode valves is that, for a constant control-grid voltage, the total space current (the cathode current) is virtually independent of the anode voltage. This is because the screen shields the cathode from the anode and the anode voltage has no effect upon the potential gradient at the cathode. Thus it can be appreciated that, if the anode current increases, the screen-grid current decreases, and vice versa. This fundamental point is brought out in Figs. 8a and 8b.

There are two distinct regions of the anode-volts/anode-current characteristics of a pentode; one in which the anode slope-resistance is of the order of that of a triode, the other when it is very much greater and approaches or attains values measured in megohms. There is also a transition between low and high anode slope-resistance at a medium anode voltage (Fig. 9).

When the anode voltage is much lower than the screen voltage, many electrons which shoot past the screen grid are turned back to it because its potential is higher than that of the anode. Thus the lower the anode potential, the greater the screen current (the sum of the currents being nevertheless constant). When the anode voltage is much higher than the screen voltage, no electrons are turned back. In these conditions, the screen-grid current is virtually constant and is determined solely by the screen potential. The anode current is, for a constant control-grid bias, virtually constant, too, and is nearly independent of the anode voltage.

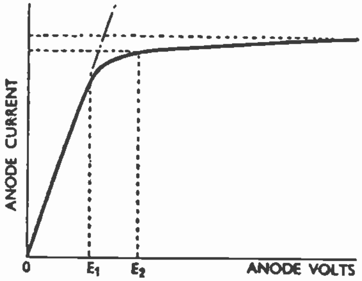


Fig. 9. Anode-volts/anode-current characteristic of a pentode at one fixed value of grid voltage. The slope resistance is low, or of the order of that of a triode, with the anode voltage between 0 and E_1, whereas it is extremely high (the normal operating condition) when the voltage exceeds E_2.

Fig. 10 shows grid-volts/anode-current characteristic graphs of a pentode. Owing to its very large slope resistance, the pentode used as an amplifier may be considered as approximating to a constant-current generator. That is to say, changing the impedance of the anode load of a pentode will almost proportionately alter the voltage across the load, provided that the impedance of the load is of the order of tens of thousands of ohms.

In comparing a triode and pentode (or tetrode), it is essential to understand that it is the AMPLIFICATION FACTOR and SLOPE RESISTANCE (q.v.) which differ, while the mutual conductance is much the same. Thus a triode and a pentode might both have a mutual conductance of 2 mA/V; the triode would, perhaps, have an amplification factor of 10 and a slope resistance of 5,000 ohms. The pentode, on the other hand, might have an amplification factor of 2,000 and a slope resistance of a megohm. In both cases the ratio of amplification factor to slope resistance is the same: namely, $g_m = 2 \times 10^{-3}$; but the values of the numbers making the ratio are vastly different. The amplification factor of a pentode is of the order of thousands, but the stage gain can never be as great as this because the anode circuit or anode load cannot have an impedance which approximates to the value of the slope resistance of the valve.

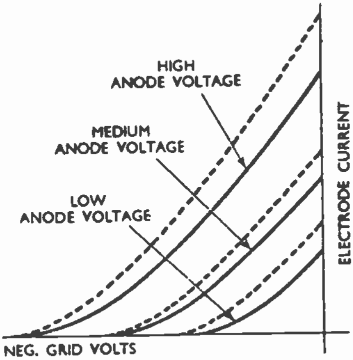


Fig. 10. From these graphs it is evident that the difference between screen-grid current and total space current increases as grid voltage is less negative. Dotted lines represent the space current, and full lines the anode current.

The load of a triode may be comfortably matched to the low slope resistance. But the amplification factor of a triode is relatively small, so, in spite of good matching, the gain is small. Thus the stage gain of both pentode and triode is of the same order; the pentode is superior in respect, chiefly, of inter-electrode capacitance and high slope resistance. See AMPLIFIER, ANODE-VOLTS/ANODE-CURRENT CHARACTERISTIC, MATCHING, MUTUAL CONDUCTANCE, STAGE GAIN, TETRODE, TRIODE.

PENTODE CONNEXION. Manner in which a pentode is connected according to which of the various forms of amplifier it is desired to produce. Four methods of connexion, producing four different results, are shown at Fig. 11.

PENTODE FREQUENCY-CHANGER. Pentode used as a FREQUENCY-CHANGER VALVE (q.v.).

PERCENTAGE MODULATION. See MODULATION PERCENTAGE.

PERIKON DETECTOR. Particular type of crystal detector using crystals of zincite and bornite in contact. See CRYSTAL DETECTOR.

PERIOD. Time required for a complete cycle of some repetitive process, typically of an alternating current; it is, numerically, the reciprocal of the frequency. Thus, if the frequency of an alternating current is 50 c/s, the period is one-fiftieth of a second.

PERIODICITY. Synonym for FREQUENCY.

PERIODIC TIME. Synonym for PERIOD.

PERMANENT MAGNET. Piece of steel or special alloy which continues to exhibit magnetic properties after being subjected to a magnetizing force. Permanent magnets are useful wherever a fairly strong magnetic field is desired without the complication of an electromagnet. They are used in measuring instruments to provide a field with which that produced by the actuating winding can interact; also in loudspeakers, microphones, gramophone pick-ups, magnetos used for car-ignition purposes, and other small generators in which it would not be convenient to provide a field current to energize an electromagnet. See MAGNETISM.

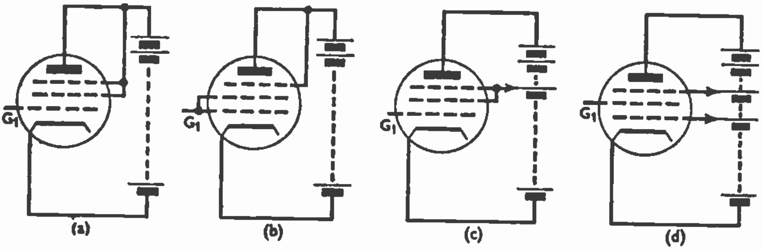


Fig. 11. Four ways in which a pentode may be connected: (*a*) for operation as a triode with a medium amplification factor; (*b*) as a high-mu triode; (c) as a tetrode, and (*d*) with the characteristics of a space-charge-grid valve.

PERMEABILITY. Property of responding to a greater or less degree to a magnetizing force. Permeability is most simply expressed in terms of the intensity of the magnetic flux produced by a given magnetizing force, which, in turn, is usually defined as a function of the ampere-turns of the magnetizing winding. Two materials might thus be compared by determining the intensity of the magnetic field of force which appears when they are inserted in turn in a current-carrying winding.

Permeability is usually expressed as the B/H ratio of the particular material; B is the flux density produced, and H the ampere-turns factor of the magnetizing winding—the ampere-turns in each unit of length of the coil. On the customary scale, a vacuum is regarded as having unit permeability; ferrous metals have the highest permeability, and are always used when it is desired to produce the maximum intensity of magnetic effect from a given magnetizing current. See INCREMENTAL PERMEABILITY.

PERMITTIVITY. Property, possessed by a particular material, of permitting an electric field of force to be set up in it with greater or less efficacy. Thus, if a material has high permittivity, an electric flux will produce more effect in it than it would in one of lower permittivity. The permittivity of a material may therefore be defined as the relationship between the displacement current and the value of the electric potential producing that current (see DISPLACEMENT CURRENT).

Permittivity is an important property of insulating materials, and is of particular significance wherever capacitance is concerned. Thus the dielectric material of a capacitor is one of the major factors which decide its capacitance; with air as a dielectric the capacitance may be, say, 10 units; but if, instead of air, sheets of mica are placed between the plates, the capacitance may go up to 50 or 60 units. Air is an insulating material with one of the lowest permittivities; if a vacuum is taken as having a permittivity of unity, air has the figure of 1·00058. The permittivity of mica is from 5 to 7, according to grade; that of ebonite is from 2 to about 4, and that of oils and waxes is between about 2 and 5. See CAPACITANCE.

PERSISTENCE OF VISION. Retention of an image by the eye after the source has been removed. When light falls on the retina, it causes certain chemical changes which stimulate the nerve of sight. When the light is removed, the retina does not immediately resume its former state, and the effect of the light persists for a short time. This can be demonstrated by swinging a lighted torch about in the dark; it appears to form a streak of light which traces its path.

Advantage is taken of this phenomenon to give the illusion of movement in the cinematograph and in television. Provided that a series of pictures is presented to the eye rapidly enough, the eye will not convey to the brain the fact that the pictures have been changed or moved. If the pictures are all identical and they are presented in the same area at a rate of not less than 16 per second, the eye will record the impression that there has been only one picture all the time.

If slight changes in position of objects occur in successive pictures, the eye will record the impression that movement of those objects has taken place, but not that any change has been made in the pictures themselves.

Extreme accuracy in the location of successive pictures is necessary, however, for the eye will be very sensitive to any movement or displacement, and flicker, blurring and eye-strain will follow any such movement. All parts of the pictures not meant to show movement must be accurately positioned to correspond with each other as the pictures are changed. Only those objects intended to show movement must be allowed to change position on the screen or in relation to the rest of the picture.

p.f. Abbreviation for POWER FACTOR.

PHANTOM AERIAL. Synonym for ARTIFICIAL AERIAL.

PHANTOM CIRCUIT. Circuit by means of which three messages may be sent independently over two balanced transmission lines. In such a circuit two transmission lines carry two different messages in the normal way; the third message is sent over what are, in effect, two conductors, each being the two wires of the two lines in parallel (Fig. 12).

If perfect balance is maintained, there will be no interference between messages sent over the phantom circuit and those sent in the normal way through the transmission lines. The circuit is often arranged so that two pairs of lines suffice for two telephony transmissions, while the phantom circuit is used for telegraphy. See TRANSMISSION LINE.

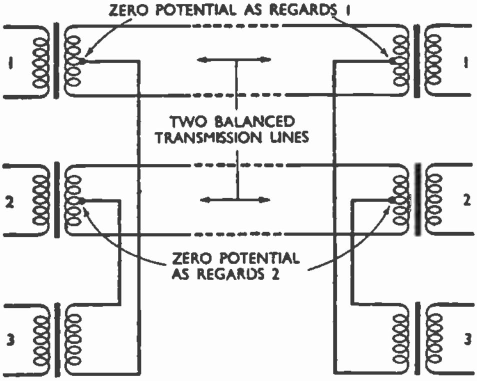


Fig. 12. Principle of the phantom circuit. Messages are sent 1–1 and 2–2 in the normal manner through two two-wire balanced transmission lines; a third channel, 3–3, is formed, the "go" and "return" circuits being respectively the parallel connexion of the two wires of each transmission line.

PHASE. One circuit of a polyphase A.C. system; or one winding of an alternator generating such a supply;

or the time-relationship implied in such terms as "phase delay" and "phase difference." In its time sense, phase implies some relation to the standard A.C. cycle of 360 deg.; thus, currents which are of the same frequency, but timed so that they reach their successive maxima at different instants, are said to be "out of phase" by an amount which is defined in degrees and called the phase angle (Fig. 13).

Currents of the same frequency which are in step are said to be "in phase," as are the current and voltage in a purely resistive circuit. See ALTERNATING CURRENT, PHASE ANGLE, PHASE DIFFERENCE.

PHASE ANGLE. Angle which represents the extent to which one regularly varying phenomenon differs in timing from another of the same frequency, expressed on the usual scale in which one complete cycle is taken as 360 deg. Thus, if the current in an alternating circuit lags behind the voltage by a quarter of the time required for the whole cycle, the phase angle is 90 deg.

PHASE-CHANGE COEFFICIENT. Imaginary part of the propagation coefficient. See PROPAGATION COEFFICIENT.

PHASE-CHANGE NETWORK. Quadripole having, ideally, zero attenuation but producing a difference of phase between the waves at the input and output terminals, the phase change varying with the frequency of the wave. Such a network is sometimes called an "all-pass" network. See PHASE.

PHASE COMPENSATION. Term describing the use of a DELAY EQUALIZER (q.v.).

PHASE COMPENSATOR. Synonym for DELAY EQUALIZER.

PHASE CONSTANT. Synonym for PHASE-CHANGE COEFFICIENT.

PHASE CORRECTION. Synonym for PHASE COMPENSATION. See DELAY EQUALIZER.

PHASE DELAY. Time taken for a wave of single specified frequency to be transmitted through a communications system or network. It is usually expressed in milliseconds with respect to the time taken by a wave of 800 c/s to be transmitted through the same circuit.

PHASE-DELAY DISTORTION. Distortion of a complex wave as received at the end of a long transmission line and caused by the difference in time of arrival of the various components of the wave. See PHASE DELAY.

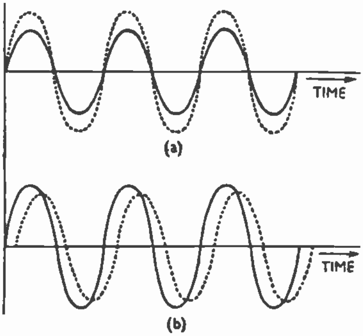


Fig. 13. Graphs showing two currents or voltages which are (*a*) in phase, and (*b*) out of phase by a small angle.

PHASE DIFFERENCE. Variation in timing between two regularly changing phenomena of the same frequency. For example, the alternating current in the secondary winding of a transformer will normally show a certain phase difference from the current in the primary. The term is sometimes used when referring to the angle of lag or lead of an alternating current in comparison with the voltage.

PHASE DISPLACEMENT. Synonym for PHASE DIFFERENCE.

PHASE DISTORTION. Distortion of a signal wave form resulting from a change in the phase relationships of the component frequencies. For example, the wave form (a) in Fig. 14 consists of a fundamental and a third harmonic with their peaks coinciding (b). After passing through an amplifier or transmission line in which the phase of the harmonic is advanced (Fig. 14c), the result is something like that shown in the fourth diagram (d).

Although the difference appears obvious, the ear is not sensitive to phase distortion in sustained complex sounds. Relative phase is important in television, however. See LINE DISTORTION, TRANSIENT DISTORTION.

PHASE EQUALIZATION. See DELAY EQUALIZER.

PHASE EQUALIZER. Network designed to compensate, within a specified frequency band, for the phase delay occurring in a particular circuit, thus compensating for PHASE-DELAY DISTORTION (q.v.).

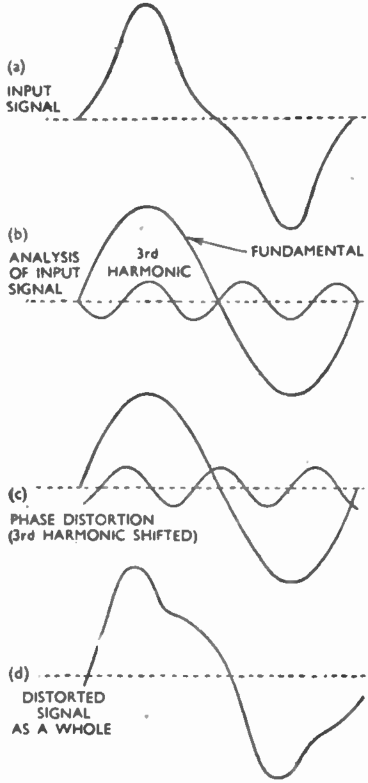


Fig. 14. Analysis of an example of phase distortion. Wave (*a*) consists of a fundamental and a third harmonic (*b*); if the phase of the harmonic is advanced (*c*), the distorted form (*d*) results.

PHASE FOCUSING. Term used in connexion with the MULTI-CAVITY MAGNETRON (q.v.) to describe the effects of the cavities upon electron concentration in the space between anode and cathode.

PHASE MODULATION. Modulation in which the modulating wave varies the phase of the carrier wave. The term "phase," in this context, means the phase of the modulated wave with respect to that of the unmodulated carrier wave. The modulation index in a phase-modulated wave is proportional to the amplitude of the modulating wave, and is independent of the frequency of the modulating wave. If the amplitude of a modulating wave is made proportional to frequency and is then applied to the terminals of a frequency modulator, the resulting wave is a phase-modulated one.

Conversely, if the amplitude of the modulating wave is made inversely proportional to the frequency and is then applied to the modulating-wave terminals of a phase modulator the output is a frequency-modulated wave. Thus a phase modulator can produce a frequency-modulated wave if the amplitude of the modulating wave is made inversely proportional to frequency. The differences between phase and frequency modulation are brought out in Figs. 15 and 16 in terms of the form of the modulated wave. See FREQUENCY MODULATION, MODULATION INDEX, PHASE MODULATOR.

PHASE MODULATOR. Modulator arranged so that the phase of the modulated wave varies in proportion to the amplitude of the modulating wave. A carrier wave is combined with a second carrier wave of the same frequency which is 90 deg. out of phase with the first wave. The amplitude of the second carrier is varied between certain limits, according to the modulating wave, and the resultant is a phase-modulated wave. In practice,

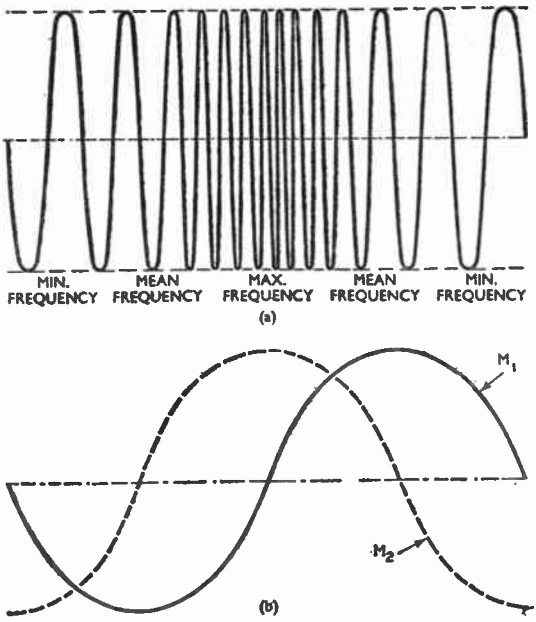


Fig. 15. When the modulating wave M_1 in (*b*) is applied to a phase-modulator, the modulated wave (*a*) is produced. The result is the same as that obtained by frequency modulation if the wave M_2 in (*b*) is applied to the modulator.

the variable-amplitude wave is the resultant of two further waves and is very similar to a suppressed-carrier, amplitude-modulated wave.

The conclusion is that phase modulation of a carrier wave can be produced by adding to it an amplitude-modulated suppressed-carrier wave, if this added amplitude-modulated wave is of the same frequency as the carrier wave, and at 90 deg. phase difference.

As only small phase modulations are possible by this system, a frequency-multiplier and a limiter are included. The limiter keeps the amplitude constant, while frequency multiplication multiplies the angle of phase-shift produced by modulation. See FREQUENCY MODULATION, FREQUENCY MODULATOR, PHASE MODULATION, SUPPRESSED-CARRIER MODULATION, SUPPRESSED-CARRIER MODULATOR.

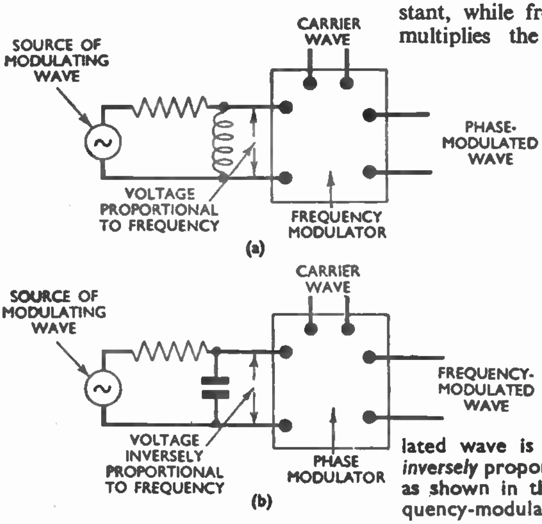


Fig. 16. If the modulating-wave voltage applied to a frequency modulator is proportional to frequency, as in (*a*), a phase-modulated wave is produced; but if it is *inversely* proportional to the frequency, as shown in the circuit at (*b*), a frequency-modulated wave is obtained.

PHASE RELATIONSHIP. For two sinusoidal waves of the same frequency, the constant angle between the rotating vectors representing the two waves. See PHASE-SHIFT, VECTOR.

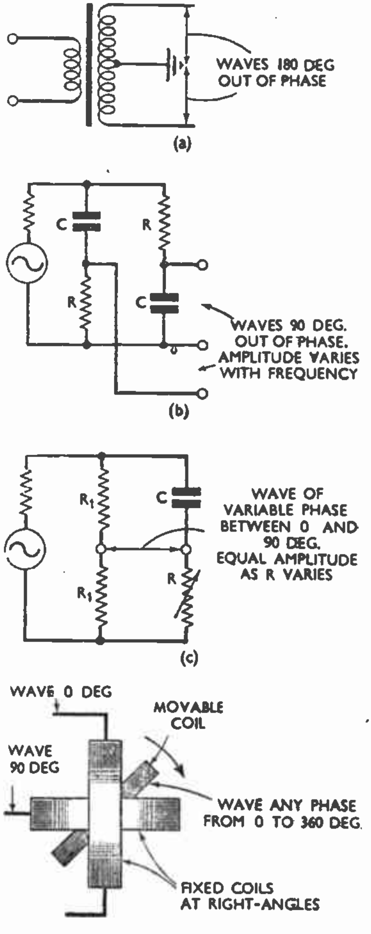


Fig. 17. Diagrams illustrating four methods of phase splitting: (*a*) by a transformer; (*b*) by a circuit which produces waves in quadrature; (*c*) by deriving a wave of any phase 0-90 deg., and (*d*) by producing a wave having any phase, 0-360 deg.

PHASE REVERSAL. Process of setting up a phase difference of 180 deg. between two regularly varying phenomena of the same frequency; for instance, between two alternating currents. An example occurs when a radio-wave is reflected from a conducting surface; phase reversal occurs in the process of reflection, and the emergent wave is 180 deg. out of phase with the incident wave.

PHASE-SHIFT. Alteration of the time relationship between two or more regularly varying phenomena of the same frequency. The term refers more particularly to such phase differences as there may be between the primary and secondary currents in a transformer, especially in the case of transformers expressly designed to make the phase difference adjustable. See PHASE ANGLE, PHASE DIFFERENCE.

PHASE SPLITTING. Production of two or more waves from one wave, the new waves having a phase difference from the original. The term has a wide significance in both electrical and telecommunication engineering. In signalling circuits, conversion from unbalance to balance can be classified as phase splitting. Thus a single phase source applied to the primary of a transformer produces what can be considered as two waves 180 deg. out of phase at the secondary (see BALANCED CIRCUIT, UNBALANCED CIRCUIT). It is often necessary to produce two waves with a 90-deg. phase difference from a single-phase wave.

A circuit such as that shown in Fig. 17b would be suitable. However, the relative amplitudes of the two waves in quadrature vary with frequency and are equal only when $\omega CR = 1$, i.e., when the reactance of the capacitor equals the value of the resistor. The phase-splitting circuit of Fig. 17c is one in which the amplitude of the two waves is always equal but in which the phase varies from 0 to 90 deg. as a resistor is changed in value. The circuit shown in Fig. 17d indicates how the phase of the currents in the movable coil can be changed by 360 deg., but, in this case, the single-phase wave must be split before being applied to the two stationary coils. See PHASE, PHASE-SPLITTING CIRCUIT, QUADRATURE, TRANSFORMER.

PHASE-SPLITTING CIRCUIT. Circuit providing two opposite-phase versions of a signal for application to the grids of a pair of balanced output valves (see BALANCED VALVE-OPERATION). In the original form of the balanced circuit the pair of opposed valves was driven by means of an inter-valve transformer with a centre-tapped secondary winding. The centre tap was earthed, either directly or indirectly, and the two ends of the winding naturally delivered signal voltages of opposite phase. The secondary became like a see-saw, with the centre anchored and the ends swinging alternately up and down.

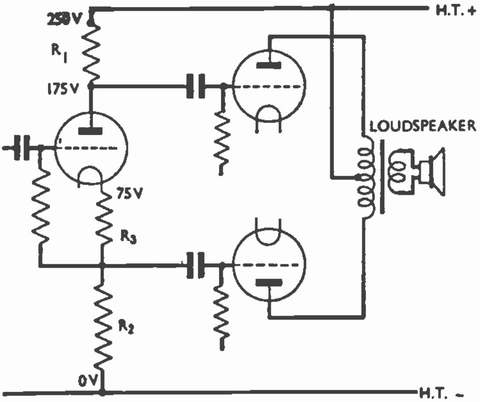


Fig. 18. Form of phase-splitting circuit in which the anode load comprises two resistors, R_1 and R_2, of equal value (R_3 is a bias resistor). Grids of the output triodes are connected to anode and cathode respectively of the "splitter" valve.

That is phase splitting in one sense; but the term is now more often applied to somewhat more specialized methods which have been devised to enable balanced-valve techniques to be used with resistance-capacitance coupling. Perhaps the classic method is that which Fig. 18 illustrates; there, the resistance load of the valve is divided between the two resistors R_1 and R_2, each of half the normal value for the particular valve.

The anode current of the valve passes through both of the resistors, and will set up voltage differences across them. The cathode of the valve will be at a considerable positive potential to earth, and the anode will be at a still higher one—higher, in fact, by the amount of the voltage drop across the valve itself. A set of possible voltage figures is marked on the diagram to make the point clear.

Now suppose the anode current is caused to increase by an incoming signal. There will then be a greater voltage drop across each resistor; so the anode voltage will fall, while the voltage of the cathode above earth will rise. It will be noted that the anode voltage has become less positive, while the cathode voltage has become *more* positive; or, in other words, the anode voltage has swung negative while the cathode voltage has swung positive.

Next, imagine that the anode current *decreases*. That will mean less voltage drop across the two resistors; anode voltage will rise to more nearly the full H.T. value, while the cathode will sink towards the earth value; the anode has become more positive this time, while the cathode has become less positive—or more negative. In fact, there is just the see-saw action we want for a balanced-valve circuit; whatever happens to the anode current, the voltages to earth of the anode and cathode move in opposite ways.

Fig. 18 shows a phase-splitter of this

type connected to a pair of balanced output valves, and it will be noted that their grid connexions come from the anode and cathode of the splitter, via blocking capacitors, of course.

Subject to certain practical precautions, a split-phase amplifying arrangement of this type will give excellent results. In theory, there is a slight unbalance on the highest audio frequencies, because the anode-earth capacitance of the driving valve is not equal to the cathode-earth capacitance, but this is harmless in practice so long as the coupling resistors are of suitably low value. Their resistance is then so much lower than the reactances of the internal capacitances in the driving valve, that any shunting effect on the signals is negligible.

Certain details of the input circuit in Fig. 18 are noteworthy; for instance, the input voltage is applied between grid and earth, and this means that the coupling resistor R_2 is common to both grid and anode circuits. In that position, it inevitably produces extremely pronounced negative-feedback effects, whereby the gain of the stage is cut down to quite a low value. Negative feedback here is not so beneficial as it is in the output stage, but it still has certain advantages; the deficiency in gain must be made up elsewhere.

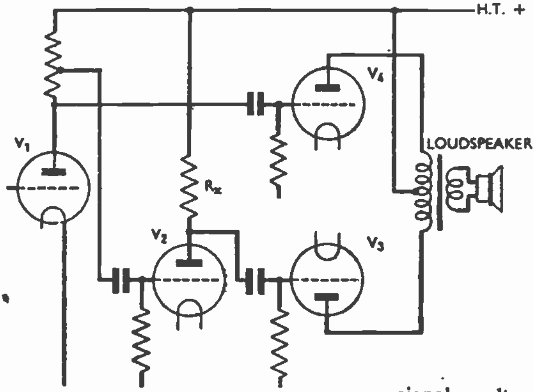


Fig. 19. Elements of the paraphase system described in the accompanying text; it may be regarded as a form of phase-splitting circuit.

Grid bias is applied to the phase-splitter in much the usual way from a cathode resistor, but the connexion thereto of the lower end of the grid leak is not quite conventional; the more usual plan of connecting the leak straight to earth would result here in an excessive bias, since the voltage across R_2, as well as that across the actual bias resistor, R_3, would be applied between grid and cathode. Instead, the leak is connected to the junction of R_2 and R_3 so that only the p.d. across R_3 is used as bias.

One of the first successful attempts to devise a balanced-valve amplifier with resistances, instead of the original transformer coupling, was a circuit known as the PARAPHASE (q.v.). In this, something which could, perhaps, be called phase splitting was done—it must be done, of course, if balanced working is to be possible—with the assistance of an extra valve in one "leg" of the balanced circuit.

Here, it should be explained that each valve in an amplifying chain normally reverses the phase of the signal voltages; when the signal causes the grid of a valve to swing positive, the anode goes negative, and vice versa. Therefore, simply by interpolating a valve between two points, a phase reversal is caused; which is the requirement of the paraphase circuit.

The elements of the paraphase system are shown in Fig. 19, where it may be seen that the essential of the system is that one of the output valves is fed direct from the first stage, V_1, and the other receives its drive by way of the intermediate valve V_3, which, of course, reverses the phase in the desired manner. It will also amplify the signal and give V_3 a bigger input than V_4 if due care is not taken; but this can be obviated by reducing the input of V_3 until it hands on a signal of correct amplitude. The diagram shows one way in which this can be done; only a fraction of the output of V_1 is applied to the grid of V_2. The gain of the V_2 stage would also in practice be limited by using a comparatively low value for the anode resistor, R_x.

There are many ways of effecting phase splitting in order to work a pair of balanced-output valves; those just discussed are typical, and demonstrate the simple principles involved. See AMPLIFICATION, RESISTANCE-CAPACITANCE COUPLING.

PHASE SWING. In phase modulation, phase angle by which the phase of a phase-modulated wave is changed by the modulating wave. See PHASE MODULATION.

PHASE VELOCITY. Velocity of a wave specified in relation to its phase. Phase velocity is the same as group velocity when the phase velocity is independent of frequency. Phase velocity is defined as the product, at any instant of time, of the frequency and the distance between corresponding points on two successive waves in a series of sinusoidal waves. Consider a complex wave being propagated in a medium; it may be electric strain, current in a transmission line or pressure of air in a sound wave. If the various sinusoidal components of the complex wave have frequencies f_1, f_2, f_3, and the distances between corresponding points in the various components are d_1, d_2, d_3, then the phase velocities of the components are f_1d_1, f_2d_2 and f_3d_3.

If all the phase velocities are equal, the complex wave is transmitted along the medium without any alteration in shape and arrives at the receiving end undistorted. In this case, the phase velocity is equal to the group velocity. But if all the phase velocities are not equal, the wave shape at the receiver differs from that radiated from the sender. The distortion so produced is termed "delay distortion" and can be corrected in part by a delay equalizer. See DELAY DISTORTION, DELAY EQUALIZER, GROUP VELOCITY.

PHILIPS-MILLER RECORDER. Sound-recording system in which the sound track is cut on a moving film and reproduced by a photocell. The recording system is basically similar to gramophone recording, a wide-angle sapphire cutter being used to produce a variable-area track (see ELECTRICAL RECORDING). The reproducing system is identical with that used with photographic sound film.

PHON. Unit in which loudness level is measured; to find the loudness level of a particular sound or noise it is compared subjectively by the ear with a 1,000-c/s note the level of which is adjusted until the apparent loudness of both is the same. The intensity level of the 1,000-c/s note expressed in decibels then gives the loudness level of the sound or noise in phons. Alternatively, the comparison between the sound to be measured and the 1,000-c/s note can be carried out objectively by means of a microphone and amplifier, the latter including a frequency-discriminating network.

PHONIC WHEEL. Simple form of synchronous motor which can be driven from valve oscillators of low power. The frequency of the oscillators can be calculated by means of a revolution counter on the motor.

PHOSPHOR. Name given to the coating which forms the screen on the glass of a cathode-ray tube; that is, the coating which fluoresces or phosphoresces on the impact of electrons.

Fluorescence and phosphorescence are so closely linked that it is almost impossible to obtain one without some degree of the other where a cathode-ray tube is concerned. Though fluorescence should, strictly, be applied only to the effect given by the coating which radiates light on electron impact and *ceases to radiate* immediately the impact ceases, and while phosphorescence should denote the material that *continues to radiate* light after cessation of impact, in actual fact, some degree of each is present in every type of screen, and they have been generically termed phosphors.

Among the best-known phosphors are willemite and sidot blende, the former giving a yellow-green light and the latter a green. It is strange that the pure substances emit hardly any light at all and that the luminescence depends on the presence of small amounts of impurities, such as oxides, traces of copper, silver, lead, etc. If wrong impurities are allowed to be present, the luminescence may be completely absent.

The following list gives some of the most used phosphors and the colour of their luminescence:

Barium platinocyanide	Blue-violet
Zinc sulphide and cadmium sulphide ..	Sepia
Zinc silicate and cadmium tungstate ..	Blue-white
Zinc phosphate ..	Red-orange
Cadmium tungstate ..	Green-blue
Manganese silicate ..	Red

The degree of after-glow of a cathode-ray tube is a very important feature. In radar plan-position indicator tubes long after-glow is desirable so that the position of the target can be seen during the whole of the time taken for the trace to rotate round the tube. In other cases, such as the normal oscilloscope, a smaller after-glow is desirable.

In television, a very small amount of after-glow is desirable so that the picture will not flicker in the highly illuminated portions, though the after-glow must not be enough to cause defocusing.

The grain of the material forming the phosphor must be sufficiently fine that it does not cause a spreading of the spot of light on the impact of the electron beam. The smaller the diameter of the spot of light caused by a finely focused beam of electrons, the greater the degree of focus and definition that is possible in television or oscilloscope operation. Spreading of the spot size must not occur; the luminescence must not spread away from the area actually under electron impact.

PHOSPHORESCENCE. Luminosity produced by certain substances after subjection to visible or ultra-violet light, such luminosity persisting after the withdrawal of the light. In connexion with cathode-ray tubes, see AFTER-GLOW.

PHOTOCELL. Device which emits electrons when exposed to light. Any metallic substance has power to throw off electrons when subjected to the influence of light. In most cases, the number of electrons released is very small, but the alkali metals, potassium, rubidium, caesium, strontium, lithium, sodium and barium are comparatively sensitive, caesium being the most affected by exposure to light.

Photo-electric action was first discovered in 1888 by Hertz when he noticed that some electrical equipment was "upset" when a strong light fell on it. Today photocells are employed in hundreds of commercial spheres. They are used in burglar alarms, the alarm ringing when a beam of infra-red light falling on a photocell is interrupted; automatic signalling devices use them; the well-known light meter used by photographers contains a photocell and a meter; the cinema employs them for reproducing the film sound track, and television uses myriads of minute photocells in the storage camera.

Most photocells contain a caesium-silver compound which is not only light-sensitive but particularly sensitive to the red end of the light spectrum, making them of particular value in many industrial processes where artificial lighting is so important.

The caesium-silver combination is known as the cathode of the cell. There is also an anode, a simple metal structure, such as a loop of wire, or a piece of wire gauze. In the storage camera the anode is a metal plate, and the two electrodes are mounted in an evacuated glass bulb, the vacuum being a hard one. Where the normal photocell is concerned, however, a certain amount of inert gas, usually argon, is inserted to increase the sensitivity of the cell by ionization.

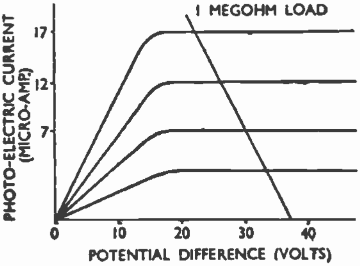


Fig. 20. Response characteristics of a photocell. The vacuum type of caesium cell tends to give linear output with change of p.d. after an initial rise; the load line for a cell with a load of 1 megohm is approximately as shown.

The cell is operated with a positive voltage on the anode. This electrode attracts the electrons emitted by the cathode. On the way over, they encounter the atoms of gas in the bulb. If the anode voltage is low, the electrons merely bump into the gas atoms and fly off again without anything happening. But if the anode voltage is increased, and the electrons speeded up, they collide with the gas atoms with sufficient force to knock electrons off them.

These electrons add to the number of those travelling from the cathode. A great deal of multiplication can be obtained by increasing the anode voltage. There is, however, a definite lag in the gas-filled photocell which makes it unsuitable for use at high frequencies.

The sensitivity of caesium varies with the sensitizing process. Greatest sensitivity is obtained by a very thin deposit of the metal, but its response shows pronounced maxima in the infra-red and ultra-violet ends of the spectrum. The response shows a decided falling-off between orange and green. By the use of mixed cells, it is possible to obtain a fairly even chromatic response. Thus caesium and barium might be used, the output currents being fed to separate amplifiers. The outputs of these amplifiers could then be mixed at will.

Owing to the chromatic sensitivity of photocells, the sensitivity should be reckoned as the current response to a given light-flux emitted by a Planckian radiator at some definite temperature. The brightness should be measured by a visual photometer. A tungsten source at 2,800 deg. Kelvin is suitable, the sensitivity of the photocell being stated as so many micro-amperes per lumen tungsten.

Some idea of the sensitivity of a modern caesium-oxide cell, such as that used for television in the storage camera, can be gained from the fact that, at the "far red" range (one of the two maxima points), the sensitivity is 10 μA per lumen tungsten.

It has been stated that increase of potential across the photocell provides increased emission. That is true particularly where gas-filled cells are concerned. In the case of the cell in vacuo, however, it is only a part-truth. The caesium cell in vacuo, for instance, gives a linear output with change of p.d. after an initial rise. By having a working potential well above saturation value, it can be run in series with a high resistance without fear of non-linearity, the load line for, say, 1 megohm being roughly as that shown in Fig. 20.

PHOTO-CHEMICAL CELL. Photocell consisting of two electrodes of the same metal immersed in an electrolyte. A potential difference is set up between the electrodes when light falls on one of them. This type of cell is sometimes called photo-electrolytic or photo-voltaic.

PHOTO-CONDUCTIVITY. Phenomenon exhibited by certain substances, such as the element selenium, in which their electrical resistance varies with change in the intensity of light falling upon them.

If a selenium cell is connected in series with a source of e.m.f. and a galvanometer, and light is directed on to the cell, the resistance of the cell varies in accordance with the intensity of the light falling on it. As the intensity of illumination increases, the resistance of the cell decreases, while it increases with diminution of light until the light reaches zero. At this point, the resistance of the cell is termed the dark resistance.

There is a definite lag between the incidence of the light on the cell and the change of resistance, the decrease on increase of light intensity being rapid at first, slowing down to a matter of several tenths of a second at each light change, the amount of time lag depending on the type of cell and the intensity of the light. If a sudden decrease in light is experienced, the resistance of the cell returns to its former value more slowly than the reaction in the opposite direction, that is, on an increase of light. Further, the dark resistance of the cell is not a constant figure, variations being experienced with changes of ambient temperature, humidity and the degree and duration of exposure to light.

Thallium sulphide which has been oxidized is also very sensitive to light changes, particularly in the infra-red part of the spectrum. The cells, made up in an evacuated glass envelope, are almost instantaneous in their return to dark-resistance value after exposure to low light intensities. The dark resistance ranges between 5 and 500 megohms.

Various methods of combating the sluggishness of the photo-conductive effect have been tried, but probably the most successful was that adopted by Baird in which he introduced into the current output from the cell a current proportional to the rate of change of that current. This was tried in an endeavour to make the cell useful from a television point of view.

PHOTO-CURRENT. Current emitted by a photocell under the influence of light.

PHOTO-ELECTRIC CELL. Synonym for PHOTOCELL.

PHOTO-ELECTRIC EFFECT. Production of an electric current, or an emission of electrons, when light falls on a suitably treated surface; or variation in an existing current when light acts on a "light valve" (see SELENIUM CELL). The strict application of the term denotes the emission of electrons under the impact of light rays on certain metals, notably caesium.

In a vacuum, such emission can be attracted to a positively charged anode, just as in a thermionic valve, and extracted as a current which is proportional (over a certain range of values) to the total light flux falling on the emissive surface. This effect is the basis of the PHOTOCELL (q.v.), and, in a slightly different form, of the STORAGE CAMERA (q.v.) used in television.

PHOTO-ELECTRONICS. Science of the light-activation of substances resulting in electron emission.

PHOTO-EMISSION. Emission of electrons from a substance under the influence of light. See PHOTOCELL.

PHOTO-RADIOGRAM. Facsimile transmission of a letter or picture by means of radio. The Fultograph was a crude method of achieving a photo-radiogram. See FACSIMILE, TYPE A4 WAVE.

PI (π)-NETWORK. Network composed of three impedances connected in delta formation. The three junction

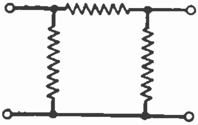


Fig. 21. A pi-network is composed of three impedances as shown.

points are connected to an input terminal, an output terminal, and a combined input and output terminal (Fig. 21).

PICK-UP. See DIRECT PICK-UP, GRAMOPHONE PICK-UP, VISION PICK-UP.

PICK-UP FACTOR. Ratio of the voltage generated across a specified receiver input impedance to the strength of the field at the aerial location, the aerial being orientated to produce maximum signals.

PICOFARAD. Synonym for MICRO-MICROFARAD.

PICTURE-CHASING CIRCUIT. In television, a circuit used with intermediate film scanning systems in which the film is continuously moving.

PICTURE-ELEMENT. Small portion of a picture or scene which is capable of being transmitted as a complete entity. Whether facsimile or television transmission is employed, no system is capable of sending the whole of a picture at one time, that is, as a complete entity. All pictures have to be transmitted in small pieces or elements, the elements being arranged at the receiver in regular order to form the complete picture(see SCANNING).

Attempts to transmit all the elements of a picture simultaneously over one channel have failed. The alternative is to send and receive them successively, or in some regular order, so that the picture can be rebuilt correctly. So, by various means, every picture to be transmitted is divided up into points (much in the same way as a photograph printed in a newspaper is composed of small dots) and each point, or element, is the subject of a separate radio signal.

There is nothing unusual about this, since the eye itself is built up of a number of tiny cells, each of which receives the light from a picture or scene, and transmits the effect to the brain. Thus the eye, in fact, builds up its vision in element form.

PICTURE-FREQUENCY. Rate of repetition of a complete picture in television, each picture being offered to the eye of the observer at a rate which provides the illusion of continuity. In the B.B.C. system of television, the picture frequency is 25 per second. See INTERLACED SCANNING.

PICTURE POINT. Synonym for PICTURE-ELEMENT.

PICTURE RATIO. Ratio of horizontal to vertical dimensions of a television picture. It is sometimes referred to as the aspect ratio. In the B.B.C. high-definition television system, the picture ratio is 4 : 3.

PICTURE-STRIP. Synonym for SCANNING-LINE.

PICTURE TELEGRAPHY. See FACSIMILE TELEGRAPHY.

PICTURE-TRAVERSING CIRCUIT. In television, the circuit associated with the frame-scanning generator producing the current or voltage required for vertical deflection of the scanning beam.

PIEZO-ELECTRIC CRYSTAL. Crystal which has piezo-electric properties. Crystalline substances which are piezo-electric include quartz, tourmaline and Rochelle salt. See PIEZO-ELECTRIC EFFECT.

PIEZO-ELECTRIC EFFECT. Phenomenon exhibited, in certain circumstances, by a piezo-electric crystal whereby the application of mechanical force produces electric charges. Conversely, strains and mechanical distortion are produced when the crystal is placed in an electric field.

If a plate, suitably cut from a piezo-electric specimen of natural quartz crystal, is mounted between two electrodes and a potential difference applied, the plate will undergo mechanical distortion. If the potential difference is suddenly removed, the plate will execute a series of mechanical vibrations of decreasing peak values. In so doing, it will produce an oscillating potential difference between the electrodes.

The application of an alternating voltage at the resonant frequency can maintain the crystal plate in a continuous state of vibration.

PIEZO-ELECTRIC OSCILLATOR. See CRYSTAL OSCILLATOR.

PIEZO-ELECTRIC RESONATOR. See QUARTZ CRYSTAL.

PIEZO LOUDSPEAKER. Synonym for CRYSTAL LOUDSPEAKER.

PIEZO MICROPHONE. Synonym for CRYSTAL MICROPHONE.

PIEZO RECEIVER. Synonym for CRYSTAL HEADPHONE.

PIEZO TELEPHONE. Synonym for CRYSTAL HEADPHONE.

PILOT CARRIER. Unmodulated wave sent through a transmission line which carries several modulated carriers transmitting a number of different messages. The pilot carrier has a frequency which may be close to the mean of the several frequencies of the modulated carrier waves; or two pilots may be used, one higher and the other lower in frequency than the highest and lowest carrier frequencies used. As the characteristics of the transmission line vary, the received level of the pilot carrier varies. The level of the pilot carrier determines the gain or frequency response of the receiver or repeater, the object being to maintain the same over-all performance of the system in spite of variations in the transmission line. See CARRIER, TRANSMISSION LINE.

PILOT LAMP. Small lamp connected across a circuit to give warning that the power is "on." It may indicate merely that a radio receiver is switched on, or it may show that some danger-point is "alive."

PINCH. Glass stem, inside the glass bulb of a valve, which supports the stout wires upon which the electrodes are assembled.

PINCUSHION DISTORTION. Intermodulation between X and Y deflector systems in a cathode-ray tube, causing, for example, a picture to be distorted as shown in Fig. 22. It is caused by non-uniformity of the deflecting fields. See X PLATE, Y PLATE.

PITCH. In music, the subjective property of a tone which enables the ear to differentiate between it and another of a different frequency. The British Standards Institution give 264 c/s as the pitch for middle C, although for purposes of convenience 256 c/s is usually taken in physics. British Standards Institution have fixed the pitch of A in the treble clef at 440 c/s which coincides with concert pitch; this latter standard has been generally accepted as the standard for orchestral performance.

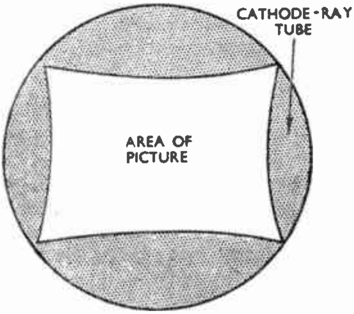


Fig. 22. Shape of a received television picture when suffering from what is known as pincushion distortion.

PITCH CONTROL. In general, a means of altering the frequency of an audio-frequency signal. In particular, however, it is the name given to the beat-frequency-oscillator control of a communications receiver. By altering the setting of this control, the frequency of the oscillator is varied and the pitch of the audio-frequency note corresponding to a type A1 signal is correspondingly changed. See TYPE A1 WAVE.

PLAIN-AERIAL SENDER. Sender in which the main oscillatory circuit is tightly coupled to the aerial. Originally the plain-aerial sender was a ship's emergency set. It employed a spark-coil connected directly to the aerial and radiated waves so broadly tuned that they would attract attention by breaking through the tuning of receivers over a wide area.

PLANE OF POLARIZATION. Direction of electrostatic lines of force in an electromagnetic wave. Thus, when the electrostatic lines are vertical, the wave is said to be polarized in the vertical plane. See HORIZONTALLY POLARIZED WAVE, POLARIZATION, VERTICALLY POLARIZED WAVE.

PLANE-POLARIZED WAVE. Radiowave, the plane of electric field polarization of which is either vertical or horizontal. The plane of polarization of a wave radiating from a sending aerial is horizontal if the aerial is horizontal, and vertical if the aerial lies in the vertical plane. If reception of the ground wave is attempted at some distance from the sender, it is usually found that the polarization is more or less the same as when it left the sending aerial; such waves are said to be plane-polarized. Should reception of the ionospheric wave be attempted, however, it is almost invariably found that the wave is no longer plane-polarized, but is circular or elliptical. See HORIZONTALLY POLARIZED WAVE, POLARIZATION, VERTICALLY POLARIZED WAVE.

PLAN-POSITION INDICATOR. In radar, a display on the screen of a cathode-ray tube which shows in effect a map, or plan, of the area surrounding the aerial, and on which moving objects such as ships or aircraft can be seen. See RADAR.

PLASMA. In an electric discharge through a gas, a region containing equal numbers of positive ions and electrons and some un-ionized molecules. This region is electrically neutral. See GAS-FILLED DIODE, IONIZATION.

PLASTIC EFFECT. Form of double image in a television picture in which the objects are outlined in duplicate, the lines being close together. It is caused by phase distortion and can be recognized by the fact that a black outline is not only depicted as a black outline but is followed closely by a white line.

Plastic effect, occasionally termed plasticity, is especially evidenced when a picture is strong in contrasts, with sudden changes from black to white as the scanning lines go across it. Then, the phase distortion of the transient voltages, generated when the change occurs from black to white, is most marked. Amplitude distortion may also cause a double outline, but this is usually accompanied by lack of detail as well as excessive contrast, whereas phase distortion does not affect detail and contrast.

PLASTICITY. See PLASTIC EFFECT.

PLASTICS. General term applied to materials now widely used in industry to replace basic materials, such as wood, metal and fabrics. The advantages gained are that the raw materials used in their manufacture are more plentiful, and a given plastics is adaptable to a variety of purposes. Plastics may be derived from natural substances, such as casein, or may be artificially produced; but, in all cases, carbon is an essential constituent.

Plastics may be divided into two groups: thermoplastics and thermosetting plastics. The former soften with the application of heat under pressure and become rigid on cooling; this cycle can be repeated again and again. Thermosetting plastics undergo physical and chemical changes when heated and subjected to pressure and, once moulded, are resistant to further processing but, being organic substances, if heating is continued, they will char at about 650 deg. F.

Thermoplastics include nitro-cellulose, which is inflammable; cellulose acetate, polystyrene, vinyl resins, polyethylene and acrylic resins, such as polymethyl methacrylate which is light in weight, hard-wearing, easily shaped and resistant to corrosion. Casein is an intermediate between thermosetting plastics and thermoplastics, but is seldom employed in radio apparatus, being chiefly used in the manufacture of buttons, combs, imitation tortoiseshell, etc.

Thermosetting plastics include phenol-formaldehyde, cresol-formaldehyde and urea-formaldehyde resins. Glyptal resins also come within this group and are formed from glycerol and phthalic anhydride. They are used particularly for surface coating.

In radio, plastics are used extensively as insulators and capacitor dielectrics because their breakdown voltage is high and power factor low, their electrical characteristics remain reasonably constant up to 60 deg. C., resistance to corrosion by water and chemicals, such as acids, is high, and surface and volume resistivity is high.

For example, polystyrene foil of thickness 5 mils has withstood 20,000 volts, is very resistant to corrosion and, owing to its high surface and volume resistivity, shows little tendency to track under electrical stress. Further advantages of plastics are that they are light in weight and can be cemented by the use of the appropriate solvents or can, like polyvinyl chloride, be welded.

Plastics varnishes are used for the impregnation of coils and also as the final coating for the armatures of high-speed motors. Certain plastics are very valuable as dielectrics in fixed capacitors. For example, urea-formaldehyde has a dielectric constant of 7 to 8·8 and asbestos-filled melamine-formaldehyde of 6 to 9, as compared with a normal value of 5 for mica.

Particulars concerning some of the plastics for use in radio engineering are given in the table below.

PLATE. American term for ANODE.

PLATE BATTERY. Synonym for HIGH-TENSION BATTERY.

PLATE VOLTAGE. Synonym for ANODE VOLTAGE.

PLIODYNATRON. See DYNATRON OSCILLATOR.

PLUG AND JACK. Device for rapid electrical connexion and disconnexion between parts or components of an equipment. The features of a plug and jack (Fig. 23) that distinguish it from a plug and socket are: the concentric contacts on the plug; the flat, springy contacts on the jack (as in relays and keys); the extra make-or-break contacts on the jack which are operated by the insertion or withdrawal of the plug; and the small mounting area. Plugs and jacks were first used in telephone-

PROPERTIES OF PLASTICS

Plastic	*Phenol-formaldehyde (no filler)*	*Urea-formaldehyde (moulded)*	*Cellulose Acetate (sheet)*	*Polystyrene*
Tensile Strength (lb./in.^{2})	6,000–9,000	9,000–12,000	5,000–11,000	5,000–8,000
Volume Resistivity (ohms/cm^3.) ..	$1·0\times10^{12}$ $-5·0\times10^{12}$	$2·0\times10^{13}$ $-2·8\times10^{13}$	$5·0\times10^{12}$ $-30·0\times10^{12}$	10^{17}
Water Absorption ..	0·10–0·20%	1·0–2·0%	1·5–3·0%	Nil
Breakdown Voltage at 50c/s (volts/mil) Instantaneous .. Long-term ..	400–500 —	650–720 —	600–1,000 —	500–700 450–600
Dielectric Constant at 50 c/s	5·0–6·0	—	3·5–7·5	2·6
Power Factor At 50 c/s .. .. At Radio Frequencies ..	0·05–0·10 0·005–0·05	0·03–0·15 —	0·02–0·07 —	0·0001 0·0002

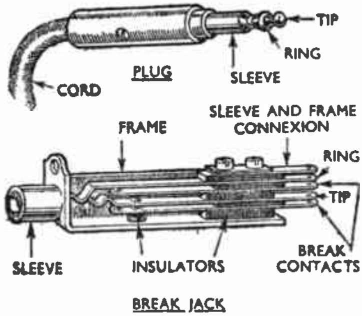


Fig. 23. Details of a plug and jack, showing how tip, ring and sleeve of the plug form three concentric contacts.

exchange switchboards where it is necessary to mount as many as ten thousand on panels within reach of a single operator. Hence the concentrated design and small mounting area. See PLUG AND SOCKET.

PLUG AND SOCKET. Quick and ready means of joining or separating electrically two pieces of apparatus or equipment, or of joining or separating a piece of equipment and a source of power supply. It consists of two parts; one is provided with one or more metallic contact pins designed to register and engage with metallic contact tubes in the other part. The former is called the plug portion; the latter is the socket.

Plugs and sockets may be placed into three classes, according to their use; those for mains supply, those for R.F., and those which are miscellaneous.

Mains plugs and sockets are used for mains-energized transportable telecommunications equipment which has to be connected to the power-supply mains. There are two basic types: *outlet* and *inlet* (Fig. 24). In the former, the socket is a fixture connected to the power-supply system, and the plug is wired to the end of a flexible cord connected to the equipment. The latter is used when it is not convenient to have the cord permanently attached to the equipment.

The equipment then carries the pin contacts, and attached to the cord are the tubular contacts protected by an insulating shroud in case the other end of the cord is energized. Either two or three contacts are provided (the third for earthing the framework of the equipment); ratings of 2, 5, 15 and 30 amp. at 250 volts are most common.

R.F. types of plug and socket are usually concentric (Fig. 25) for terminating and making connexions to co-axial cables. A single contact pin and tube forms one connexion and the metal casing or body serves the double purpose of second connexion and screen (in contrast with the insulating body of other types). Care is taken in design to keep losses and capacitance to a minimum; dimensions are chosen to suit the co-axial cable with which they are to be used and insulation of high-grade material, such as polythene or polystyrene, is used to space the pin and tube from the casing.

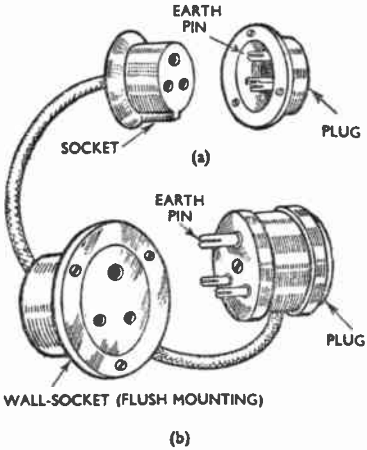


Fig. 24. The two basic forms of three-pin power plug and socket: (*a*) the inlet type and (*b*) the outlet type.

Miscellaneous types range from the single-pole wander plug, for making contact to a simple brass tubular socket in a dry battery, to the thirty-

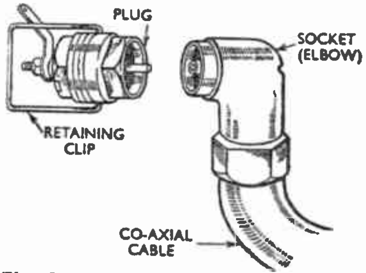


Fig. 25. Concentric type of plug and socket which is designed for use in conjunction with co-axial cable handling radio-frequency currents.

pole type used in aircraft wiring systems; and from designs suitable for working at 24 volts to special types capable of withstanding many thousands of volts.

Certain components, such as valves and telegraph relays, which have to be removed from a circuit fairly frequently for testing, adjustment or replacement, are connected by means of plugs and sockets. The plug is usually attached to the component and the socket to the chassis or panel. See PLUG AND JACK.

PLUG-IN COIL. See PLUG-IN INDUCTOR.

PLUG-IN INDUCTOR. Inductor fitted with plug-type connectors. Its purpose is to facilitate changing the frequency range of a tuned circuit, particularly when the size of the inductor is large, or the capacitance of a selector switch is undesirable. Plug-in inductors were used in early types of broadcast receivers but, in modern sets, the various inductors are connected into the circuit by means of a low-capacitance switch. Plug-in inductors are sometimes used in measuring or testing equipment.

POLAR DIAGRAM. Diagram employing polar co-ordinates to show (1) how the signal strength received from a given sender varies with the angular setting of the rotating member of a direction-finder, or (2) the relative efficiency of pick-up or radiation of an aerial in different directions, in either the vertical or the horizontal plane.

As examples of the horizontal polar diagram, that applicable to a half-wave dipole and that for an inverted-L aerial are shown in Fig. 26.

The effect of the height above ground upon the radiation from a horizontal dipole is indicated by vertical polar diagrams. When the height is equal to half a wavelength, the radiation is confined to two lobes inclined upwards at 30 deg. to the horizontal (Fig. 27a). If the aerial height is raised to three-quarters of a wavelength, the inclination of the lobes comes down to 20 deg. to the horizontal; but there is a third lobe which is vertical and represents a waste of power in most circumstances (Fig. 27b).

When the height is equal to several wavelengths, the vertical polar diagram becomes a "fan" of closely spaced lobes (Fig. 27c), of which the lowest pair gets nearer and nearer to horizontal as aerial height is increased. At a height of five wavelengths, for instance, the bottom lobe on each side is at only a 3-deg. inclination to the horizontal.

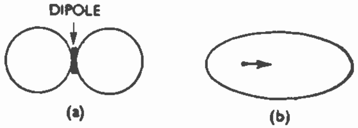


Fig. 26. Polar diagrams of (*a*) a half-wave dipole in free space, and (*b*) a moderately directive aerial such as, for example, an inverted-L aerial.

POLARITY. Condition of having regions of positive and negative charge as in electrostatics, or north and south poles as in the case of a magnet. Thus, to define the polarity of an electrically charged object is simply to state whether it is positively or negatively charged. See ELECTROSTATICS, MAGNETISM.

POLARIZATION. Plane in which the electrostatic lines of flux radiated by an aerial-system are found to lie. A sending aerial along which a radio-frequency electric charge is oscillating produces lines of electric stress in the space surrounding it. Each electron travelling up and down the aerial wire has its own associated electric charge from which electric lines of force radiate in all directions. Because of the inertia of the system, the electric lines of force cannot follow the motion of the electrons immediately; as a result, the electric lines are continually being detached and losing contact with the aerial wire.

As long as the electrons continue to oscillate there will be a steady succession of these lines of force radiating from the aerial wire. The process is called *radiation* of an *electric wave;* Fig. 28 shows the process pictorially. It is important to note that the electric lines do not require any material medium to support them; they can exist in free space completely devoid of matter. The wave motion imparted to the lines of force is in the same direction as the motion of the electrons themselves, so that, if the aerial wire is vertical and electrons are made to move up and down it in an oscillating manner, waves will be produced whose electric fields are vertical. Such waves are said to be vertically polarized.

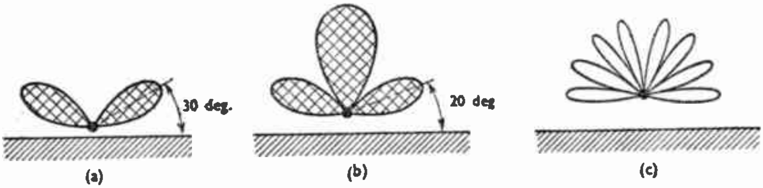


Fig. 27. Vertical polar diagram used to illustrate the effect of height above ground on the radiation from a horizontal dipole (shown end-on). The height of the aerial at (*a*) is equal to half a wavelength; at (*b*) it is equal to three-quarters of a wavelength, and at (*c*) it is much greater than a wavelength.

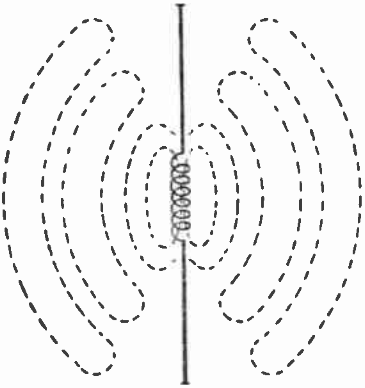


Fig. 28. If an aerial is vertical, electrons made to oscillate up and down it cause vertical electric fields of force to be radiated from it; i.e., the waves are vertically polarized.

In addition to the changing electric field, the aerial wire is also surrounded by a changing magnetic field, as one cannot exist without the other. The magnetic lines of force are in the horizontal plane and are at right-angles to the electric lines, but in dealing with radiation, only the electric lines are usually considered.

To receive a vertically polarized wave, a vertical receiving aerial must be used, as, for maximum induced voltage, the receiving aerial must lie wholly in the direction of the electric field. Therefore, if a vertical field is moving horizontally, as illustrated in Fig. 29, the maximum voltage is induced when the wire is also vertical. The voltage will decrease to zero as the wire is moved to a horizontal position. The plane of polarization may vary from vertical to horizontal, and in

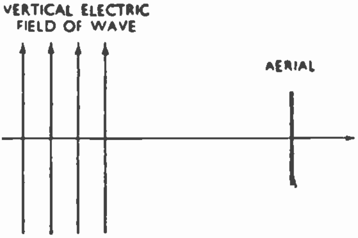


Fig. 29. A vertically polarized wave, moving horizontally, will induce maximum voltage in a receiving aerial when this also is vertical, and zero voltage when the aerial is horizontal.

many cases is circular or elliptical. See CIRCULARLY POLARIZED WAVE, ELLIPTICALLY POLARIZED WAVE, RADIATION.

POLARIZATION ERROR. Form of direction-finding error which is due to a change in the plane of polarization of the received waves, usually occurring in the course of reflection at the E- or F-layers of the ionosphere. If a loop direction-finder is used to receive vertically polarized waves, as is normal, and if a particular signal contains a proportion of horizontally or obliquely polarized energy, the aberrant component induces voltages in the horizontal top and bottom of the receiving loop. These voltages obscure and possibly distort the indications which the operator is seeking in the voltages induced by the vertically polarized fraction of the wave in the vertical sides. Polarization errors are sometimes called NIGHT ERROR (q.v.), because they are more prone to occur after dark.

POLARIZED RELAY. Relay, the operation of which depends on both the direction and the magnitude of the current in the winding. The core contains a permanent flux usually produced by a magnet. See ELECTROMAGNETIC RELAY, RELAY.

POLARIZED WAVE. Electromagnetic wave in which the electric force is in a particular direction or is confined to a certain plane. The term is often loosely used to mean a plane-polarized wave. See ABNORMALLY POLARIZED WAVE, CIRCULARLY POLARIZED WAVE, PLANE-POLARIZED WAVE.

POLAR RESPONSE. Measure of the pick-up efficiency of an aerial receiving signals arriving from particular directions.

POLAR-RESPONSE CURVE. Synonym for POLAR DIAGRAM.

POLES OF A MAGNET. Points on a magnet at which the magnetic field of force is most intense; the points at which the magnetic force leaves the metal and emerges into space (Fig. 30). The poles are normally at the ends of the magnetic structure, but this is not an invariable rule. See MAGNETISM.

POLYPHASE. Term which denotes an A.C. system in which there are several circuits supplied with voltages of identical frequency, but displaced from each other in phase. A common example is the three-phase system, with three circuits fed with voltages equally spaced in phase.

POLYPHASE-RECTIFIER CIRCUIT. Rectification circuit designed to produce a direct current from a polyphase supply. In cases where it is required to produce very large direct-current power from an alternating-current source, for example, the mains supply, there is every reason to use all the phases of the distribution system, not only to distribute the load economically so far as the supply system is concerned, but also to minimize the problems of designing a suitable smoothing circuit. A diagram, showing a three-phase rectifier circuit, appears on page 370 under MAINS UNIT. See also FULL-WAVE RECTIFICATION.

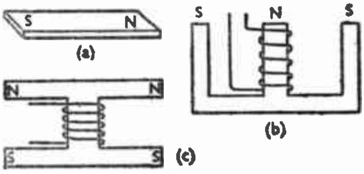


Fig. 30. The simple bar magnet (*a*) has only two poles; but electromagnets, examples of which appear at (*b*) and (*c*), may have three or more poles.

PONGING. See MICROPHONY.

PORTABLE RECEIVER. Radio receiver designed for easy carriage from point to point. Usually it is entirely self-contained with built-in loop-aerial, loudspeaker and batteries; sometimes it may also be mains-operated.

POSITION FINDING. See DIRECTION-FINDER, DIRECTION-FINDING, NAVIGATIONAL AID.

POSITIVE. Condition of being deficient in the normal complement of electrons, or being deficient in them with respect to some reference point, or being at a higher electrical potential than some other point in a circuit. (This term is a convenient relic of the older "two-fluid" theory of electricity, which assumed that positive and negative charges were distinct in kind.) See NEGATIVE.

POSITIVE ELECTRICITY. Condition of electrical charge. Positive electricity is, in fact, a deficiency of electrons in comparison with some reference point. See ELECTROSTATICS, POSITIVE.

POSITIVE ELECTRON. Synonym for POSITRON.

POSITIVE FEEDBACK. Interconnexion of the input and output terminals of an amplifier in such a way that the output signal is in phase with the input signal. This results in increased amplification but, if the feedback is sufficient, oscillation may result. See FEEDBACK.

POSITIVE ION. Molecule or atom of a gas which has lost one or more electrons and is therefore positively charged. See ELECTRON.

POSITIVE PHASE-SEQUENCE. Normal sequence of phases in a polyphase alternating-current system. See NEGATIVE PHASE-SEQUENCE, POLYPHASE.

POSITIVE PLATE. Plate of a secondary cell having a potential which is positive with respect to the negative electrode of such a cell. See NEGATIVE PLATE, VOLTAIC CELL.

POSITRON. Particle of which the mass and charge are of approximately the same order as those of an electron but in which the charge is positive. See ELECTRON.

POTENTIAL. Measure of electrical pressure or voltage as between one point and another, or between a certain point and earth.

POTENTIAL DIFFERENCE. Measure of the difference in voltage between two points. Thus, if the potential difference between point *A* and point *B* is 10 volts, there is an electromotive-force of 10 volts available to drive a current from the one point to the other when they are connected by a conductor.

POTENTIAL DIVIDER. Combination of two resistors, two capacitors, or two inductors connected in series across a source of potential difference, so that the p.d. across one element of the pair is smaller than the applied p.d. and in phase with it. The value is determined by the ratio of the resistance or impedance of this element to the total resistance or impedance.

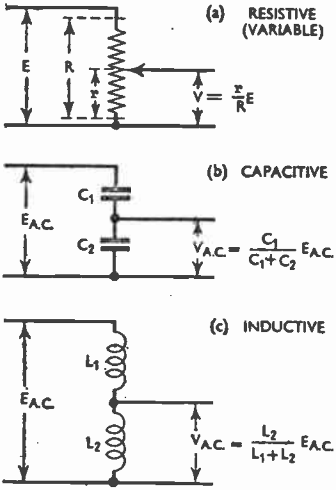


Fig. 31. Diagrams showing (*a*) resistive, (*b*) capacitive and (*c*) inductive forms of potential divider; also formulae which relate *V*, the significant potential difference, with *E*, the applied e.m.f.

The term potential divider is more particularly applied to a variable component consisting of a single resistor effectively subdivided by a sliding contact, as shown in Fig. 31. In this form, the device is very commonly used in electronic circuits as a gain or volume control.

The inductive and capacitive types can be used only in A.C. circuits. The former type, if there is mutual coupling between the two parts, is more usually described as an auto-transformer; and a variable form of the latter type as a differential capacitor. See GAIN CONTROL, VARIABLE RESISTOR, VOLUME CONTROL.

POTENTIAL GRADIENT. Voltage which gradually increases or decreases along a conductor or round a particular part of a circuit. The potential gradient depends on the resistance per unit length of the particular conductor and the magnitude of the current flowing therein; the higher the resistance and the greater the current, the steeper the potential gradient.

POTENTIAL MINIMUM. Point of minimum potential in a circuit. The term may also be used to denote a VIRTUAL CATHODE (q.v.).

POTENTIOMETER. Instrument for the measurement of potential differences, working on the principles of the potential divider. The term potentiometer is often applied to a potential divider performing the function of a volume control. See POTENTIAL DIVIDER.

POULSEN ARC. Arc discharge produced between carbon and water-cooled copper electrodes which are placed in a strong magnetic field and surrounded by hydrogen. The Poulsen arc is used for the generation of continuous waves.

POWER. In general, the rate of doing work. If work is performed at the rate of 550 ft.-lb. per second, the rate of working, i.e., the power is said to be 1 horse-power. This is the unit of mechanical work.

In D.C. electrical circuits the rate of working is measured by the product of the voltage V and the current I and, if these are stated in volts and amperes respectively, it is given in watts (symbol W). It is easily shown that the power is also given by I^2R or V^2/R, where R is the circuit resistance. In A.C. circuits the power is given by the product of r.m.s. voltage, r.m.s. current and power factor.

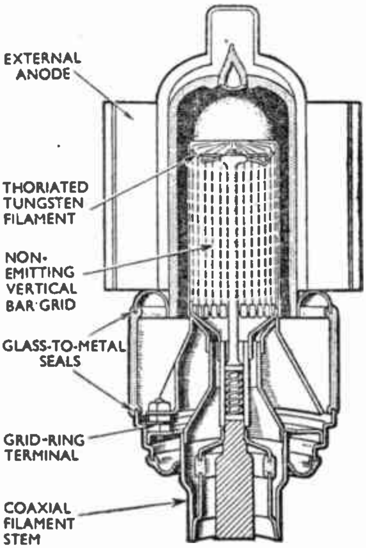


Fig. 32. Special constructions are often used for valves employed as power amplifiers in radio senders. This Eimac external-anode triode delivers, in class-C operation, up to 5 kW at an electrode voltage of only 3,500.

The relationship between mechanical and electrical power is expressed by:

$$1 \text{ watt} = 10^7 \text{ ergs/sec.},$$
$$1 \text{ h.p.} = 746 \text{ watts.}$$

See ERG, POWER FACTOR.

POWER AMPLIFIER. Valve or apparatus which delivers an output of considerable power, as distinct from a mere voltage swing such as is given by one of the earlier valves in an amplifying chain; an example is illustrated in Fig. 32. In general, the output valve of an amplifier is a power stage (see OUTPUT VALVE, VOLTAGE AMPLIFIER).

A special use of the term occurs in some sending circuits, wherein power is generated by a self-oscillating valve and amplified by another before being passed to the aerial for radiation (Fig. 33): here, the amplifying valve is called the power-amplifier stage.

POWER COMPONENT. Synonym for ACTIVE COMPONENT.

POWER DETECTION. Form of grid detector suitable for a large input (see GRID DETECTION). A valve of low internal resistance and large cut-off bias is used with a relatively high anode voltage. Under these conditions, the grid capacitor can accept a large negative charge before the bottom bend of the characteristic is reached. Hence the limiting effect, which occurs as a result of anode-bend rectification (which opposes the grid-rectifying action), does not take place until quite a high signal strength is reached.

The arrangement is, of course, appreciably less sensitive than the normal grid detection, because the amplification factor of a valve of this type is less than that of the customary detector valve.

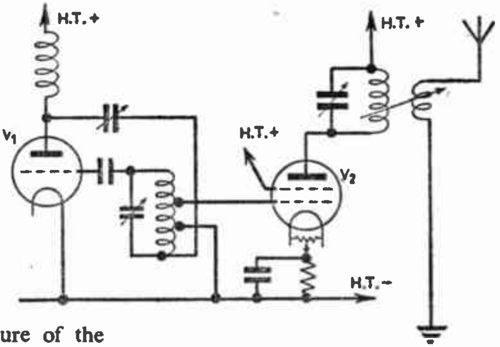


Fig. 33. One of the numerous ways of arranging a low-power sender with a self-oscillating "drive" valve V_1 and a tetrode power amplifier V_2. Here the power-amplifier valve is shown with automatic bias for simplicity; extra bias is often used for class-B or class-C operation.

POWER FACTOR. Measure of the true power dissipated in an A.C. circuit, taking into account the phase angle between current and voltage. It is equal to cos ϕ, where ϕ is the phase angle, and is multiplied by the ordinary volt-amperes figure to give the power. See PHASE ANGLE, PHASE DIFFERENCE.

POWER PACK. Term, of American origin, sometimes used instead of MAINS UNIT.

POWER SUPPLY. In general, the source of energy for operating any device. In radio, the term is used to describe a unit containing batteries, a rotary converter or vibrator converter, or a mains rectifier, which supplies H.T. and L.T. current for the operation of a sender, receiver or amplifier. See MAINS UNIT, MOTOR GENERATOR, ROTARY CONVERTER.

P.P.I. Abbreviation for PLAN-POSITION INDICATOR.

PRACTICAL SYSTEM OF UNITS. System designed to produce units of convenient magnitude for everyday use, and with some convenient method of definition in terms of each other and some fundamental unit, for example, of time. In electrical work, the practical units are the ampere, ohm, volt and watt, with their less-often-used relatives the henry, coulomb and farad, and such subdivisions and multiples as may be found necessary from time to time. The relationship between these units is explained in Fig. 34. The ampere is too large for convenience in dealing with most valve-anode currents, thus the *milli*ampere is used; the ohm, on the contrary, is too small for some radio purposes and, in consequence, its multiple, the *meg*ohm, is employed.

PRE-AMPLIFIER. Small amplifier of one, and sometimes two, stages used to raise the output of a low-sensitivity

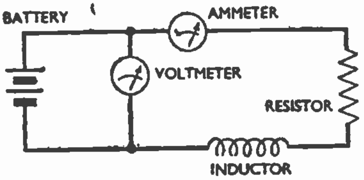


Fig. 34. Relationship of practical units: if the battery provides an e.m.f. of *one volt* (shown by the voltmeter) and the resistor has a value of *one ohm*, then the ammeter will read *one ampere*, assuming that the inductor and ammeter have no resistance. That is the "steady" state; when first switched on, however, the current will take *one second* to rise to 0·63 *ampere* if the value of the inductor is *one henry*.

microphone to a suitable level for passing over a line. The name is sometimes applied also to any low-power amplifier which privides preliminary amplification close to some source of signals before they are passed to a main amplifier. In this sense, the term covers an amplifier located close to a low-output gramophone pick-up, or to the photocell of a sound-film projector.

PRECIPITATION STATIC. See ATMOSPHERICS.

PRE-EMPHASIS. Increase in the relative depth of modulation of the higher modulation frequencies at the sender, as shown in Fig. 35. This is to enable the resulting signal to compete more effectively with noise and interference, which are generally more troublesome at the higher frequencies. By using complementary reduction at the receiver (see DE-EMPHASIS), noise is reduced, while preserving the original balance of modulation frequencies. See INTERFERENCE, MODULATION, NOISE, TONE CONTROL.

PRE-SELECTION. Process of increasing the selectivity of a superheterodyne receiver by means of additional tuned circuits preceding the frequency-changer. A simple version of pre-selection might involve merely the replacement of a single tuned input circuit by a coupled primary-and-secondary arrangement, preferably of the band-pass type.

More often, however, pre-selection includes the addition of a stage of radio-frequency amplification interposed between aerial and frequency-changer valve, usually with band-pass input circuits. In this way, any loss of sensitivity in the band-pass arrangement is more than made up by the gain given by the R.F. valve, and there is an all-round improvement in the receiver's performance.

PRESS-BUTTON RECEIVER. Radio receiver employing press-button station selection. See PRESS-BUTTON TUNING.

PRESS-BUTTON TUNING. Tuning of a receiver in which frequency changes are made by pressing labelled buttons for the desired stations, rather than by rotating a control. Various methods of achieving this have been devised. In a simple one, the press-buttons are in fact small switches, each bringing into circuit one or more pre-set adjustable capacitors.

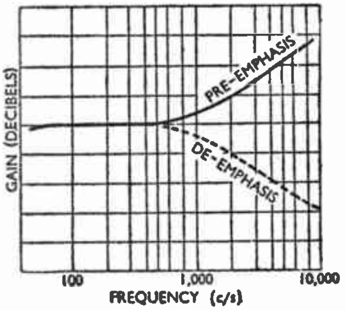


Fig. 35. Complementary pre-emphasis and de-emphasis characteristics, which together give level response but reduce the intrusion of high-pitched noise.

In another, the buttons may control a mechanical stop-and-start system which causes a small motor to revolve an ordinary variable capacitor to the setting for the desired station. Difficulties in securing the necessary precision in the mechanical system have often led designers to take an interest in automatic frequency-control for the local oscillator in such receivers.

PRESSURE CAPACITOR. Form of capacitor similar to an air capacitor but having a higher voltage rating by reason of it being housed in a strong container filled with air or other gas, such as nitrogen, maintained at a high pressure. See FIXED CAPACITOR.

PRESSURE CONDENSER. See PRESSURE CAPACITOR.

PRESSURE-GRADIENT MICROPHONE. Synonym for VELOCITY MICROPHONE.

PRESSURE MICROPHONE. Microphone in which one side only of the diaphragm is exposed to the sound wave, the other side of the diaphragm being totally enclosed. The electrical output of such a microphone is proportional to the pressure of the sound wave. See MICROPHONE, VELOCITY MICROPHONE.

PRE-TUNED CIRCUITS. Circuits previously adjusted to a particular frequency, ready for bringing into use. They are sometimes used in senders which are required to work on several alternative frequencies at short notice. In this case, semi-automatic switching gear is often provided, so that the operator has only to press a button to cause a series of contactors to throw out and another set to close, thereby making such changes in the circuit inductance and capacitance values as may be required to select the frequency he wants.

The term may be applied also to the tuned circuits of the type of press-button receiver which employs a number of adjustable capacitors, brought in by switches, to select the particular station the user wishes to receive.

PREVENTIVE CHOKE-COIL. See PREVENTIVE INDUCTOR.

PREVENTIVE INDUCTOR. Inductor connected across the twin contacts of an on-load tap-changing switch associated with a power transformer or variable inductor. Its purpose is to limit the current flowing through the section of the coil, which would otherwise be short-circuited during the passage of the switch arm.

PREVENTIVE RESISTOR. Resistor connected across the twin contacts of an on-load tap-changing switch associated with a power transformer or variable inductor. Its purpose is to limit the current flowing through the section of the coil, which would otherwise be momentarily short-circuited during the passage of the switch arm.

PRIMARY. Abbreviation for PRIMARY WINDING (q.v.), or primary coil, of a transformer.

PRIMARY CELL. Cell in which chemical energy is changed to electrical energy when a circuit is completed between its terminals. The distinction between a primary and a secondary cell is that the primary cell cannot be recharged as can a secondary cell.

The discovery that dissimilar conductive materials in contact with a liquid established an electromotive force between them was made some hundreds of years ago. The only source of electricity available to early experimenters came from the primary cell and the pioneer Faraday relied upon it alone to lay the foundations of the methods for the production of electricity from dynamo-electric machinery.

Many cells, usually known by the names of those who perfected them, have been produced; today the Leclanché cell is the one most used, particularly in its form as a dry cell (see DRY CELL, LECLANCHÉ CELL). Apart from the cadmium cell, which has the remarkable property of maintaining a more constant e.m.f. than any other and is, therefore, used as a standard of voltage in laboratories, most other primary cells are of more historic than practical interest.

The basic constituents of a primary cell are the two electrodes of dissimilar conductive materials and an electrolyte. When a circuit is made externally and a current passes through the cell, gas is liberated at the positive electrode and this, in reducing the effective area of the electrode, increases the resistance of the cell and thus limits the current that can be drawn from it. This process is called polarization. In order to diminish the effects of polarization, a de-polarizer is used to absorb the gas and so decrease the internal resistance of the cell. All primary cells produce some polarization and so have a considerable internal resistance limiting the current that may be drawn from them. If excessive current flows other effects take place resulting in permanent damage to the cell.

The secondary cell has the distinctive characteristic that the chemical action, necessary to establish and maintain the e.m.f. at its terminals when current is drawn from it, may be re-established by charging the cell. This process requires that a current shall be passed through the cell in the reverse direction to that flowing when the cell discharges. See SECONDARY CELL, VOLTAIC CELL.

PRIMARY COIL. See PRIMARY WINDING.

PRIMARY CURRENT. Current flowing in the primary winding of a transformer.

PRIMARY ELECTRONS. Electrons emitted by a cathode, as distinct from secondary electrons emitted from other (cold) electródes when bombarded by electrons. See SECONDARY EMISSION.

PRIMARY KEYING. In telegraphy, the intermittent interruption of the primary circuit of a transformer supplying H.T. to an amplifier or oscillator in the transmission chain.

PRIMARY RADAR. Radar system employing the difference of time between sending and return of a radar pulse, as a means of estimating distance, or making other measurements. See RADAR, SECONDARY RADAR.

PRIMARY WINDING. Winding of a transformer that is energized, directly or indirectly, from a source of electricity. The term distinguishes this winding of a transformer from the secondary winding, in which voltages are induced by alternating currents flowing in the primary winding. See TRANSFORMER.

PRINTING TELEGRAPH SYSTEM. System of telegraphic transmission in which the received signals are automatically recorded in the form of printed characters.

PROGRAMME REPEATER. Repeater used in a telephone-line link between broadcasting control rooms, senders and so on. The repeater must give little or no distortion over frequencies of, approximately, 50–6,000 c/s. The term is not in general use. See SIMULTANEOUS BROADCASTING.

PROGRESSIVE SCANNING. Synonym for SEQUENTIAL SCANNING.

PROGRESSIVE-WAVE AERIAL. Synonym for TRAVELLING-WAVE AERIAL.

PROPAGATION COEFFICIENT. Coefficient denoting the changes in attenuation and phase of a wave when it travels along a transmission line. The attenuation coefficient and the phase-change coefficient are added together vectorially to form the propagation coefficient. A more formal definition says that the propagation coefficient is "the natural logarithm of the vector ratio of the steady-state

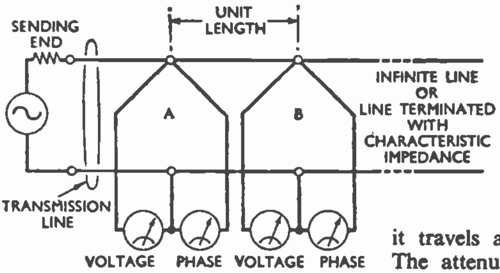


Fig. 36. Diagram which illustrates the formal definition of propagation coefficient; it shows the characteristics of the wave as being measured at two points *A* and *B* along a transmission line.

amplitudes of a wave at a specified frequency at points in the direction of propagation separated by unit length."

Thus, in Fig. 36, a uniform transmission line of infinite length is shown (see INFINITE LINE). The vector amplitudes are compared at two points *A* and *B*. The natural logarithm of the ratio of these vector amplitudes gives the propagation coefficient.

The propagation constant is not determined by measuring the magnitude of the voltages and comparing them (this would give the attenuation coefficient); nor is it obtained by comparing the phase of the waves at *A* and *B* (this would give the phase-change coefficient). To determine the propagation coefficient, both amplitude and phase must be found so as to get the vector ratio (see PHASE VECTOR). Having obtained this ratio, the numerical value of the propagation constant is given by taking the natural logarithm of the ratio.

The propagation coefficient is made up of the attenuation and phase-change coefficients; thus the ratio of voltage amplitudes at *A* and *B*, which are actually measured by a voltmeter, will give the attenuation constant; while the change of phase will give the phase-change coefficient. The former is often written as α and the latter as β; and the propagation coefficient is $\alpha + j\beta$, where j represents a means of giving the instruction to make a vectorial—not arithmetical—addition of α and β. Frequently, α is spoken of as a real part and β as the imaginary part of the propagation coefficient, because j is the square root of minus one and thus an "imaginary" quantity.

But, in determining the propagation coefficient of a line, it is not necessary to make the measurements at two points (such as *A* and *B* in Fig. 36) exactly unit distance apart; there are various indirect ways of finding the value of the coefficients concerned. In fact, given the inductance, resistance, leakance and capacitance of a line, it is possible to calculate the attenuation, phase-change and propagation coefficients. See ATTENUATION COEFFICIENT, PHASE-CHANGE COEFFICIENT, TRANSMISSION LINE.

PROPAGATION CONSTANT. Synonym for PROPAGATION COEFFICIENT.

PROTON. Particle carrying a charge equal to that of an electron, but positive in sign. It forms one of the major constituents of the nucleus of the atom. The mass of the proton is roughly 1,800 times that of an electron; thus it provides the greater part of the total mass of the atom.

PROXIMITY EFFECT. Increase in high-frequency resistance brought about by the losses in a conductor resulting from the induction of eddy currents in conducting objects in its near vicinity. Such losses occur to some extent with alternating currents of all frequencies, but are more severe as the frequency is increased.

PSOPHOMETER. Instrument for assessing the disturbing effect which voltages of various frequencies have on the ear. They are mainly used in telephone systems. See PSOPHOMETRIC E.M.F., PSOPHOMETRIC VOLTAGE.

PSOPHOMETRIC e.m.f. That e.m.f. at 800 c/s which must be induced into a telephone circuit to give the same psophometric voltage at the point of measurement as does the disturbing signal. See PSOPHOMETER, PSOPHOMETRIC VOLTAGE.

PSOPHOMETRIC VOLTAGE. That voltage at 800 c/s which must be applied between two points in a telephone system to produce the same degree of interference with speech over the system as does the disturbing signal. See PSOPHOMETER.

PUBLIC-ADDRESS SYSTEM. System of electrical communication for diffusing speech or musical programmes to large audiences by means of microphones, amplifiers and loudspeakers, without the use of radio transmission.

The system is used for both industrial and entertainment purposes.

Common industrial applications are railway-station announcements and contact between executives and staff in an industrial establishment. In the entertainment world, a public-address system ensures equal distribution of sound volume to all sections of the audience. Other applications are the dissemination of political propaganda, commentaries on sporting events and general advertising.

A public-address (P.A.) equipment consists essentially of at least one microphone, an amplifier and a loudspeaker, together with associated power supplies and control switching. Since even the most modest equipment must be capable of providing sound volume sufficient for an average-size auditorium, the power-handling capacity of the amplifier must be large compared with that of a radio receiver designed for relatively small rooms.

A fundamental requirement is that the apparatus should be portable, unless specially designed for permanent installation, such as on a railway station.

Where the equipment has to be used for outdoor work, the power supply should be designed to operate from a heavy-duty accumulator, or from the ignition battery of the vehicle in which the equipment is carried. Fig. 37 shows a typical system designed to meet these requirements; it includes a portable microphone, a 15-watt amplifier and a horn-type loudspeaker.

An important consideration for P.A. equipment designed for indoor and outdoor use is that of frequency response. When used in the open air, high frequencies are attenuated progressively as distance increases and the reproduced speech or music tends to be low-pitched or "boomy." This can be counteracted to some extent by the incorporation of an equalizer in the amplifier, designed to emphasize the higher frequencies in the audio range.

In a concert hall, there may be some attenuation of high frequencies

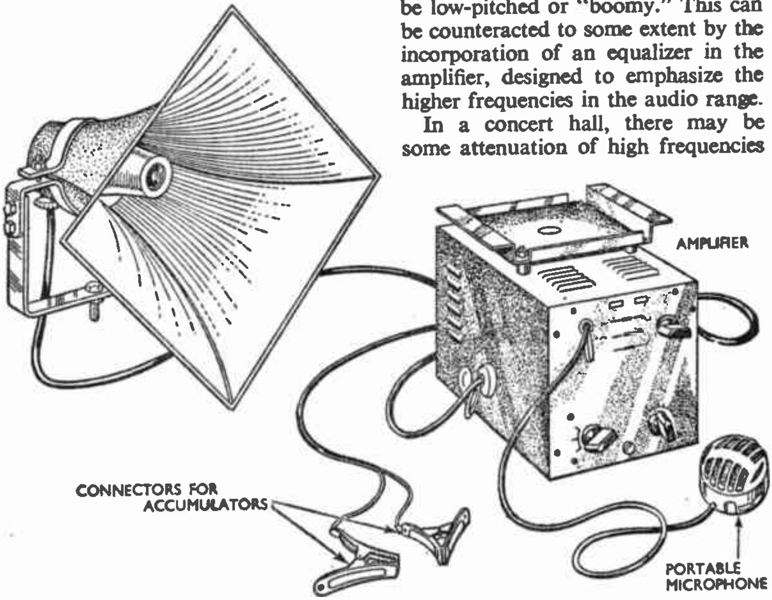


Fig. 37. Portable Tannoy public-address equipment designed for operation from a private car, current being taken from the 6-volt or 12-volt car battery. The amplifier incorporates pick-up terminals for the reproduction of records, and includes a limiter for the automatic prevention of distortion on overloading.

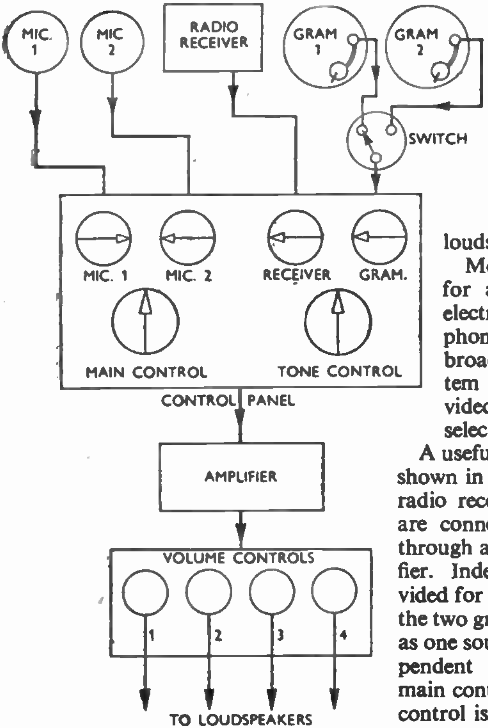


Fig. 38. Schematic arrangement of a multi-purpose public-address system. Two microphones, a radio receiver and two gramophones are connected, through a control panel and amplifier, to four loudspeakers.

but, because of reflection from the walls and ceiling, the effect is much less marked; it follows therefore that the equalizer should take the form of a variable tone control in order that the effective frequency response of the system as a whole may be adjusted to the required conditions.

For outside use, a single loudspeaker is rarely satisfactory because of its directional properties, and it is customary to use two or more arranged in such a way that the sound is disseminated radially. Similarly, in large concert halls, it is usual to install loudspeakers in each corner. The number of loudspeakers operated from a given system must not exceed the power-handling capacity of the amplifier, hence the choice of amplifier used is largely determined by the number of loudspeakers it has to supply.

Most P.A. systems are required for amplifying speech, and for electrical reproduction of gramophone records or the relaying of broadcast programmes. The system should, therefore, be provided with pick-up terminals and selector switch.

A useful layout of P.A. equipment is shown in Fig. 38, two microphones, a radio receiver and two gramophones are connected to four loudspeakers through a control panel and an amplifier. Independent controls are provided for the four programme sources, the two gramophones being considered as one source. The outputs of the independent faders are governed by a main control unit, and a variable tone control is provided.

With such equipment, it is possible to compensate for differences in volume between individual sources, and the provision of a separate volume control for each loudspeaker adds flexibility to the system. See AMPLIFIER, ELECTRICAL REPRODUCTION, LOUDSPEAKER, MICROPHONE.

PULLING. Synonym for COGGING.

PULSATING CURRENT. Current which rises and falls regularly in magnitude, but which does not reverse in direction as an alternating current.

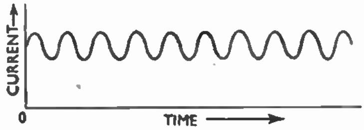


Fig. 39. One form of pulsating current; it consists of an alternating current superimposed on a direct current.

A typical pulsating current, which rises and falls in value without dropping to zero at each minimum, is shown in Fig. 39. Such a current can be regarded as an alternating current superimposed on a direct current.

PULSE-CODE MODULATION. Method of transmitting intelligence in which the message is conveyed from the sender to the receiver by interrupting the carrier wave to produce regularly occurring groups of pulses. At any instant, the pulses in a group give information about the amplitude of the modulating wave at that instant, according to a code. Thus the message, instead of being transmitted by varying some property of the carrier wave in accordance with the modulating wave (as in amplitude, frequency and phase modulation), takes the form of a series of instructions which are reconstructed by the apparatus at the receiving end.

One advantage of pulse-code modulation over other methods of modulation is that it enables a very good signal-to-noise ratio to be obtained. This is because communication is effected by a succession of pulses, and their amplitude and wave form do not greatly matter. At the receiver, these pulses are, in effect, required only to trigger a relay, and this triggering action occurs with certainty, provided that the pulses are appreciably greater than the noise at the receiver input. Thus perfectly shaped pulses can be obtained from distorted ones and noise can be greatly reduced.

This system works satisfactorily in spite of a poor signal-to-noise ratio at the receiver input, and permits low sending power and consequent economy in running costs. Another advantage of pulse-code modulation is that the transmitted messages can be interpreted only if the pulse code is known; it thus permits transmission in secrecy. The system suffers from the disadvantage of requiring a wide band width, and, if used for a radio link, it is confined to the metric or centimetric wavelengths.

When speech is transmitted by pulse-

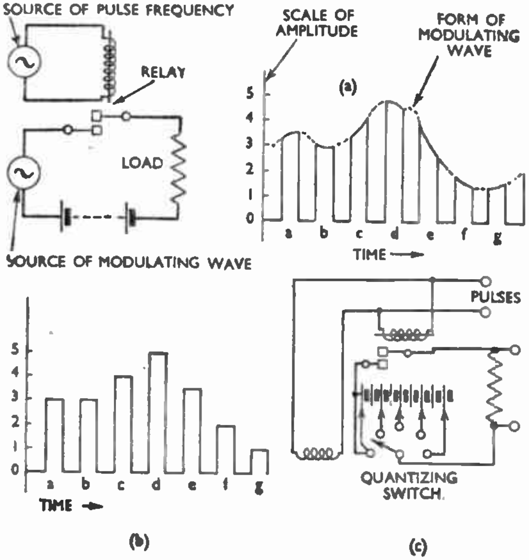


Fig. 40. Diagrams showing the principles of pulse-code modulation: (*a*) the modulating wave is broken up into pulses; (*b*) the effect of quantizing, whereby the pulses are given discrete values of amplitude, e.g., 1, 2, 3, 4 and 5. By means of a relay and quantizing switch (c) at the receiver, the pulses are re-formed to resemble, in both frequency and amplitude, the original signal.

code modulation, the modulating wave is first passed through a low-pass filter to eliminate all frequencies higher than, for example, 3,000 c/s. The resulting wave is then "sampled"; that is to say, it is applied to a circuit whose output consists of regular pulses, which at any instant have an amplitude equal to that of the modulating wave at that instant (Fig. 40).

To minimize distortion, the frequency of these pulses (i.e., the frequency of sampling) must be at least twice that of the highest frequency within the band it is intended to transmit and, in this example, is 6,000 c/s. The pulses at the output of the sampler may be of any amplitude within a wide range, but the system can only transmit information to the receiver of certain definite discrete values of amplitude. This is a consequence of the coding system used for transmission, and can be understood from the following explanation.

If the chosen code has two pulses in a group, the first pulse might represent an amplitude of 1 and the second an amplitude of 2. If the first pulse only is present, an amplitude of unity is indicated; if only the second is present, an amplitude of 2 is represented. If neither pulse is present, the amplitude portrayed is zero; if both are present the amplitude is 3. Thus, by means of a two-pulse code, four different values of amplitude can be represented, these being in unit steps from 0 to 3. By using more pulses in each group, a greater number of different amplitudes can be indicated; for example, a five-pulse code can be used to send information about thirty-two different amplitudes, and a seven-pulse code about 128 different amplitudes.

The pulses forming the output of the sampler cannot be translated directly into the code because they may be of any amplitude; before coding can occur these amplitudes must be changed slightly, where necessary, to make them all agree with the chosen discrete values of amplitude. This process is known as QUANTIZING (q.v.). The basic aspects of a binary code are shown in Fig. 41.

8	4	2	1	NUMBER REPRESENTED
				0
			■	1
		■		2
		■	■	3
	■			4
	■		■	5
	■	■		6
	■	■	■	7
■				8
■			■	9
■		■		10
■		■	■	11
■	■			12
■	■		■	13
■	■	■		14
■	■	■	■	15

Fig. 41. How a code of four pulses may represent amplitudes of discrete values 0–15. Total value is obtained by adding the pulse values; thus, for example, 6 is 4 + 2, and 13 is 8 + 4 + 1.

After quantizing, the pulses are applied to the coder, whose output consists of groups of pulses corresponding with the changing input level in accordance with the chosen code. In a multi-channel telephony system, the pulse groups from a number of coders are interlaced to produce a continuous stream of pulses which is applied to a magnetron modulator to be radiated. Marker pulses are inserted at the sender to permit synchronization of the receiver and to aid separation of the pulses belonging to a particular channel.

At the receiver, the pulse groups belonging to the various channels are separated and applied to separate decoders. The output of a decoder is a series of pulses with an amplitude which depends on the code group at the decoder input. The decoder output is passed through a low-pass filter, having a cut-off frequency at 3,000 c/s, which smoothes the pulses into a recognizable replica of the original speech.

This is a very brief description of a complicated system and a number of assumptions have been made to simplify explanation. For example, it is usual to reduce the amplitude range in the modulating wave before coding by passing it through an instantaneous compressor; a complementary expander is used at the receiver to restore the true amplitude values. The steps in amplitude which can be represented by the code are not of equal value, but are graded logarithmically so that each of the steps represents an equal increase in loudness. The transmitted pulses forming the code are not all separate but have rounded corners, and neighbouring pulses run together to form broad pulses; this gives a useful saving in the band width occupied by the system.

PULSE-CODE MODULATOR. See PULSE-CODE MODULATION.

PULSE MEASUREMENT. Of ionosphere, method of determining heights above the earth of the various ionospheric layers. This method is capable of measuring the height of maximum electron density only, and so gives the central height of the layer. In comparision with the ground ray, the radiation reaching a receiver by means of the ionospheric ray always arrives late.

Since the velocity of propagation of all radio-waves in free space is 186,000 miles per second, the time lag between the ground and ionospheric rays is very short, of the order of one-thousandth of a second. As the distance from the sender increases, so does the time lag. The measurement is made by sending a very short impulse of radio energy upwards into the ionosphere; its reflection is received at a station a mile or two away. The ground ray is therefore received, and also a ray which is sent almost vertically, a small portion of which may be reflected from the ionosphere. The output of the receiver is fed to the deflecting plates of a cathode-ray oscillograph, and, providing the speed of the time base is suitably adjusted, the screen of the oscillograph shows a succession of large pulses due to the ground ray, each of them followed by a secondary pulse corresponding to the reflected signals. As the speed of the time base and the velocity of the wave are both known, it is a comparatively simple matter to calculate the time taken by the impulse to reach the ionosphere, be reflected, and reach the earth again.

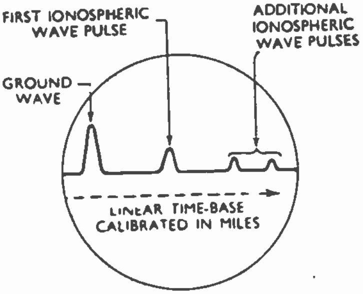


Fig. 42. Example of the traces received on the screen of an oscilloscope or oscillograph during pulse measurement of the ionosphere. The additional wave pulses recorded may be either multiple reflections of the first pulse or waves returned from higher layers.

From this data, the height at which reflection occurs may be calculated.

For measurements of F-layer height, care must be taken to select a frequency which is high enough to pass through the E-layer without reflection. If the frequency selected approaches the critical frequency of the E-layer, two reflected pulses may be observed on the screen of the oscillograph, the first from the E-layer and the second from the F-layer. Fig. 42 shows a typical pattern on the oscillograph obtained when measuring the height of the E-layer. See E-LAYER, F-LAYER, IONOSPHERE, IONOSPHERIC RAY, IONOSPHERIC REFLECTION, OSCILLOGRAPH, OSCILLOSCOPE.

PULSE-MODULATED WAVE. Carrier wave which has been interrupted or whose amplitude has been changed to produce a series of wave-trains, the duration of which is usually small compared with the interval between them. See PULSE MODULATION.

PULSE MODULATION. Method of modulation in which the amplitude of a carrier wave is instantaneously and repeatedly changed between two values, the smaller of which is commonly zero, to produce a series of wave-trains of increased amplitude the duration of which is usually small compared with the interval between the wave-trains. Intelligence can be conveyed by varying the duration of these wave-trains or by grouping a number of wave-trains of equal duration according to an agreed code. See PULSE-CODE MODULATION.

PULSE-NAVIGATION SYSTEM. System, generally employing radar techniques, in which pulses of electromagnetic energy are made to form a hyperbolic lattice (see HYPERBOLIC NAVIGATION). Typical of such systems are Gee and Loran, described under the heading NAVIGATIONAL AID. See also RADAR.

PULSE-WIDTH MODULATION. Modulation in which the duration of the carrier wave is altered by the modulating wave. Modulation may be described as the alteration of some characteristic of the carrier wave by the modulating wave. Thus there is amplitude modulation, frequency modulation and phase modulation (see MODULATION).

In pulse modulation, the remaining characteristic of a wave, namely time, is controlled. Characteristics other than time may be varied in pulse modulation, as when, for example, the amplitude of a pulse changes. Fundamentally, however, the term pulse means that the distinctive feature of this type of modulation is the creating of bursts, or quanta, of energy to represent the form of the modulating wave.

Every technician is familiar with telegraphic signalling by the Morse code. In one such system the distinguishing features are two-fold; first, the pulse of energy transmitted through the channel operates some kind of relay (electronic or electromechanical) in the receiver, which closes or opens a circuit. The circuit is either closed or open; there are no intermediate conditions. In telephony, on the other hand, the power from the output terminals of the receiver has an amplitude which varies within very wide limits.

The second distinctive feature of telegraphic transmission is that the signal may be completely reformed at repeater stations without any distortion. A world-encircling telephone message must pass, on a rough estimate, 500 repeater stations, each of which will add some noise and distortion. A telegraph signal must pass 500 repeater stations and will pass them without distortion, because at each station a substantially perfectly shaped pulse will be reformed from a slightly distorted one.

The result of these differences between telegraphic and telephonic transmission systems is, that the signal-to-noise ratio in telegraphy is inherently greater than that in normal telephonic transmission. Pulse-code modulation seeks to combine the advantages of telegraphy transmission (i.e., good signal-to-noise ratio) with the facilities of telephony transmission (e.g., great speed and direct contact between speakers). See PULSE-CODE MODULATION.

PURE CONTINUOUS WAVES. See TYPE A0 WAVE.

PUSH-BUTTON RECEIVER. Radio receiver, the tuning of which can be automatically switched to one or more chosen carrier frequencies by operation of push-buttons. See PRESS-BUTTON TUNING.

PUSH-PULL AMPLIFIER. Synonym for BALANCED VALVE-AMPLIFIER.

PUSH-PULL MICROPHONE. Synonym for BALANCED MICROPHONE.

PUSH-PULL VALVE-OPERATION. Synonym for BALANCED VALVE-OPERATION.

PYRON DETECTOR. Detector consisting of an iron conductor in contact with a crystal containing iron pyrites. See CRYSTAL DETECTOR.

Q

Q. Abbreviation of Q-FACTOR.

Q.A.G.C. Abbreviation for QUIET AUTOMATIC GAIN-CONTROL.

Q.A.V.C. Abbreviation for quiet automatic volume control, a term sometimes used instead of QUIET AUTOMATIC GAIN-CONTROL.

Q-FACTOR. Factor which compares the quality of conductors, inductors, and capacitors in relation to the power absorbed by such conductor-elements from a sinusoidal wave. Q is equal to the reciprocal of power factor; that is, $Q = \frac{1}{\text{power factor}}$. The commonest use of the Q-factor is in comparing the quality of inductors. If L is the inductance value and R the resistance of an inductor at a frequency f, then the Q-factor of the inductor is the ratio of its reactance to its resistance, or $Q = \frac{2\pi fL}{R}$.

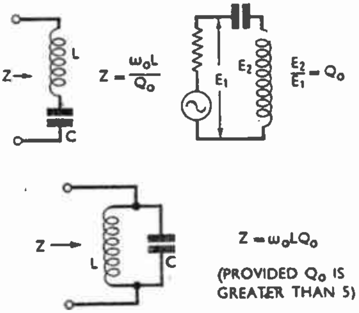


Fig. 1. Various relationships which involve Q. The assumption in each case shown is that the Q-factor of the capacitor C is so great that it may be disregarded. $\omega_0 = 2\pi f_0$, where f_0 is the resonant frequency of the tuned circuit; Z is the impedance of the circuit.

The Q-factor of a capacitor is $\frac{1}{2\pi fCR}$, where C is the capacitance and R the resistance of the capacitor. The quality of capacitors is more often expressed as a power factor than a Q-factor, but obviously one quantity may be derived from the other; a power factor of 0·01 is a Q-factor of 100.

A series-tuned circuit has a Q-factor given by $\frac{1}{R}\sqrt{\frac{L}{C}}$, where R is the resistance of the circuit, and C the capacitance. We may say also that any conductor can be given a Q-factor value, and this is 2π times the ratio of the average value of the oscillating energy of the electric or magnetic fields to the energy dissipated during half a cycle of oscillation.

The Q-factor of inductors is of chief interest to those concerned in designing filters, resonant circuits and such. There are various useful relationships, involving the constants of tuned circuits and Q, and these are illustrated in Figs. 1 and 2. The assumption here is that the Q-factor of the capacitor is very great compared with that of the inductor; this assumption is justified in all but very rare cases.

The Q-factor of an inductor often varies with frequency. In some cases, however, particularly where radio-frequency inductors are concerned, the resistance of the inductor is proportional to frequency over a quite large frequency range, so that $\frac{2\pi fL}{R}$ remains fairly constant. The Q-factor of inductors may vary between values as low as 5 or 10 for an inductor which has a laminated-iron core and is used at 50 c/s frequency or thereabouts, to 200 or 300 for an inductor with a dust-iron core used at $\frac{1}{2}$—$1\frac{1}{2}$ Mc/s.

The Q-factor of a quartz crystal energized from a wave which is resonant to a mode of vibration of the crystal, can be enormously greater than that of any manufactured inductor. Values as high as 100,000 are known. Thus, in filter design, crystals may be used to form a shunt or series element

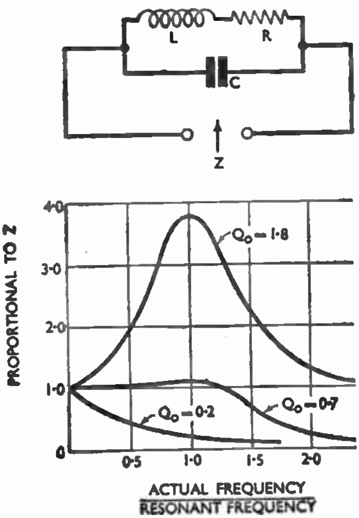


Fig. 2. When the Q-factor in a parallel-tuned circuit is less than unity, no resonances occur; when the Q-factor is 0·7 or thereabouts, the impedance of the circuit is virtually constant over a wide range of frequencies. The value of Q_o is $\omega_o L/R$, where $\omega_o = 1/(2\pi\sqrt{LC})$.

of an almost ideal type, because the crystal simulates a circuit containing both capacitance and inductance in series and having a very high Q-factor. See FILTER, POWER FACTOR, TUNED CIRCUIT.

Q.P.P. Abbreviation of quiescent push-pull.

QUADRATURE. Condition in which one alternating current or voltage has a 90-deg. phase difference from another current or voltage. See PHASE, PHASE DIFFERENCE.

QUADRATURE COMPONENT. Synonym for REACTIVE COMPONENT.

QUADRIPOLE. Network having not more than two pairs of terminals (four "poles"). Quadripoles can be symmetrical or asymmetrical; that is, they may be balanced or unbalanced. Reference to Fig. 3 will help to make this clear. See BALANCED CIRCUIT, NETWORK, UNBALANCED CIRCUIT.

QUADRUPLEX SYSTEM. In telegraphy, a multi-way system in which the circuit is arranged for simultaneous transmission of two messages in both directions over a single line. See MULTIPLE-WAY SYSTEM.

QUANTITY OF ELECTRICITY. Synonym for CHARGE OF ELECTRICITY. See CAPACITANCE, COULOMB.

QUANTIZER. Apparatus for carrying out the process of quantizing. See PULSE-CODE MODULATION, QUANTIZING.

QUANTIZING. For a quantity that can have any value between certain limits, the process of representing any value between those limits by the nearest of a limited number of values selected to cover the range. The process is similar to that of "taking the nearest

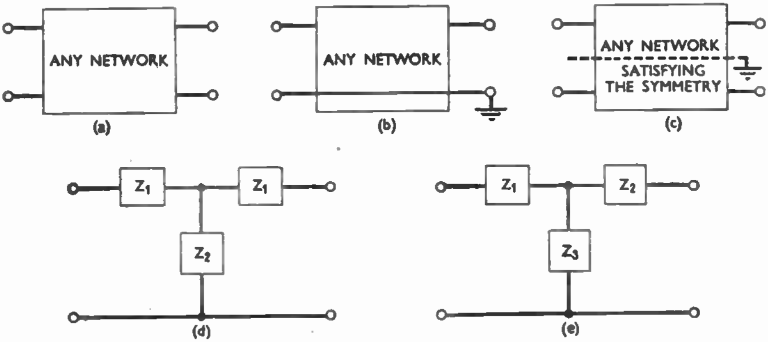


Fig. 3. Forms of quadripole: (*a*) is of a general character; (*b*) is unbalanced and (c) balanced; (*d*) is a symmetrical and (e) an asymmetrical quadripole.

whole number" in arithmetic; this may be regarded as a quantizing process in which the selected values are the natural numbers 1, 2, 3, etc.

Quantizing is of importance in such communications system as PULSE-CODE MODULATION (q.v.) which, by their nature, are limited to sending information about a comparatively small number of discrete values of signal amplitude.

QUANTUM. Hypothetical unit quantity of radiant energy. The conception of the quantum is based on the theory that radiant energy does not consist of a continuous stream but rather of a succession of definite units or even particles.

QUARTER-WAVE AERIAL. Aerial approximately a quarter-wave in length, but more specifically one earthed at the bottom and resonating at its fundamental frequency. In its basic form, the quarter-wave aerial (also known as a Marconi aerial) consists of a vertical, straight conductor, earthed at the foot. When resonating at its lowest natural, or fundamental, frequency, the current and voltage distribution in such an aerial are as shown in Fig. 4, where it will be seen that they are identical with those of one-half of a half-wave dipole. The quarter-wave aerial can, indeed, be compared instructively with half a dipole, the missing portion of the latter aerial being represented by the surface of the earth below and around the quarter-wave one.

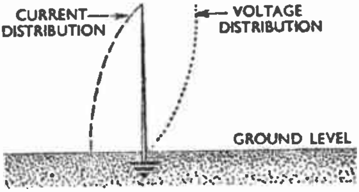


Fig. 4. Current and voltage distribution in a quarter-wave vertical aerial which is earthed at its base. Current is zero at the top of the aerial and has its maximum value at the base.

For instance, if the quarter-wave aerial is disconnected from earth at the base for the insertion of a coupling to a sender or receiver, this point will be found to be one of low impedance, as is the middle of a half-wave dipole. The impedance is, in fact, of the order of 40 ohms in the quarter-wave aerial.

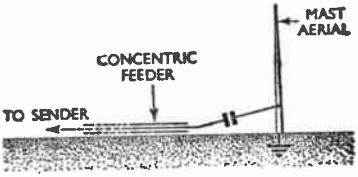


Fig. 5. A quarter-wave mast or tower aerial is sometimes excited by a shunt feed-connexion at a height sufficient for suitable coupling effects. The mast is then earthed directly at the base.

For sending purposes, the quarter-wave aerial sometimes takes the form of a metal mast or tower; it is commonly made somewhat less than an actual quarter-wave high, to allow for the loading effect of the inductor inserted for coupling purposes between the foot of the aerial and earth. Alternatively, the aerial can be shunt-excited, as in Fig. 5, and in this circuit it can be more nearly an actual quarter-wavelength in height. Naturally this method can be used only when the frequency to be radiated is such that a quarter-wavelength is a convenient height for a practical mast or tower.

For example, a frequency of 600 kc/s requires a mast about 120 metres high, allowing for the effect of the necessary small inductor for coupling to the sender when series feed is used; and this is feasible though somewhat costly.

At lower frequencies, a full quarter-wave mast becomes impracticable, and the quarter-wave resonant condition must be obtained by some form of loading applied to a shorter mast. Inductance may be added in series, or some sort of "top" may be attached to the mast, possibly as a ring or a set of projecting metal rods. In this way lumped capacitance is added at the top of the mast, and increases the effective height of the aerial. Without artificial loading or any other disturbing factor the effective height of a vertical quarter-wave aerial is $\frac{2}{\pi}$ times the physical height.

The single, vertical conductor of roughly quarter-wave height is not the only, though it is the classic, form of the quarter-wave aerial. A number of variants function in a basically identical way. Thus, the inverted-L and T-aerials resonate in quarter-wave fashion, and belong to the general class of flat-top aerials so widely used on the lower frequencies. Increased top-capacitance is desirable in any quarter-wave aerial used for sending because it increases the effective height for a given physical height, and reduces the peak voltage at the top of the aerial for a given amount of power, with a corresponding easing of the problems associated with insulation and corona.

Although the quarter-wave aerial is most familiar in its uses for medium and low frequencies, it has also been widely used of recent years on frequencies of the order of 150 to 300 Mc/s in applications where the size of a half-wave dipole would be inconvenient, as on aircraft and vehicles; in such instances, the metal frame of the machine may be used as an earth, or an artificial one may be provided. An artificial earth may consist of crossed half-wave dipoles or, to define it differently, four radial quarter-wave elements.

The familiar whip aerial, for instance, commonly functions in the quarter-wave manner. In these applications, the aerial is sometimes called a unipole, and is a valuable type in all cases where a small and robust structure is required for high frequencies. See INVERTED-L AERIAL, T-AERIAL, WHIP AERIAL.

QUARTER-WAVELENGTH LINE. Section of feeder measuring a quarter of the wavelength in use. More generally, any pair of parallel conductors of that length. The quarter-wavelength line is a device of some importance on the higher frequencies and possesses valuable properties. For example, if a shorting bar is placed across one end of a quarter-wave line, the other end offers a nominally infinite impedance to the frequency at which the section represents a quarter of a wavelength. If connexion is made to the section at a variety of points along its length, it will be found to offer a range of impedances from nominal infinity between the free ends, to what is practically a short-circuit (zero impedance) close to the shorting bar.

It is necessary to use the qualifying terms "nominally" and "practically," because, to offer truly infinite impedance, the quarter-wave section would need to be a theoretically perfect one, without losses.

A device offering a range of impedances in this fashion can be used as a transformer, in the same way as the more familiar parallel-tuned circuit, by tapping circuits into it at appropriate points. Thus, one circuit can be matched to another of different impedance by connecting the two of them to a quarter-wave section, often called a stub, at suitable points; the section being closed at one end with a shorting bar.

In another method of matching, the two impedances to be connected (say, a sender and a feeder line) are joined to the opposite ends of an open quarter-wave section, the impedance of the section being chosen to bring about the desired match. The impedance of the section depends on the diameter of the conductors and their spacing, and on the permittivity of the material, usually air, between the conductors.

The quarter-wave line may also be used in place of insulators to support a feeder line. Since it offers an infinite impedance across its ends, a shorted quarter-wave section can be connected across a feeder wherever desired without introducing losses. Theoretically, this arrangement is superior to an insulator, but in practice it is less attractive; because the "metal insulator," as a shorted stub is sometimes called, is efficient at one frequency only; thus, if the sender wanders even slightly from its correct frequency, losses occur. Where the necessary frequency stability can be assured, however, the quarter-wave stub performs a useful secondary function; it is a virtual short-circuit for frequencies widely removed from the resonant one, and prevents them from reaching the aerial. It is sometimes used, therefore, to suppress undesired frequencies which a sender may be generating.

Another useful property of the quarter-wave line is that when open-circuited at one end, it offers almost a short-circuit to the resonant frequency at the other end. This property can be applied in various ways to solve otherwise difficult problems of switching the output of high-power senders from one aerial to another.

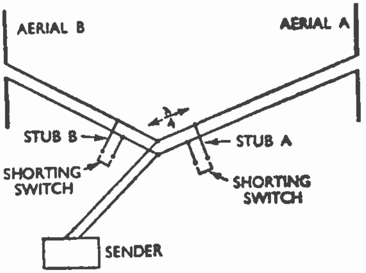


Fig. 6. Feeder line with branches to alternative sending aerials *A* and *B*. The effect of the two stubs, situated at a distance of one quarter-wavelength from the branching point, is explained in the accompanying text.

A simple example is illustrated in Fig. 6, which shows the feeder line from a sender branching off to alternative aerials. At a distance of a quarter-wavelength from the branching point, a quarter-wave section is connected to each line, and a relay-controlled low-capacitance switch is connected to the end of each stub remote from the feeder.

When the switch on stub *A* is closed, this stub resembles a practically infinite impedance from the feeder line, and allows the power to pass on to aerial *A*.

If the switch on stub *B* is open, it acts as a short-circuit across the feeder to which it is connected. It is joined, however, to a point a quarter-wavelength from the branch-point of th feeders; thus this particular section o feeder acts as an end-shorted stub, and presents a very high impedance at the branch-point. No power will, therefore, go into that branch of the feede system; and all will go along the othe line to aerial *A*.

In practice, the quarter-wave sec tions are neither truly infinite no actual zero impedances, but they ar of sufficiently high and low impedanc to ensure that about 90 per cent of th total power is delivered to the intende aerial at the high frequencies on whicl quarter-wave lines are commonly use in this way.

QUARTER-WAVELENGTI TRANSFORMER. Quarter-wave length of transmission line used as matching device to connect a high frequency generator (such as a short wave sender) to a load (such as a aerial).

QUARTZ CRYSTAL. Term applie in radio, to a plate, rod or cube cu from a piezo-electric specimen c quartz and so cut as to possess a part cular desired natural frequency c vibration when used as a resonating c oscillating device.

Desirable properties for the cryst as resonator or oscillator are: (1) hig piezo-electric activity; (2) very sma change of natural frequency wit change of temperature, and (3) n double-frequency effects in the regic of the desired resonant frequen resulting from elastic coupling between two modes of vibration.

A large variety in orientations of cut with reference to the crystallographic axes is employed in producing crystals for practical work, specified types of cut being made to produce particular characteristics.

QUARTZ OSCILLATOR. See CRYSTAL OSCILLATOR.

QUARTZ RESONATOR. See QUARTZ CRYSTAL.

QUASI-OPTICAL WAVE. Electromagnetic wave of very short length, whose behaviour is governed by the same laws as those applicable to light waves. Waves having lengths between 1 and 10 mm. are generally regarded as quasi-optical.

QUENCHED SPARK-GAP. Type of spark-gap designed to meet the requirements of the quenched spark system. The construction of the spark-gap must provide for rapid dissipation of heat; also for rapid de-ionization.

A form of quenched spark-gap is illustrated in Fig. 7. It consists of a number of circular plates separated by mica washers. The plates are made of copper, with silver-plated sparking surfaces. This provides good conduction of heat away from the sparking regions. In addition, each plate carries a heat-radiating fin.

The gap is divided into a number of very short sub-gaps in series; this assists in cooling. In addition, deionization is assisted because, at the instant of quenching, no ion in a sub-gap has far to travel to reach the electrode of opposite potential.

Each sparking surface is bounded by a circular groove cut in the plate. This aids quenching because, when a spark discharge occurs, the repulsion between ions causes it to move outwards towards the groove where there is a large increase in gap width.

In the spark-gap illustrated, the sub-gaps are totally enclosed. An alternative type of spark-gap has the mica separators at the centre, the sparking surfaces being ring-shaped and open to the air.

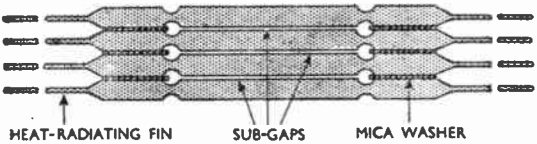


Fig. 7. Section through a quenched spark-gap, showing how it comprises a series of totally enclosed sub-gaps.

QUENCHED SPARK SYSTEM. Spark system, employing primary and secondary oscillatory circuits with the spark-gap in the primary, in which the spark is extinguished at the first instant that the energy in the primary circuit becomes zero.

Particular features of the system are a special form of spark-gap, designed to provide rapid dissipation of heat, and tighter coupling between the two oscillatory circuits than is used in spark systems employing non-quenching spark-gaps.

At the commencement of the spark discharge, a very rapid transfer of energy from the primary to the secondary circuit begins. As a result of this quick transfer of energy, the oscillations in the primary are highly damped. After a small number of primary oscillations, the energy transfer is complete and at this particular instant, and before the secondary circuit is able to transfer energy back again into the primary circuit, the spark is quenched and the spark-gap becomes non-conductive.

The breaking of the primary circuit leaves the secondary circuit free to continue oscillating at its own natural frequency and without damping being imposed by the primary circuit.

The primary oscillations start with a maximum initial peak value and a very rapid decrease, the train of oscillations being of very brief duration. The secondary oscillations start with a small initial peak value, build up very rapidly to a maximum and then continue with decreasing peak values (the damping being governed by the secondary-circuit losses) for a period of time greatly exceeding that of the primary train of oscillations.

Slight mistuning between the two circuits is an aid to the prevention of re-transfer of energy from the secondary circuit. See QUENCHED SPARK-GAP, SPARK SENDING SYSTEM.

QUENCHING. Periodical suppression of oscillation. It may refer to the rapid damping-out of each primary wave-train in a quenched spark system; or to the periodical suppression of oscillation in a super-regenerative receiver. See SUPER-REGENERATIVE RECEPTION.

QUENCHING OSCILLATOR. Valve whose state of self-excited oscillation is periodically suppressed at a high audio frequency. See SUPER-REGENERATIVE RECEPTION.

QUIESCENT AERIAL. Synonym for ARTIFICIAL AERIAL.

QUIESCENT-CARRIER MODULATION. Synonym for FLOATING-CARRIER MODULATION.

QUIESCENT MODULATION. Synonym for FLOATING-CARRIER MODULATION.

QUIESCENT PUSH-PULL AMPLIFIER. See BALANCED VALVE-OPERATION, CLASS-B VALVE OPERATION.

QUIESCENT PUSH-PULL VALVE OPERATION. See BALANCED VALVE-OPERATION, CLASS-B VALVE OPERATION, CLASS-C VALVE OPERATION.

QUIET AUTOMATIC GAIN-CONTROL. System of automatic gain-control in which the receiver is muted while tuning between stations, so that no random noise is then heard. The device is operated from the delayed A.G.C. circuits, suppressing the receiver output until a signal is received of sufficient amplitude to bring the A.G.C. into action. See DELAYED A.G.C.

R

RADAR. Method of measuring the range and bearing of an object by means of a radio-wave radiated from a pulse sender and returned to the sender by reflection at the object. The word is made up of the initial letters of *R*adio *A*ircraft *D*etection *A*nd *R*anging. The original British designation was "radiolocation," which was derived from "range and direction finding" (R.D.F.).

Probably the most important contribution to the origin of radar was Prof. E. V. Appleton's series of experiments to measure the distance of the Appleton layer by directing radio pulses upwards, receiving the reflected echoes and measuring the time between sending and reception.

The measuring device was a cathode-ray oscilloscope in which the time base was of known speed and could be calibrated in fractions of a second. The time base was triggered when the sender radiated its pulse, and the received echo was made to deflect the trace; by this means, the time taken for the wave to reach and return from the layer could be measured (Fig. 1), as it is known that radio-waves travel at a speed of 300,000,000 metres per second. The pulses used in the early experiments were of long wavelength and of about 50–100 microseconds in duration; the leading edge of the pulse was taken as the measuring point.

A few years before the Second World War, the National Physical Laboratory and specially chosen re-

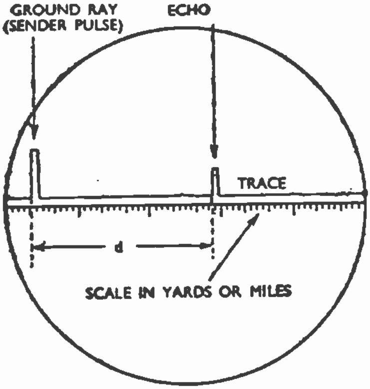


Fig. 1. The trace produced by deflection of a spot from left to right across the screen of a cathode-ray tube is a fundamental of radar. The vertical deflections, or blips, caused by the sender pulse and the echo pulse, indicate, by their spacing *d*, the distance of a reflecting object, because *d* is proportional to the time taken for the pulse to travel from the sender to the reflecting medium and back again.

search workers combined to develop R.D.F. as a means of detection of enemy aircraft. Pulse lengths were reduced and the pulse-repetition frequency—known as P.R.F.—was increased. Pulses of 8–20 microseconds were used with a P.R.F. of 25–50 c/s. Comparatively high-power stations were erected.

During the war, radar developed very rapidly. A system of direction-finding was produced which used rotating aerials, with stacked dipoles to concentrate the radiated signal into a beam. These aerials were geared to cathode-ray tubes containing a radial time base in which the trace revolved like the hand of a clock. Thus, the time base swept through an angle of 360 deg. in step with the rotating aerial and showed, at a glance, the bearing of the aerial whenever a signal response was shown on the tube.

At first, these responses were obtained by applying the amplified signal voltage to one pair of the deflector plates of the cathode-ray tube, the other pair being employed for the time base. Thus the responses were seen in the form of "blips," or lines, on the trace. If a number of aircraft were detected, the responses were jumbled up and formed a bulge; if only one was seen, or the aircraft were well separated, a distinct blip would be seen for each aircraft.

The above refers principally to equipment installed on the ground and used for the detection and ranging of aircraft. A corresponding but much more compact installation was carried by fighter aircraft, and known as A.I. (aircraft interception). The aerial system—normally four receiving and one sending aerial—was mounted on the forward part of the aeroplane, while the indicator unit had two cathode-ray tubes: one to give elevation and the other to give azimuth bearings. In each case the range was given by the distance of the blip from a zero position on the cathode-ray trace. Direction-finding was provided by a

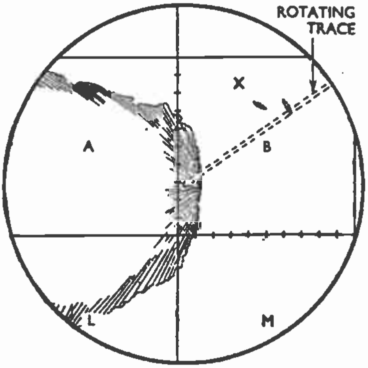


Fig. 2. A revolving radar trace, modulated by received echoes, provides a plan-position indication of the points of reflection. By placing a grid map over the tube, the positions can be plotted; thus the station is at *B*2903 (square *B*, vertical scale 2·9, horizontal scale 0·3), and the ship *X* is at *B*7245.

switching device which connected each of the four receiving aerials in turn to the receiver. There were various modifications to, and Marks of, this equipment, so it is possible to give only a brief résumé of the essential principles.

With the later introduction of the rotating time base (the P.P.I., or plan-position indicator), the blip display gave way to intensity modulation of the tube; responses were made by brightening the trace instead of deflecting it. And to enable the observers to report exactly where the target was, a map of the relevant area was drawn on the face of the tube. Cathode-ray tubes with long after-glow properties were used, so that the brightened trace "painted" a small bright arc on the screen as it rotated (Fig. 2), the length of the arc depending on the time period of the pulse, the beam width and the speed of rotation of the aerial.

By means of electronic switching, one aerial was used for both sending and reception. Special arrangements automatically protected the receiver when the pulse was sent, and "opened" the receiving path immediately after to permit the reflected response to be picked up.

The first radar stations operated within a range of 20–50 Mc/s. When beamed aerials were used with rotating arrays, the frequency was increased to 200 Mc/s. Later, in order that very short pulse lengths and narrower beams could be used to improve definition of echoes from targets, the frequency was further increased to 3,000 Mc/s, and later to 10,000 Mc/s.

As the width of the beam is dependent on the size of the aerial-system (the greater the number of bays of dipoles the narrower the beam), obviously, the smaller the dipoles, the narrower the beam will be for a given over-all width of aerial. And if the aerial is to be rotated, the smaller it is physically, the better. So the tendency was to increase frequency as far as possible to reduce the physical size of dipoles. This led to the use of centimetre-wavelength equipment, with wave-guides instead of wire feeders, and solid or mesh reflecting parabolae instead of arrays of dipoles.

With the low-frequency equipment, estimation of the height of a target was carried out by measurement of the phase difference between the ray received on two sets of aerials, one above the other, the path difference accounting for the difference in phase. Later, with centimetric equipment, the height was measured to an astonishing degree of accuracy by means of specially designed aerials which could be tilted. As the angle of tilt and the range of the target are known, the height can be calculated.

Further research into radar technique resulted in the development of automatic signal-locking devices which automatically "locked" the equipment on to a response once it had been detected. By use of a spinning dipole set so that its plane of rotation is parallel to the rim of a parabolic reflector, the beam was moved in a circle; unless the target were at the centre of the beam so emitted, the response at the receiver would be larger at one particular position of the dipole.

Thus, if readings of the received signal strength were taken at 360, 90, 180, and 270 deg. of dipole rotation and the target were at a position between 90 and 180 deg. somewhere along the beam, a stronger signal would be received from the equivalent dipole readings at 90 and 180 deg.

By feeding the signals through special self-synchronizing motors, the aerial could be made to move until signals received at 360, 90, 180 and 270 deg. were equal. In this position the parabolic aerial would be directed straight at the target. Radar devices with this type of aerial-system and control were used to operate anti-aircraft guns, the guns themselves being electrically locked to the radar unit.

Today the tendency is to increase the

frequency still further to enable smaller and smaller aerials to be used, so that aircraft can carry radar as a means of seeing the ground through cloud.

This applies particularly to the airborne equipment developed during the Second World War and known as H_2S. It operates on centimetric waves and employs a rotating scanner comprising a dipole mounted in a parabolic reflector. The P.P.I. type of display resembles a rough map of the terrain over a circular area beneath the aeroplane. After practice in the correct interpretation of the display, a navigator can readily detect the main features such as coast lines, rivers, mountains, built-up areas and open sea or country; he can thus recognize and identify a target with accuracy by comparing the display with his target map.

High definition calls for a very narrow beam, for it is obvious that the narrower the beam, the fewer the objects seen at the same time and the greater the possibility of differentiating between neighbouring objects. Further, the use of extremely high-frequency pulses enables more types of objects to be seen, since such waves give better reflections from non-metallic objects than those of lower frequency. Thus, while a 45-Mc/s wave cannot provide a detectable echo from a man, a 25,000-Mc/s wave will certainly show a response.

There are difficulties in using these extremely high frequencies; attenuation due to atmospheric particles, especially of moisture, is serious, and the design of sender valves to give high power is not easy. Ordinary sender valves are useless at frequencies higher than 3,000 Mc/s, and at that frequency it has been found impossible to obtain high peak power from normal valves. Magnetrons have superseded triodes or tetrodes for sending, and the oscillator section of the mixer stage in superheterodyne receivers is a klystron.

Certain centimetric radar receivers dispense with signal-frequency amplification, the received energy being fed direct to a klystron oscillator and mixer. Several stages of intermediate-frequency amplification at 45 Mc/s follow, and demodulation is by a conventional form of detector, which is, in turn, followed by a vision-frequency amplifier to feed the signal to the cathode-ray tube. Band widths of the I.F. stages must be not less than 4 Mc/s with less than 1 db. drop at the extremes of the band, and the vision amplifier should give a level response from 25 c/s to 2 Mc/s.

If good frequency response is not obtainable, the picture on the P.P.I. will not be well defined, and definition between P.P.I. responses will be poor. To obtain good, clear definition on the P.P.I., the spot diameter of the cathode-ray tube should be small. With modern pulse widths of 0·1 microsecond duration, the spot size should not be greater than ¼ mm., or it will not be sufficiently modulated by the received signal. Moreover, a large spot takes up too much area on the P.P.I. screen, and tends to mask the resolution of large responses into separate neighbouring entities.

Attempts are being made to design radar equipment operating on frequencies of 50,000 and 75,000 Mc/s. Equipment working on 25,000 Mc/s is in use for aircraft navigation; shipping and harbour authorities are beginning to use 10,000-Mc/s equipment for harbour navigation and control and for anti-collision purposes. With each increase in frequency, aerials can be made smaller, beams narrower and the equipment (particularly aerials and wave guides) lighter. On the other hand each increase of frequency introduces new problems, e.g., attenuation, absorption by moisture in the air, difficulties in valve design, and the need for better focusing and narrower beams in the cathode-ray tube.

One of the greatest boons which radar bestows is that of enabling airliners to land in conditions of bad visibility. To do this, the aircraft is brought into the vicinity of the airfield

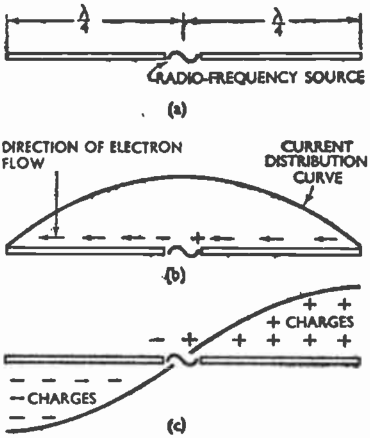


Fig. 3. Diagrams illustrating the current and charge distribution on a dipole aerial (*a*); the condition indicated at (*c*) is that which arises one-quarter of a cycle later than the condition at (*b*).

by normal signal control, and then the pilot makes his approach and landing under the instruction of a controller on the ground.

By the use of a centimetric radar equipment known as ground-controlled approach (G.C.A.), the controller can plot the exact position and height of the incoming aircraft. He can thus tell the pilot when he is in line with the landing strip and to fly on a certain course at a certain speed and height, so that the aircraft can be brought in correctly to land. Orders from the ground are given to lower the landing wheels, throttle-back and so on, and the plane is brought down by this means until it is a few feet above the ground, and the flare path can be discerned. The pilot then completes the last few steps in landing by himself. Even if the visibility is nil, the plane can be landed completely by radar, the pilot receiving instructions until his landing wheels actually touch the runway.

Centimetric radar has also been applied to the control of airfields and ferry systems, usually by ground-based and shore-based equipments respectively. See DIRECTION-FINDING, KLYSTRON, MAGNETRON

RADAR BEACON. Transponder on the ground or at sea which, when triggered by a series of radar pulses, returns a characteristic and/or amplified response. See NAVIGATIONAL AID, SECONDARY RADAR.

RADIAN. Unit of angle which is defined as the angle subtended at the centre of a circle by an arc of its circumference equal to a radius of that circle. It follows that 2π radians are equal to 360 deg., and one radian to 57 deg. 18 min.

RADIATION. Electromagnetic fields which become disengaged from an aerial wire and radiate outwards into free space. In Fig. 3a, a piece of wire is cut in half and attached to the terminals of a high-frequency generator,

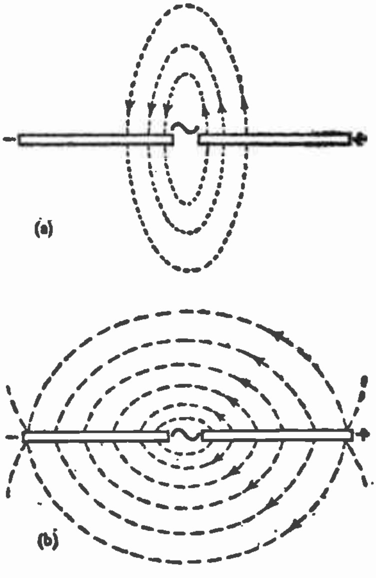


Fig. 4. Effects which produce radiation from a dipole aerial: (*a*) the magnetic field *round* the aerial and (*b*) the electric field. Arrowheads indicate the direction of the flux in each case.

which may well be a radio-frequency oscillator. The frequency is so chosen that each half of the wire is one-quarter of the wavelength of the generator output. The result is a common type of aerial known as a dipole.

At any given instant, the right-hand side of the generator is, say, positive, and the left-hand side negative. As like charges repel each other, electrons will flow away from the negative terminal, while the positive terminal will attract electrons to it. Fig. 3b shows the distribution and direction of electron flow. One-quarter of a cycle after the electrons have begun to flow because of the voltage developed by the generator, the generator will develop its maximum voltage and the current will decrease to zero. At that time the condition shown in Fig. 3c will exist. No current will be flowing, but there will be a maximum number of electrons at the left end of the wire and a minimum at the right end.

There is thus a sinusoidal distribution of current in the dipole aerial, and at the same time a sinusoidal distribution of charge. Both vary in amplitude sinusoidally, but the charge variation is one-quarter-cycle, or 90 deg., behind the current variation. A current flows in the aerial, therefore a magnetic field is set up around the aerial; positive and negative charges also appear on the aerial, causing an electric field to be set up (Fig. 4). Since the current and charges producing these fields are 90 deg. out of phase, the two fields must also be out of phase by 90 deg. These fields constitute the induction field, the energy of which cannot be detached from the aerial, and whose effect is only local.

Henceforth, only the electric field set up round the aerial will be considered. The charges producing this field vary sinusoidally; at one instant one end of the aerial is positive and the other end negative, an instant later the aerial is uncharged, and the next instant the end which was positive becomes negative, and so on cyclically.

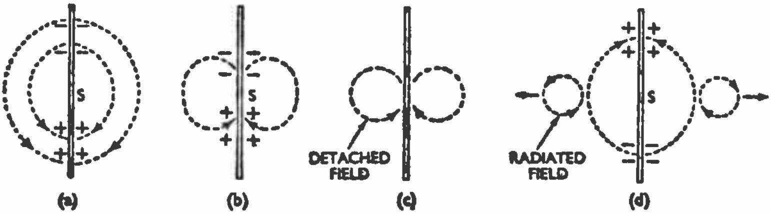


Fig. 5. How a portion of the electric field surrounding a dipole aerial becomes detached and radiated into space: (*a*) the electric charge at a maximum; (*b*) charge diminishing; (c) zero, and (*d*) charge building up in the opposite direction.

In Fig. 5a, flux lines are drawn between positive and negative charges. An instant later, as in Fig. 5b, the aerial is almost discharged as the charges approach each other. When the charges do touch, they seem to disappear and their flux line should also disappear. Most of the flux which represents the induction field has disappeared; but because of the inertia of the system, the flux lines cannot collapse rapidly enough and lag behind the diminishing charge. Thus a closed electric field is created without an associated electric charge. An instant after the independent field has been formed, the aerial charges up again in the opposite direction and produces lines of force that repel the recently formed independent electric field. The radiated field is forced away from the aerial at the speed of light, as shown at Fig. 5d.

As stated previously, a moving electric field has associated with it a moving magnetic field. This results in a radiated electromagnetic field that can travel great distances and deliver a part of its energy to a receiving aerial. Unlike the induction field where the magnetic and electric fields are 90 deg. out of phase, the two fields in the radiated field are in phase, but are perpendicular to each other in space. See HALF-WAVE DIPOLE, OSCILLATOR, POLARIZATION.

RADIATION EFFICIENCY. Property of an aerial which can be expressed as the ratio between the total power input and the power which is usefully radiated at a particular frequency. In other words, a measure of the efficiency of the aerial in its intended function as a radiator of energy.

RADIATION RESISTANCE. See AERIAL RADIATION-RESISTANCE.

RADIO ALTIMETER. Device, carried in an aircraft, in which radio waves are used to determine the height of the aircraft above the ground.

There are two basic types of radio altimeter; in one, known as the *capacitance altimeter*, the capacitance of the aircraft to the ground is included in a tuned circuit coupled to the output of an oscillator. As the aircraft nears the ground its capacitance to ground increases; the tuning of the circuit to which it is connected is altered and the potential difference across it also changes. The change in p.d. can be measured by an instrument calibrated in feet above ground. The capacitance altimeter can be used only at comparatively low altitudes because the change in capacitance becomes negligible at heights above about 100 ft. It is mainly used, therefore, during landing operations.

The second type of radio altimeter makes use of the time taken for a radio wave to travel from the plane to the ground and back again to the plane. A sender in the plane radiates a high-frequency wave towards the ground from a horizontal dipole and the frequency is varied cyclically by a small variable capacitor driven by an electric motor. A receiving aerial is so mounted on the aircraft that it picks up the radiated waves, both directly and after reflection at the ground, at approximately equal strength.

During the time occupied by the reflected wave in travelling to the ground and back its frequency changes appreciably, and the extent of the change depends on the height of the plane above the ground. Thus the two waves received at the aircraft differ in carrier frequency and the frequency difference depends on the height of the plane above the ground. Thus the output of the detector consists of a single frequency which is connected to a frequency meter directly calibrated in feet above ground.

Radio altimeters are sometimes called "terrain-clearance indicators."

RADIO BEACON. Sender radiating some form of signal useful to ships or aircraft for navigational purposes. See BEACON DIRECTION-FINDER, DIRECTIVE-SIGNALLING BEACON.

RADIO-BEACON SYSTEM. Navigational-aid system employing a series or multiplicity of beacons. The term is also used to denote a system or method of navigation by means of beacons. Certain air routes offer an example of a beacon system in practice. Radio beacons are sited at suitable intervals along the track and by homing on each beacon in succession an aircraft can traverse the whole route with accuracy in the worst visibility. See COURSE-INDICATING BEACON.

RADIO BEAM. Radiation confined to a particular zone or range of bearings from the sender. It may be used to preserve the secrecy of communications, to increase the working range by concentrating the available power into a narrow path, or to play some part in a position-finding system such as radar, or certain blind-landing systems. See BLIND-LANDING SYSTEM, RADAR.

RADIO BROADCASTING. Broadcasting in which the link between senders and broadcast receivers is made by radio-waves. The term may be used to distinguish radio broadcasting from wire broadcasting.

RADIOCOMMUNICATION. Process of sending and receiving signals by means of electromagnetic waves of radio frequency.

RADIO COMPASS. Broadly, any direction-finder; but particularly one which is calibrated in some special manner for reading bearings of fixed stations from a ship or aircraft.

RADIO DIRECTION-FINDER. See DIRECTION-FINDER.

RADIO ECHO. One or more signals indentical to, but received at some finite time after, the original signal has been received. These echoes may be classified into three distinct types: quick echoes, one-seventh-second echoes, and very long-delay echoes.

Quick echo, or, as it is sometimes called, multiple echo, is most common and is evident to some extent on all short-wave transmissions. The transit time from the sender to the receiver is slightly different according to whether the ionospheric rays have travelled with one reflection only, or with several reflections. At the receiver, there will be a number of signals following each other in rapid succession, the strongest signal being that which has undergone the least reflections, because attenuaation by the E- and F-layers has been less.

At very great distances, the rays which undergo many reflections may become attenuated so much that there may be only one really strong ray left at the receiving point. Under such conditions the echo may be so weak as to be negligible. The effect of quick echoes on morse signals is to cause a lengthening of the symbols which gives rise to slight, but not troublesome, distortion. Speech reception becomes rather hollow sounding, as if the speaker were in an empty room. Facsimile transmission may become difficult; the blurring of the characters on the received message may become so bad as to make it unintelligible. The remedy for quick echoes is to reduce high-angle radiation from the sender by the use of beam aerial-systems, so that the ionospheric rays suffer a minimum number of reflections.

One-seventh-second echoes are caused by the signal making a complete circuit of the earth. The original signal travels to the receiver from the sender and then travels right round the earth and back to the receiver again, the time taken by it to circuit the earth being approximately one-seventh of a second. The signal travels round the earth by successive reflections from the F-layer, and if conditions are favourable it may circuit the earth several times with but little attenuation. The conditions required are that the great-circle line between the two stations coincides with the twilight zone, the dividing line between night and day; and, in such conditions, wavelengths between 15–18 metres show very prominent round-the-world echoes. There is no remedy for this type of echo, as directional methods of reception are of no avail.

Echoes of the third type, having a long delay of up to 30 seconds, are sometimes called Stormer echoes, after the man who first observed them. They are quite a rare phenomenon and have been reported by few observers. The cause of these echoes is not known and they are so distorted and unlike the original as to be almost like an atmospheric disturbance. One theorist has explained them by assuming that the signal becomes trapped between the F1- and F2-layers so that it circles the earth some hundreds of times and eventually breaks through a lightly ionized patch in the F1-layer. But it is difficult to explain why the signal is not completely absorbed. See E-LAYER, F-LAYER, IONOSPHERIC RAY, IONOSPHERIC REFLECTION, TYPE A4 WAVE.

RADIO EXCHANGE. Synonym for RADIO RELAY SYSTEM.

RADIO FREQUENCY. Frequency at which electromagnetic radiation is used for radiocommunication, industrial, and medical purposes. Originally, radio frequencies were used only for communication, but they are now used extensively for heating purposes in industry, heat treatment of hospital patients, radio control of guided projectiles and remote control of machinery. See RADIO-WAVE.

RADIO-FREQUENCY ALTERNATOR. Synchronous generator for producing alternating currents of radio frequency. See SYNCHRONOUS GENERATOR.

RADIO-FREQUENCY AMPLIFICATION. Amplification of a modulated or unmodulated radio-frequency signal without change in wave form. In a radio receiver, the valve stages preceding the detector or frequency-changer perform radio-frequency amplification.

RADIO-FREQUENCY CHOKE. Fixed inductor designed to offer a high impedance to R.F. currents. It has, usually, an air or iron-dust core, and is untuned. See CHOKE.

RADIO-FREQUENCY PENTODE. Synonym for SCREENED PENTODE.

RADIO-FREQUENCY RESISTANCE. Resistance that a circuit or conductor offers to the passage of radio-frequency currents; it is normally of a higher value than the low-frequency and D.C. resistance.

RADIO-FREQUENCY TRANSFORMER. Transformer for operation at radio frequencies. The losses in laminated-iron cores forbid their use in transformers which handle waves of frequency much greater than 0·5 Mc/s. Dust-iron cores are suitable, however, and radio-frequency transformers often use such cores for waves having frequencies up to several megacycles. At still higher frequencies, air-cored transformers are generally used. See CORE, LAMINATION, TRANSFORMER.

RADIOGONIOMETER. Instrument for determining the relative intensity of radio-frequency currents in two separate circuits and expressing the result in the form of an equivalent angle. The instrument is more commonly known as a goniometer. Fundamentally, the goniometer consists of two field windings set accurately at right-angles and embracing symmetrically a third, or search winding, which is capable of rotating in the magnetic field of the other two. The angular setting of the search winding gives the relation between the currents in the field windings.

If there is a current flowing in one field winding, and none in the other, maximum induced voltage is obtained in the search winding when this is parallel to the winding carrying the current. If the current in the fixed winding ceases and another flows in the other, the search winding must be rotated through 90 deg., making it parallel to the active winding, to obtain the maximum induced voltage.

If equal current flows in each field winding, the search winding must be set to a mid-way point, at 45 deg. to the field windings, to give maximum induced voltage.

As is so often the case in dealing with electromagnetic induction effects, the position of minimum induced voltage is more sharply defined than the maximum. In the simple case of current in one field winding and none in the other, the search coil must be set at right-angles to the active winding to give minimum voltage. This, of course, is a position at 90 deg. from that for maximum.

When one field winding carries a large current and the other a small one, voltages must be induced in the search coil to obtain minimum response in the search coil; furthermore, these voltages must be in exact phase opposition; the search coil must be set almost parallel to the field winding which carries the weaker current, to give this minimum response.

In short, whatever the ratio of the currents in the field windings, there is a setting of the search coil which gives minimum-signal in it, and the angular setting of the coil is then a measure of the ratio of the two currents. If the field currents are obtained from a pair of loop-aerials set at right-angles to each other, so that the current in each is related to the direction of the radio-waves passing across the loops, the goniometer reading will provide a definite indication of that direction. This is the basis of many direction-finding systems. See BELLINI-TOSI DIRECTION-FINDER, SPACED-AERIAL DIRECTION-FINDER.

RADIOGRAM. Telegram, the word content of which has been transmitted by radio telegraphy. The term radiogram is also used as an abbreviation for RADIO GRAMOPHONE.

RADIO GRAMOPHONE. Instrument combining the functions of a radio receiver and an electrical gramophone (see ELECTRICAL REPRODUCTION). The electrical gramophone was a logical development of valve amplification. The discovery of the amplifying properties of the triode revolutionized the design of radio receivers and, at the same time, opened up a new field of progress in the gramophone industry.

The triode supplied the means of obtaining power for the reproduction of sound, and it was obvious that, provided the sound track on a gramophone record could be converted into electrical energy (see GRAMOPHONE PICK-UP), such energy would correspond to that obtained from the detector in a radio receiver; therefore, the same system of amplification could be applied to both radio receiver and gramophone reproducer.

These principles were applied long before the radio gramophone was produced as a self-contained instrument. Fig. 6 illustrates a clockwork gramophone on which the sound-box has been replaced by a pick-up. The pick-up is connected to a pair of terminals on the battery receiver, and a switch is incorporated in the receiver to change over from radio reception to gramophone reproduction. The circuit is shown in Fig. 7.

The musical quality of these electric gramophones was limited by two important factors; first, the receiver was prone to considerable attenuation and harmonic distortion and, secondly, electrical recording was in its infancy and many commercial records were still being made by the acoustic system (see ELECTRICAL RECORDING).

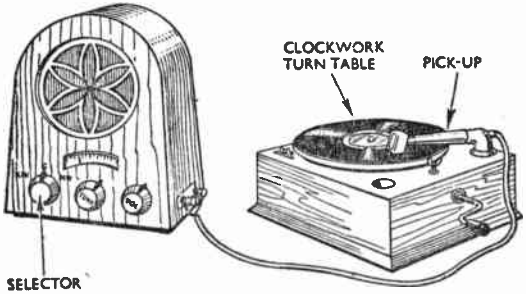


Fig. 6. Earliest form of radio gramophone; the sound-box of the clockwork gramophone has been replaced by a pick-up, the terminals of which are connected to a battery-operated radio receiver.

By the time that electrical recording had become universally established, improvements in receiver and loudspeaker design resulted in a corresponding advance in the quality obtained from electrically reproduced records. Attention was then paid to the development of electrically driven turntables and, when these were perfected, all the essential components of a radio gramophone were available.

It was a relatively simple matter to design a single instrument incorporating a radio receiver, a gramophone pick-up and an electrically driven turntable. Design was simplified by the introduction of the indirectly heated valve which dispensed with the need for batteries, power for both receiver and turntable being taken from a single mains supply point.

The next stage in development was the introduction of automatic record-changing mechanisms. With these, a number of records can be played in succession without manual attention. The series of selected records are placed on the machine and, as each record is completed, the pick-up swings clear and the next record is automatically lowered to the playing position. The system introduces difficulties, however, the first of which is that of ensuring continuity.

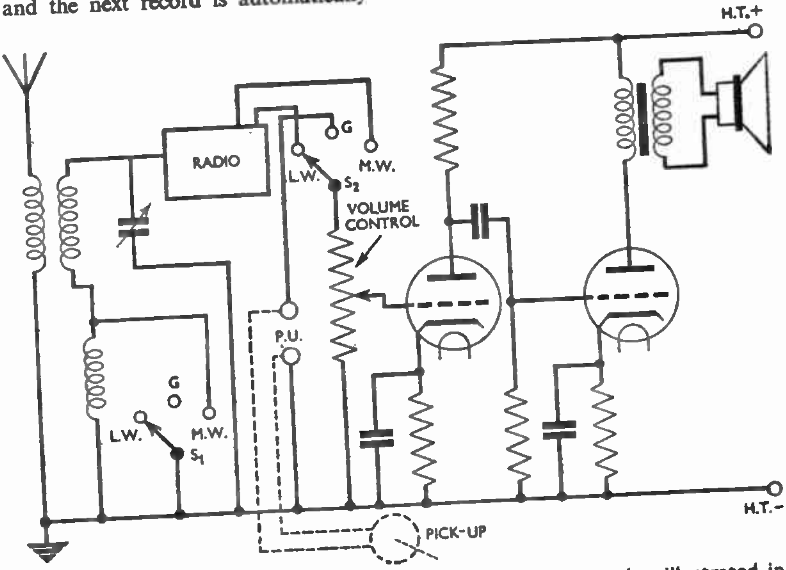


Fig. 7. Basic electrical circuit of a radio gramophone such as that illustrated in Fig. 6. Switches S_1 and S_2 are ganged; when the pick-up is switched to the volume control by S_2, it leaves the radio-receiving circuit disconnected.

To reverse each record after one side has been played calls for great complication in design of the record-changing mechanism. To avoid this, works such as orchestral symphonies are arranged in alternating sequence; thus, assuming a work to occupy five double-sided discs, the first five parts would each be on one side of five separate discs and the remainder in consecutive order on the other sides. By turning over all five records simultaneously, after the fifth side has been played, correct continuity is achieved.

The older type of record-changer introduces considerable wear on the disc edges and, moreover, was designed for use with pick-ups having large mass. Modern light-weight pick-ups call for a changing mechanism having a more delicate operation.

A radio gramophone using a light-weight pick-up and improved record-changing mechanism is illustrated in Fig. 8. This instrument is designed for radio reception on long, mediu and short waves; it has push-button controls for automatic tuning of selected stations and for bringing the gramophone into operation. A tone control is fixed to the side of the instru-ment.

The record-changing mechanism o this instrument consists of a number o

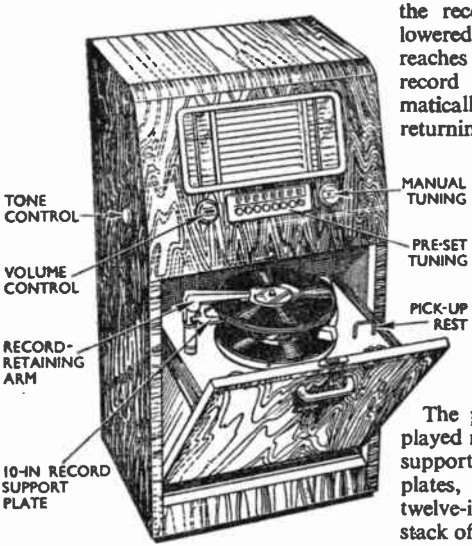


Fig. 8. A modern mains-operated radio gramophone, the automatic record-changer of which is capable of handling both ten-inch and twelve-inch records. It is an "H.M.V." model.

swivelled links and sliding levers mounted beneath the base plate. This form of construction is adopted in preference to the older type of cam motion because it gives the machine the delicacy in operation referred to previously.

The operating spindle projects through the turntable and consists of two tubes, the outer of which is notch-shaped at the top and spring-loaded. Another spindle is stepped, or offset from the outer tube, the stepped spindle supporting the records; the weight of the records is taken by the outer spring-loaded tube.

When the pick-up reaches the run-off groove of the record being played, the changing mechanism is brought into operation, the pick-up being gently lifted from the record and swung clear. The spring-loaded tube now revolves and fits into the hole of the next record to be dropped, easing it off the stepped spindle. The record now slides down the main spindle into the playing position, and the pick-up swings gently back into the outermost groove.

This cycle continues until the last of the records on the stack has been lowered and played. When the pick-up reaches the run-off groove of the last record the turntable motor is automatically switched off, the pick-up returning to the rest position.

The periphery of the stack of unplayed records is held in position by a supporting plate. There are two such plates, one for ten-inch and one for twelve-inch records. Fig. 8 shows a stack of records resting on the ten-inch plate and it will be seen that a retaining arm is lowered on to the top record so that the stack is held between a mechanical thumb and forefinger. The top retaining arm is hinged and gradually lowers as the stack decreases; when the last record has been lowered to

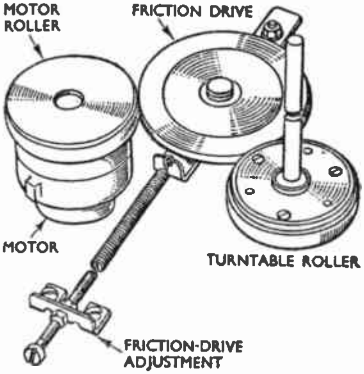


Fig. 9. "H.M.V." gramophone friction-drive unit. The 78-r.p.m. hysteresis electric motor is coupled to the turntable through a friction drive.

the turntable the retaining arm falls still lower and prepares the mechanism for switching off the motor when the last record has been played.

The operating controls comprise two push-buttons, one for setting the mechanism into operation and the other for disengaging the mechanism and switching-off the motor. With some models, a further knob control is provided which permits the playing of a single record without bringing the record-changing mechanism into operation.

The turntable drive is illustrated in Fig. 9; it will be seen that a roller attached to the driving-motor shaft is coupled through a friction-drive wheel to a roller under the turntable; the hysteresis motor has a constant speed of 78 r.p.m., and the spring-loaded adjusting device ensures even pressure between motor and turntable rollers.

In recent years, considerable progress has been made in improving the frequency response obtained from gramophone records and it does not necessarily follow that the audio-frequency stages of a radio receiver are suitable for producing the best results obtainable from modern gramophone records.

A reproducing amplifier designed specifically for use with a high-fidelity pick-up and wide-range records will give greater realism to the reproduction. Nevertheless, the modern radio gramophone provides a means of obtaining both high-quality reception of radio programmes and a good standard of gramophone reproduction. See ELECTRICAL REPRODUCTION, GRAMOPHONE PICK-UP, RADIO RECEIVER.

RADIO LINK. That part of a transmission system in which the transmission channel is formed by a radio sender and a radio receiver. In broadcasting systems, it is sometimes impossible or uneconomic to use a transmission line, such as a telephone pair or pairs, to join a microphone to the control room (and hence the sender). For instance, the running commentary on a boat-race must be done from a launch following the boats. It would be impossible in such circumstances to use a telephone line to join the commentator's microphone to the control room in the headquarters of the broadcasting undertaking concerned. A small radio sender is therefore used to send signals to a receiver on shore and these form a radio link. Similarly, commentators on ships or aeroplanes must use a radio link.

When a telephone subscriber makes an inter-continental call, he may be connected via a radio link because, as yet, the large oceans cannot be bridged by means of telephone cables. See RADIO TELEPHONY, TRANSMISSION LINE.

RADIOLOCATION. Obsolete British name for RADAR.

RADIOPHARE. Synonym for RADIO BEACON.

RADIO RANGE. Ground station providing automatic navigational and homing assistance to aircraft by the emission of four medium-range equi-signal beams. Each pair of beams is similar to that provided by a RANGE BEACON (q.v.). Normal "A-and-N" radiation is interrupted at intervals for the transmission of a coded signal by which the particular ground station may be identified.

RADIO RECEIVER. Apparatus for receiving messages or pictures radiated by a sender. The work done by a receiver of sound is of three main kinds. It must select the desired signal and exclude all others; it must amplify the signal sufficiently; and, at some point in the chain, it must "detect" the signal, this latter process being one in which radio-frequency oscillations, varying in peak value or otherwise modulated to convey the intelligence, are converted into audio-frequency currents suitable for the operation of a loudspeaker or other device (see RECEPTION).

Selection is the task of the tuned circuits and the coupling effects between them (see TUNING). In a modern

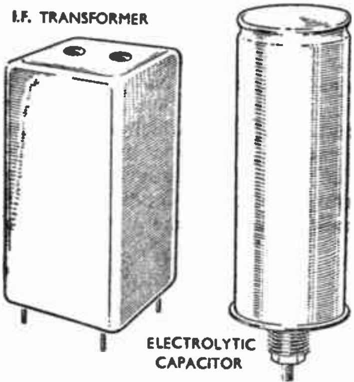


Fig. 10. Examples of radio-receiver components which are manufactured with individual screening, or "cans."

receiver, the over-all resonance curve is a matter for careful planning in which the design of the inductor units plays a major part. Since direct-coupling effects between successive tuned circuits are likely to upset the functioning of the system, each inductor unit is almost always separately screened in its own "can."

This requirement, in turn, puts a premium on small and compact windings, so that losses in the metal screen may be minimized. This again leads often to the use of special cores of magnetic materials, since the higher permeability of such a core enables the necessary inductance to be obtained with less wire in the winding and, therefore, lower R.F. resistance (see IRON-CORED INDUCTOR, IRON DUST).

Screening is indeed one of the most important factors in receiver design. Upon it depend to a considerable extent the selectivity and the stability (i.e. freedom from objectionable feed-back effects) of the receiver. In its earlier applications, screening took the form of a series of compartments, each containing a single amplifying stage, or a tuned circuit. Although compartment screening is still used to a limited extent, modern tendencies are more in the direction of individual screening of components, each one being mounted in its own small can (Fig. 10).

Inductors, valves and even certain capacitors are usually thus enclosed, while undesirable interactions between wires are avoided mostly by separation and careful lay-out generally, with the assistance of the screening effects of the metal cases of the components, and of the metal chassis on which the whole receiver is built.

Amplification is, of course, done by the valves, arranged in successive stages according to the particular circuit. Almost all small broadcast receivers employ three valves in what is

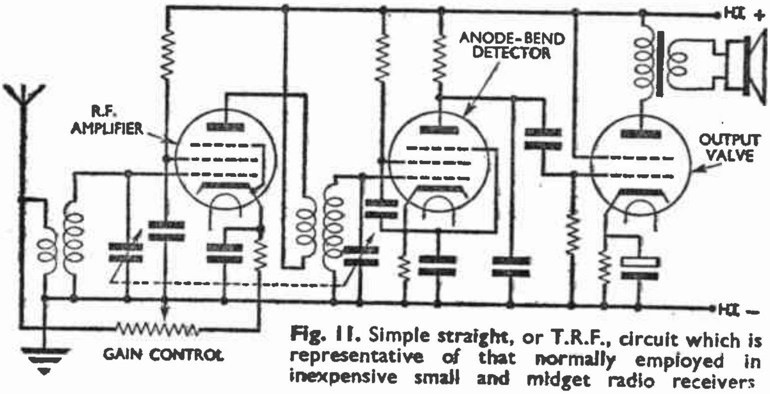


Fig. 11. Simple straight, or T.R.F., circuit which is representative of that normally employed in inexpensive small and midget radio receivers

called a straight circuit (Fig. 11), the functions of the valves being respectively radio-frequency amplification, detection, and audio-frequency amplification; the last of the three stages actuating the loudspeaker.

For R.F. amplification, the variable-mu type of tetrode or R.F. pentode is generally used, advantage being taken of its characteristic to provide a simple manual gain-control. This is often arranged as shown in Fig. 11, so that the resistance shunted across the aerial inductor is reduced as the automatic bias resistance is increased.

The arrangements give a greater range of control, with the result that volume can be progressively reduced to zero. Automatic gain-control is occasionally applied, but, because of the limited R.F. gain and selectivity, this is not very effective in a simple receiver of this nature.

Detection is normally by means of a triode or pentode operating on the leaky-grid principle, but an anode-bend detector is also suitable. Regeneration may be employed in the detector stage, although this is not customary. If automatic gain-control were to be incorporated a separate diode or metal rectifier would be necessary; alternatively, a double-diode could be used for detection and A.G.C., but this is not generally very successful.

A beam tetrode or a pentode is usually employed in the output stage and is fed through a resistance-capacitance circuit as illustrated in Fig. 11.

Larger receivers are almost invariably superheterodynes (Fig. 12), in which the greater part of the pre-detector amplification is done at a fixed frequency to which all incoming signals are converted by frequency-changing (see SUPERHETERODYNE RECEPTION). A certain amount of amplification may be done at the original signal frequency, but this is largely for the sake of the extra selectivity provided by the tuned circuits associated with the R.F. amplifying valve.

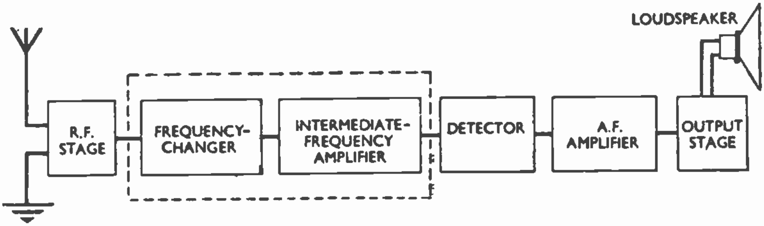


Fig. 12. Block diagram of a typical superheterodyne receiver. The sections within the dotted lines are additional to those found in a T.R.F. receiver.

This valve, as well as those which amplify the signal at the new (intermediate) frequency, is usually a variable-mu tetrode or R.F. pentode; and a double-diode triode is a likely choice for detection, A.G.C. rectification, and preliminary A.F. amplification. A further valve (triode or pentode) forms the output stage. In smaller receivers, these final stages may consist of a double-diode pentode, combining the functions of detection, A.G.C. rectification and output stage.

The frequency-changer valve is also likely to be a multiple type, the triode-hexode being a common choice. Here, the triode section acts as a generator of local oscillations, while the hexode portion serves to combine the signal with the local oscillations to form the intermediate frequency.

Valve combinations based on those just considered are employed in the majority of present-day broadcast receivers. Differences between individual sets occur mostly in such details as inter-valve couplings. Here, the R.F. transformer is most often used in various forms. At its simplest, it consists of a tuned secondary inductor, with an untuned primary tightly coupled to it (or a tuned primary and untuned secondary in some instances).

In a more elaborate form giving greater selectivity, both primary and secondary are tuned, the coupling between them being suitably reduced. Again, the coupling may be so adjusted that a flat-topped resonance curve results (see BAND-PASS TUNING). This is a common practice in the intermediate-frequency circuits of superheterodynes. In some such receivers, it should be added, the effect of a flat-topped over-all resonance curve is obtained by "staggering" the tuning of the intermediate-frequency circuits, tuning some a little above and some a little below the true frequency.

Such usual features of a broadcast receiver as automatic gain-control, tone control and ganging are described elsewhere, but there remains the provision of audio-frequency amplifying arrangements.

It will have been noted that the output valve has usually been quoted as either triode or pentode. The designer's choice here is largely influenced by the amount of amplification he expects from the rest of the receiver. If he wants to increase the over-all performance a little, he will choose a pentode, so this valve is usually found in at least the smaller receivers. Similar considerations govern the inclusion or omission of a preliminary stage of A.F. amplification.

Inter-valve coupling in the A.F. stage is now rarely done with a transformer. Present-day circuits and valves lend themselves more readily to resistance-capacitance coupling; moreover, the greater gain now obtained from R.F. and I.F. stages makes it unnecessary to squeeze the last drop from the A.F. circuits. There are also the factors of cost and compactness, in both of which the resistance-capacitance method shows advantages.

In the matter of power supply to a receiver, recent years have seen a considerable measure of standardization. The battery-operated set calls for no comment, but the mains receiver now almost always employs a transformer-supplied rectifier valve, one or two inductors for smoothing, and electrolytic capacitors.

The field winding of the loudspeaker is sometimes used as a smoothing inductor. In a few sets, the smoothing is done with resistance-capacitance filters. The so-called "universal" receiver, for use on either A.C. or D.C. mains, remains a minority despite its earlier promise. The arrangement is still found, however, in many midget receivers.

See ALL-MAINS RECEIVER, AMPLIFICATION, BROADCAST RECEIVER, DETECTION, SCREENING, SELECTIVITY, SMOOTHING CIRCUIT. For details of apparatus designed for the reproduction of pictures, see TELEVISION RECEIVER.

RADIO RELAY SYSTEM. Reception of programmes by master receivers which redistribute the programmes through a wire network to a large number of houses. Those who subscribe to a radio relay service thus have a laid-on service. Sometimes a selector switch is provided by which the listener may choose one of two or more programmes received for him on the master receiver.

The commonest type of audio-frequency relay system is the one-programme system (Fig. 13). This is, essentially, a master receiver, located outside the densely populated area in which the service is given, and in a situation favouring good reception. A link joins the non-central receiving station to the amplifying station from which pairs of wires run out, spider-web fashion, among the houses.

Amplifiers are located at the amplifying station to raise the level incoming from the receiving station to a value sufficient to energize the net-

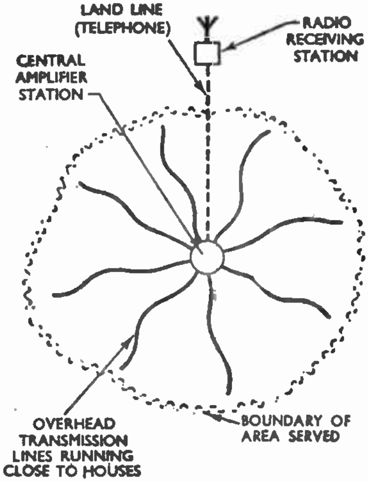


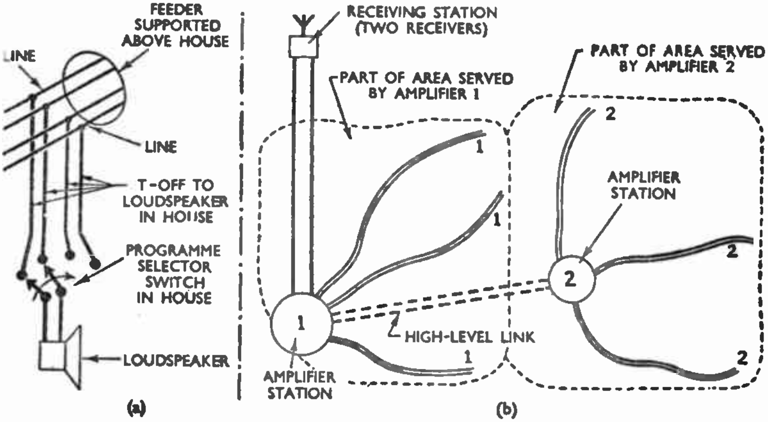
Fig. 13. Single-programme radio relay system. At a central amplifying station, the power of the audio-frequency output from the receiving station is amplified to a level suitable for distribution by overhead lines to the loudspeakers of the subscribers.

Fig. 14 (*below*). Two-programme system: (*a*) connexion of a loudspeaker through a programme-selector switch; (*b*) use of a second amplifier station to extend the service area. The latter serves to limit the length of feeders and so to avoid attenuation distortion.

work, and loudspeakers are installed in the houses so that, when connected to a feeder, they reproduce the programme picked up by the master receiver. The lines carry audio-frequency currents and so the loudspeaker may be connected directly to them through an on-off switch and a volume control.

In order to distribute more than one programme it is only necessary to add the appropriate number of receivers at the receiving station, increase the number of pairs of wires, and allocate amplifiers to each pair. A multi-position switch near the loudspeaker connects it to any one pair. In order to cover a wider area it is necessary to set up more amplifying stations, making each the centre of a network of pairs of wires.

Thus, Fig. 14 sets out a more complete scheme in which each amplifying station becomes the centre of a separate network, and the amplifying stations are linked by what is called a high-level link (Fig. 14b). In some cases, a small network may be energized via a high-level link and a matching transformer, as shown in Fig. 15. The reason that the size of the network (the length of any two-pair line) is limited, is that the many loudspeakers fed from it take power from the line and so produce attenuation.



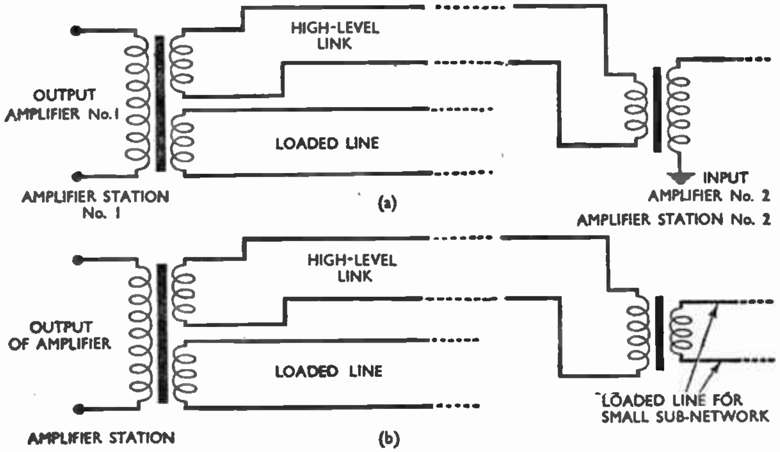
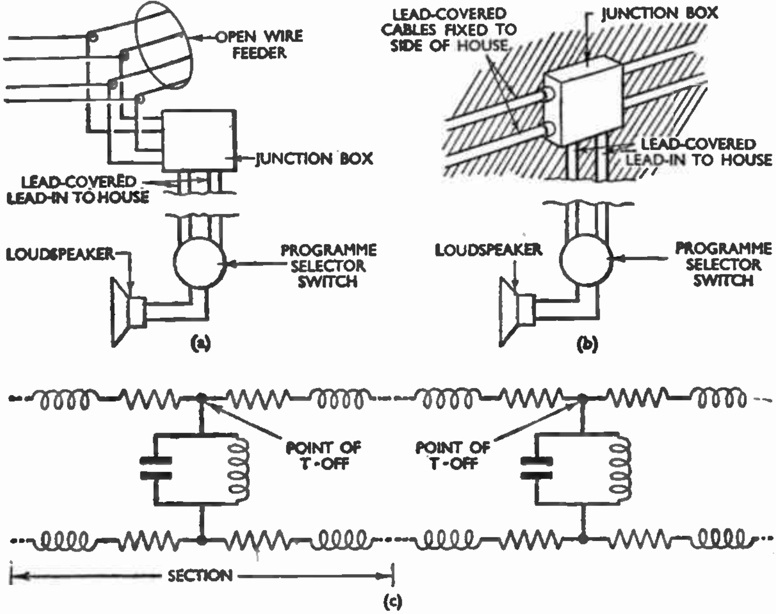


Fig. 15. Principle of the high-level link used in radio relay systems; "high-level" implies use of a high voltage so that copper loss is minimized. In (*a*) the link is a direct line between amplifier stations 1 and 2, but in (*b*) the link runs to a transformer, the secondary of which energizes a line loaded by loudspeakers.

Fig. 16 (*below*). Arrangements at T-off points are shown: (*a*) for open lines, and (*b*) for cables. At (c) is shown the basic electrical equivalent of a radio relay line; the shunt arm contains capacitance—chiefly representing that between lead-in wires—in parallel with the impedance of a loudspeaker.



A typical arrangement of an audio-frequency relay feeder consists of two lines, that is to say, two pairs of wires, each carrying a different programme (Fig. 16). The lines may be open wires attached to insulators, often held on brackets on chimneys; or they may run in lead-covered wire attached to the outside walls of houses. Whichever arrangement is used, the electrical equivalent of a radio relay line is a series of sections having series arms containing inductance and resistance, and shunt arms having capacitance and inductive impedance in parallel. The capacitance is that of the take-off wire, while the inductive impedance represents that of the loudspeaker (Fig. 16c).

The effect of these "lumped" impedances at the point of take-off is to give the loaded-line a non-uniform frequency-amplitude response, the lack of uniformity increasing as distance from the sending end increases. (Fig. 17 shows and explains the reasons for non-uniformity of the frequency-attenuation characteristic.) Provided the line is of the correct length, and terminated in its characteristic impedance, measured at about 1,000 c/s, the attenuation characteristic may be made reasonably flat.

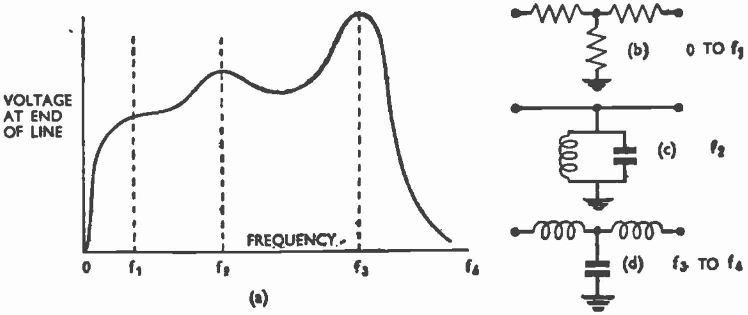


Fig. 17. Diagrams indicating: (*a*) the attenuation-frequency characteristic of a heavily loaded or a long radio relay line having the electrical characteristics shown in Fig. 16; and (*b*), (*c*), (*d*) the predominant characteristics of the section at various frequencies, attenuation at f_4 being due to a low-pass filter action.

About 900,000 households in Britain take advantage of radio relay services, which are all of the audio-frequency type described. In other countries, notably Switzerland, the telephone network is used to distribute modulated waves which are fed to receivers installed in the houses. In Britain, a choice of two or three programmes may be offered; in other countries, notably Holland, four or even six may be available. Proposals have been made to use modulated carrier waves impressed upon the electricity-supply mains-network for a radio relay service, and a practical demonstration of such a system has been given. See CHARACTERISTIC IMPEDANCE, QUADRIPOLE, TRANSMISSION LINE, WIRE BROADCASTING.

RADIO SENDER. See BROADCAST SENDER, SENDER.

RADIO SOUNDING. Method of obtaining meteorological data by the use of balloons fitted with small senders. During the flight of the balloons these senders automatically send signals which provide information respecting the meteorological conditions.

RADIO STATION. Complete set of equipment for the sending and/or reception of radio-frequency signals.

RADIO TELEGRAPHY. Telegraphic method of radiocommunication; it is also known as wireless telegraphy. In general, the principles of operating a radio-telegraph communications system are similar to those applied to telegraphy over a wired circuit. Messages to be sent are translated into the Morse code either during or before sending and are transcribed into their original form at the receiving station.

The Morse keying may be manual or automatic; with either system the keying may take place at the sending station itself (see SHIP'S RADIO) or at a central telegraph office by remote control.

For high-speed transmission, the code is punched on a strip, usually paper, the strip being passed through a mechanism which is used to "key" the radio sender. The radiated waves are thus interrupted in a timing sequence corresponding to the spatial punchings on the strip. At the receiving end, the output terminals of the radio receiver are connected to an instrument which records the spaced signals on a strip, from which the original message is then transcribed.

A possible method of high-speed automatic telegraphy is shown in Fig. 18. The message to be sent is punched in Morse-code form on a strip. As the strip passes between contacts, current from the battery passes to the line connecting the telegraph office to the sender station.

The contacts of an electromagnetic relay are connected in series with the H.T. supply to the anode of one of the sender valves (see HIGH-TENSION KEYING); these contacts close when current passes through the relay coil and are released when there is no current along the line. The duration of the line currents will, therefore, be controlled by the relative positions of the perforations in the strip and, since the H.T. supply to one valve of the sender is also controlled by these currents, the signals radiated by the sender follow the same sequence.

The chief advantage gained from high-speed radio-telegraph transmission is that a large amount of traffic can be handled in a short time, thus saving electric power. Under good conditions speeds up to several hundred words a minute are possible, whereas, with manually operated keying, the maximum speed does not exceed 40 words a minute, the average being 20 words a minute.

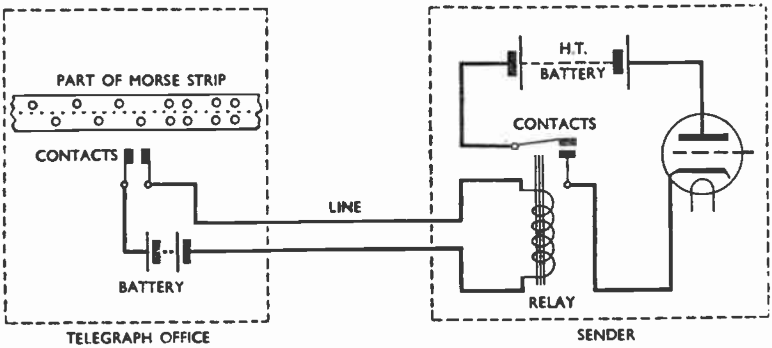


Fig. 18. Skeleton circuit for high-speed radio telegraphy. The punchings on the Morse strip are caused to open and close the contacts of a line circuit at the telegraph office. At the sender, the line currents operate a relay in the H.T. supply of a valve; this arrangement is called high-tension keying.

For the early history of radio telegraphy, see SPARK SENDING SYSTEM. The spark sending system is now rarely used, having been replaced by valve senders employing type A0 or A2 waves.

The chief advantages of radio telegraphy over line telegraphy are: first, it can be employed where the use of line telegraphy would be impracticable, for example, on ships and aircraft; secondly, with a high-power sender messages can be sent to any part of the globe without intermediate relay stations; moreover, the messages transmitted can be radiated in all directions or, by the use of the beam system, may be directed to a particular point (see BEAM SYSTEM).

The advantages of radio telegraphy over radio telephony are: (1) greater secrecy, since only skilled personnel can receive the messages; (2) telegraphic signals can often be read through atmospheric conditions which would cause speech to be unintelligible, and (3) by the use of type A0 waves, a greater range is possible for a given power.

In radiocommunication, the use of telegraphy is becoming more confined to long-distance transmission. It is used extensively on ships at sea, and on long-distance air routes. It is also used for supplementing the cable services in the dissemination of press messages to distant parts of the world.

The wave bands chosen for radio telegraphy are normally outside the broadcasting band but cover a very wide range including the long-, medium- and short-wave bands. See ARC SENDER, CARRIER TELEGRAPHY, ELECTROMAGNETIC WAVE PROPAGATION, FACSIMILE TELEGRAPHY, KEYING, SPARK SENDER, TELEGRAPH SYSTEM, TELEPRINTER.

RADIO TELEPHONY. Telephonic method of radiocommunication; it is the science of transmitting speech sounds over a distance, by means of electromagnetic waves. Communication by this means is possible by feeding amplified speech currents directly to a sending aerial but, because of the low frequencies of speech, such a system has a very limited range. Moreover, it is not possible, at the receiving end, to distinguish between different speech transmissions.

The speech currents are not, therefore, radiated directly but are impressed upon a locally generated high-frequency wave. This wave is used to carry intelligence to the receiver, and is known as a carrier. To ensure adequate range, the carrier is usually of a high radio-frequency and, by arranging for each sending station to radiate a different carrier frequency, it is possible to separate the desired transmission from others at the receiver by the use of tuned circuits.

The carrier is made to convey intelligence by arranging for the amplified speech currents to control one of its characteristics; this process is known as modulation.

Three systems of modulation are in common use: the commonest is amplitude modulation, in which the speech current controls the amplitude of the carrier wave; frequency modulation, in which the speech current controls the frequency of the carrier, and phase modulation, in which the speech current controls the phase of the carrier.

Among the various applications of radio telephony may be mentioned broadcasting, communication between ships, aeroplanes and ground, linking the telephone systems of different countries, communication between police headquarters and mobile patrol cars, and communications in armed forces.

The carrier frequencies used depend largely on the distance to be covered. For example, broadcasts for home reception are largely carried out on both long (150-300 kc/s) and medium (550-1,500 kc/s) waves; broadcasts for foreign countries usually employ short waves (6–30 Mc/s), although the precise frequency required depends very largely on the time of day, time of year and ionospheric conditions.

Higher carrier frequencies (40–100 Mc/s) are used for frequency-modulated broadcasting in U.S.A., and for providing the vision and sound channels in television services. The range of these transmissions is limited under normal conditions to about 50 miles. For details of the frequencies used in ship and aeroplane communications systems, see SHIP'S RADIO and AIRCRAFT RADIO EQUIPMENT.

The senders used for linking the telephone systems of different countries generally employ short waves (5–30 Mc/s) and, to ensure secrecy, have highly directional aerials radiating very narrow beams, and the speech currents are inverted (see INVERSION, INVERTER CIRCUIT) or scrambled (see SCRAMBLER) before modulation.

For very short distances, such as that between Great Britain and France, communication is effected on centimetric wavelengths. The radiotelephony services used by police and armed forces commonly employ very high frequencies, for example, 90 Mc/s, and frequency modulation is often used.

RADIO TRANSMITTER. See SENDER.

RADIOTRON. Trade name for an American make of radio tube.

RADIOVISION. Term sometimes used for the radio transmission of moving pictures, that is to say, TELEVISION (q.v.).

RADIOVISOR. Synonym for TELEVISION RECEIVER.

RADIO-WAVE. Electromagnetic wave used for radiocommunication. According to their frequencies, electromagnetic or ether waves produce different effects and are generated and detected by different methods. The waves of highest frequency so far discovered are the cosmic rays, which appear to originate in interstellar space and reach the earth from all directions. The frequency of these rays is in the neighbourhood of 10^{17} Mc/s. Next in order down the frequency spectrum come X-rays, ultra-violet rays, and ordinary light rays, to be followed by infra-red rays and radio-waves.

The frequency range of radio-waves extends from about 10 to 10^{8} kc/s; they are of too low a frequency to be perceived by the eye, although they are of exactly the same type as light waves, which operate on higher frequencies. Because of their lower frequency, radio-waves have to be collected on an aerial-system and made perceptible by converting them to sound or vision. They have a great advantage over other forms of communication in that they follow the curvature of the earth and so are suitable for communications over great distances. See RADIATION.

RADIUS COMPENSATION. In a gramophone recording system, a form of electrical equalization applied to the recording amplifier in such a way that the higher audio frequencies are accentuated in an increasing degree as the diameter of the groove decreases (see ELECTRICAL RECORDING). The purpose is to compensate for the loss in high-frequency response arising from the cramping of the wave forms as the speed of the groove, relative to the stylus, decreases.

RANDOM NOISE. Noise having no periodic regularity. The most completely random types of noise are those called set noise, and the term is often used to refer only to these. See SET NOISE.

RANGE. The greatest distance from a sender at which it is possible to receive reliable signals. The range a sender is capable of attaining depends upon many factors, such as the power and frequency of radiation, time of year, time of day, local ionospheric conditions and the weather. See ABSORPTION, GROUND RAY, IONOSPHERIC RAY.

RANGE BEACON. Radio beacon for the guidance of aircraft along a specified course. The beacon radiates two beams on the same carrier frequency, one modulated according to the Morse A (· —) and the other according to the

Morse N (—·); there is an overlap region, covering the course to be followed, in which both signals are heard simultaneously and merge to form a continuous note. By listening to the modulating signals, the pilot can determine whether he is on the correct course, or if he is to the left or to the right of it and should take action accordingly. See Fig. 3 on page 412 under NAVIGATIONAL AID.

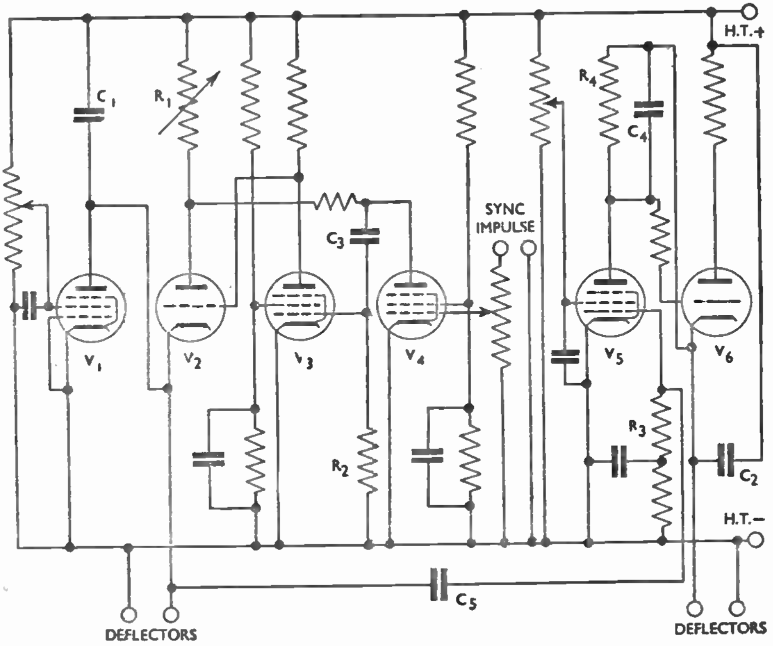


Fig. 19. No frame-synchronizing impulse is necessary for this time base, as ratcheting is used for the control of V_5–V_6 and is fed from V_2 to V_5 via capacitor C_5. V_4 is the synchronizing valve controlling the charge and discharge of C_1.

RASTER. Picture on a television screen made up of unmodulated scanning lines.

RATCHETING. Process of providing automatic fly-back and recommencement of frame scan in a television receiver. Two time bases are used in a television cathode-ray unit. One provides the deflection of the spot to form the lines of the picture. The other deflects the spot at right-angles to the path of the line to form the frame scan. At the end of this scan, either by means of the frame-synchronizing impulse or independently, the spot is made to fly back from the position on the screen where it completed the frame scan to the position where it is ready to commence another frame scan. This is the process of ratcheting.

Ratcheting may be accomplished by means of the triggering of a valve circuit by the synchronizing impulse, or by a valve relay which automatically comes into operation and returns the spot to the starting position. In the latter process no frame-synchronizing impulse is necessary.

Fig. 19 shows the fundamentals of a complete time-base unit, with time bases for line and frame scan. V_5 and

V_6 form the time base for the frame scan, V_6 being the discharge valve for C_2, which is charged through V_5.

During the charging of C_2, the valve V_6 is prevented from discharging the capacitor by bias provided by the network R_4C_4. This bias is provided by the anode current of V_5, and this, in turn, is kept constant by impulses fed to the grid of V_5 through the differentiating circuit C_5R_3 from the cathode of V_2.

V_2 is the discharge valve for the line scan, and every time this valve discharges, causing the fly-back of the spot at the end of each line, an impulse is passed to the grid of V_5. Therefore, the bias on V_6 is maintained by a series of impulses at the end of each line and, while the impulses are maintained, the capacitor C_2 continues to charge, and the spot is pulled across the frame scan.

At the end of the frame scan there is always a pause which is several times longer than the normal pause between lines. During that pause in transmission, *no impulses* reach the grid of V_5 and the network R_4C_4 allows the grid bias on V_6 to leak away. The valve is no longer "held off" and discharge of C_2 takes place. The spot flies back to the start of the frame scan.

Line scan now starts again, and anode current through V_5 applies bias to V_6, this bias being increased and maintained by line fly-back pulses from V_2.

The operation described does not apply to the present B.B.C. system.

RATCHET TIME BASE. Circuit designed to provide regular frame scans in television without triggering impulses from a frame-synchronizing signal. See RATCHETING.

RATED CAPACITY. Synonym for RATED INPUT.

RATED ELECTRODE DISSIPATION. Specified power developed at an electrode which, if much exceeded, will cause damage to the valve. See ANODE DISSIPATION, ELECTRODE DISSIPATION, VALVE CHARACTERISTIC.

RATED INPUT. Maximum power, voltage or current which can be fed into the input terminals of any apparatus without the risk of damage to the apparatus or the distortion of output voltage and current. See OVERLOAD, RATED ELECTRODE DISSIPATION.

RATED OUTPUT. Maximum power, voltage or current which may be drawn from a source of electricity without risk of damage or possible distortion of the output voltage or current waves. See OVERLOAD.

RATING. Determination of a number expressing the maximum power, voltage or current that can be drawn from the output terminals of a source, or applied to the input terminals of any apparatus or component without risk of damage or of wave distortion. See OVERLOAD, RATED ELECTRODE DISSIPATION, RATED INPUT, RATED OUTPUT.

RAY DIVERSITY. Diversion of radio-waves due to several effects. The ionospheric rays may be diverted by refraction or by reflection in the E- and F-layers, whilst the ground rays may change direction as a result of COASTAL REFRACTION (q.v.), LATERAL DEVIATION (q.v.), or refraction effects in the lower atmosphere. See IONOSPHERIC REFLECTION, IONOSPHERIC REFRACTION, REFRACTION.

RAYS. Paths traversed by wave forms, the velocity of propagation of which is $2{\cdot}9982 \times 10^8$ metres per second (the speed of light), and the wavelengths of which may vary between 3×10^{-16} and 3×10^8 metres. All light and electromagnetic energy is transmitted by such wave forms. There are many kinds of rays, and this field of research is being constantly extended; but some of the better-known are mentioned below.

Cosmic rays, which have wavelengths of 3×10^{-16} to about 3×10^{-11} metres, were first studied by Millikan. They were found to have great penetrating power and could be detected by means of an electroscope. Their source of origin has not been definitely established, but it is thought they originate in interstellar space.

Cathode rays, which give rise to X-rays, are produced by streams of electrons emitted from a cathode in the presence of rarefied gas. *Beta rays*, which are emitted by radio-active substances, are of the same nature as cathode rays and may reach a velocity of $2{\cdot}85 \times 10^{10}$ cm./sec., which is very near the velocity of light. Beta rays are less penetrating than alpha rays, also emitted by radio-active substances.

X-rays, which have wavelengths of from 0·01 to 50 Angström units (1 Angström unit is equal to 10^{-8} cm.), are produced when cathode rays strike matter. They were first studied by Röntgen and, for that reason, are frequently referred to as Röntgen rays. X-rays are widely used in medicine; they have the capacity of penetrating matter opaque to white light, making possible the photography of internal regions of the body.

The upper portion of the X-ray band includes *gamma rays*, which are emitted by radio-active substances during spontaneous disintegration. The lower part of the X-ray band includes part of the ultra-violet band. Gamma rays are less penetrating than alpha or beta rays.

When X-rays fall on any object, an emission of secondary X-rays occurs. These secondary rays may be of two kinds, the K series which are very penetrating and the L series which are less so. Both the K and L series are less penetrating than the primary X-rays which give rise to them; but it is interesting to note that the greater the atomic weight of the substance on which the primary X-rays fall, the greater the penetrating power of the secondary rays emitted. X-rays can be detected by photographic means, or by the ionization they produce in gases.

Canal rays constitute another phenomenon occurring during the emission of electrons from a cathode. They consist of positively charged particles which travel towards the cathode and take their name from the fact that they were first discovered by the use of a cathode having in it a number of holes (or canals) through which they were found to pass. Canal rays are faintly luminous and can be deflected only by a powerful magnetic force.

The particles giving rise to these rays are more complicated in structure than electrons, and their mass depends on the nature of the residual gas in the tube in which they arise. It would appear likely that they are atoms which have lost one or more electrons. *Alpha rays*, which are emitted by radio-active substances, are of the same nature as canal rays, and may reach a velocity of $2{\cdot}5 \times 10^{9}$ cm./sec.

Ultra-violet rays are invisible to the human eye, their wavelength being below 3,900 Angström units, which is the limit of visibility at the violet end of the visible light spectrum. These rays, which are beneficial to health, are emitted by hot bodies and ionized gases; they can be detected by fluorescence and will affect a photographic plate.

The band of *visible light rays* is comparatively narrow and lies between that of the ultra-violet and infra-red rays. When all visible light frequencies are present, the effect of white light is produced, but such light can be split by a prism into rays which produce the visual effect of the various colours. The well-known phenomenon of the rainbow is produced by the splitting of white light from the sun by means of raindrops which act as prisms.

Still lower in frequency are the *infra-red rays* which have wavelengths greater than 7,600 Angström units and are invisible to the eye. These are heat rays produced by materials heated to a temperature below that at which they emit a red glow. Infra-red rays can be detected by means of a thermocouple or by specially sensitized photographic emulsions.

Another method of detection of infra-red rays is the use of the bolometer, an instrument employed in the measurement of radiant energy and which consists, basically, of a strip of fine wire which, when exposed to such radiations, shows variations in electrical resistance.

The lower end of the infra-red band overlaps the band which is of particular interest to the radio engineer, the highest frequencies being employed in radar and television, and those somewhat lower in radio-frequency work. Lower still are those frequencies employed in alternating-current work.

REACTANCE. Measure of the opposition to alternating current offered by an inductor, a capacitor, or any combination of the two, additional to that due to resistance.

If an inductor is connected to a D.C. supply, the current which flows is given by E/R (see OHM'S LAW), where E is the supply voltage and R the resistance of the inductor winding. If the same inductor is connected to an A.C. supply with an r.m.s. voltage of E, the current is less than on the D.C. supply. In other words, the impedance to A.C. of the inductor is greater than its resistance to D.C.; the additional opposition is the reactance. Thus impedance is composed of resistance and reactance, but these must be added vectorially and not arithmetically to give impedance.

The reactance of an inductor is directly proportional to the inductance of the winding and to the frequency of the supply, being given by $X_L = 2\pi fL$, where X_L is inductive reactance in ohms, f the supply frequency in cycles per second, and L the inductance in henrys.

The impedance of a capacitor to A.C. is also made up of resistance and reactance (added vectorially) though the resistive component is generally very much smaller than for an inductor. Capacitive reactance is inversely proportional to capacitance and to frequency; it is given by $X_C = \frac{1}{2\pi fC}$, where X_C is capacitive reactance in ohms, f the supply frequency in cycles per second, and C the capacitance in farads.

A knowledge of the foregoing two simple relationships is of great value in radio and electrical work. The reactance of an inductor of given inductance, for instance, is the factor which decides the opposition which it will offer to an alternating current of a certain frequency, or to a pulsating current, that is, one which can be regarded as an alternating current superimposed on a direct current. This is the type of current encountered in the design of the smoothing circuit of a rectified H.T. supply in a receiver; the ripple is smoothed out by opposing it with inductive reactance, and offering it an alternative path through a capacitive reactance. To do this with economy, no more inductance and no more capacitance than is necessary must be used, and here the designer can make a correct decision only after he has calculated reactances.

For a given inductance and capacitance the smoothing becomes more efficient as the frequency of the undesired ripple is raised; the higher the frequency, the more effective the barrier of the inductive reactance and the lower the reactance of the shunt path through the capacitance.

The reactances of by-pass capacitors need consideration at all points in a radio receiver; the ideal is the provision of an amount of capacitance such as will ensure a substantially zero reactance path to earth for undesired currents; to make sure that this is being done, the designer must check the reactances of the by-pass capacitors at the lowest frequency which they will be called on to handle.

Another capacitor, the reactance of which is important, is the coupling capacitor in a resistance-coupled amplifier; here the aim is to make the reactance sufficiently low compared with the value of the grid leak to ensure that its variations with frequency do not appreciably alter the total impedance of the grid circuit. This is effected by keeping the reactance of the grid capacitor small compared with the resistance of the grid resistor. The calculation must be made at the lowest frequency which is expected to be of importance in the particular type of amplifier.

Yet another example demanding exact treatment of capacitive reactances is in tone-control circuits. Here, the differential effects which lead to the desired frequency response are usually obtained by making use of the variation with frequency of a reactance.

There is also the special case of resonance; every circuit containing inductance and capacitance (and not too much resistance) has a resonant frequency at which the inductive and capacitive reactances are equal to each other. In a series circuit, these reactances cancel because they are of opposite sign; thus the impedance of a series circuit at the resonant frequency is theoretically zero. In practice, the minimum impedance is not zero but is the resistance of the components (chiefly the inductor) and connecting leads.

REACTANCE COIL. See FIXED INDUCTOR.

REACTANCE COUPLING. Common-impedance coupling in which the common impedance has the nature of a reactance (capacitive or inductive). See CAPACITIVE COUPLING, INDUCTIVE COUPLING, RESISTIVE COUPLING.

REACTANCE DROP. Fall in voltage due to the reactance of an A.C. circuit. More strictly, the fall in *useful* voltage caused by the opposing effect of voltages developed across the circuit reactance.

REACTANCE TRANSFORMER. Network of reactances arranged to produce a transforming action between input and output terminals. It is possible, for example, to build a band-pass filter which gives a greater voltage output in its transmission band than the voltage applied to the input, no transformers being used in the process. Obviously, the image impedances of the filter are different and the output impedance is greater than the input impedance; in other words, the network is passive and cannot give an increase of power between input and output terminals.

Impedance transformers (sometimes called "impedance-transforming networks" or "impedance-transforming band-pass filters") are extremely useful, particularly when ordinary transformers are unsuitable for some reason. There is no limit to the frequency of the waves whose voltage is transformed by impedance transformers, and the action of impedance transformation may be accompanied by a filter action as well. See BAND-PASS FILTER, NETWORK, TRANSFORMER.

REACTANCE VALVE. Synonym for VALVE REACTOR.

REACTION. Synonym for FEEDBACK.

REACTIVE COMPONENT. Alternating current (or voltage) which, as a result of circuit reactance, is at a phase angle of 90 deg. to a reference voltage (or current). Thus a current which lags or leads the voltage by 90 deg. is described as the reactive component of current. It is sometimes called the "idle" or "wattless" component. See PHASE ANGLE, REACTANCE.

REACTIVE LOAD. Load whose principal characteristic is that of a reactance, and whose power factor is therefore small. See LOAD.

REACTOR. Piece of apparatus used in A.C. circuits primarily because it possesses the property of reactance. There are two kinds of reactor: inductors having positive reactance (inductance), and capacitors having negative reactance (capacitance).

RECEIVER. See DIRECTIONAL RECEIVER, RADIO RECEIVER, HEADPHONE, TELEVISION RECEIVER.

RECEIVING AERIAL. Device for deriving electrical energy from passing radio-waves. In principle, there is no distinction between receiving and sending aerials; any device which will radiate energy will also pick up energy.

In practice, however, there are considerable differences in construction and arrangement. For instance, a receiving aerial handles only small currents at extremely low voltages and therefore needs only small, simple insulators and conductors of small cross-sectional area. At medium and low frequencies it is often advantageous to use a sending aerial which has considerable capacitance, whereas a receiving aerial is usually required to have low capacitance.

Probably the only common type of receiving aerial, which is not also in general use for sending, is the closed-loop. As a receiving aerial, its comparatively poor pick-up properties are tolerated for the sake of its valuable directivity and low damping, but its low efficiency as a sending device makes it unsuitable for any except special purposes. See AERIAL, RECEPTION.

RECEIVING VALVE. Valve suitable for the reception of signals. The term is misleading, because valves suitable for use in a receiver may be perfectly satisfactory for use in a low-power sender or for use in the power circuits of a sender. But the term may be understood as denoting valves *typically* used in a receiver.

RECEPTION. Act or process of receiving messages or pictures radiated by a sender. The initial step in reception is the obvious one of arranging to generate currents by means of the passing radio waves. The familiar way of doing this is to expose a suitable conductor to the action of the waves, taking care to insulate it suitably so that the small currents induced in it may not escape by unintended paths.

This, to the broadcast listener, is perhaps merely an elaborate way of saying that an aerial is erected; but the more fundamental way of describing the operation serves, at least, to direct attention to some often overlooked facts. One of these is that the aerial is not necessarily a length of a special kind of wire slung between a chimney and a pole down the garden. It is just a conductor, but of a length and kind suited to the particular purpose, and insulated where necessary.

It may not consist of wire at all, and it may not even carry anything recognizable as an insulator; it may be a half-wave dipole made of metal rod or tube, and supported in the middle by a clamp which need not be an insulator, since the centre of such an aerial is a voltage-zero point. Only at and towards the ends are there voltages, and, with a self-supporting rod, these are "insulated" by the surrounding air.

The pick-up system may in fact take a great variety of forms, but its function is always the same; its task is to extract energy from the passing waves, and make it available to the receiving apparatus proper.

The aerial may play some part, too, in the next important process, namely, the separation of the wanted signal from all the unwanted signals with which the ether is crowded. It may, in short, be tuned, so that the invaluable phenomenon of resonance may be set to work in picking out the wanted signal from the rest at the input of the receiving system.

This was commonly done in the early days of broadcasting, and is still the usual practice in certain commercial communication work and has a number of applications in the Services. Tuning may be carried out by variable capacitance or inductance in the aerial circuit of the receiver; or the aerial itself may be made of such a length that its natural frequency coincides with that of the wanted signal. For work on a specified and not too wide band of frequencies, it may, for instance, be a half-wave dipole.

Fully tuned aerial systems are rare in broadcast practice, except in receivers working from a loop. The open aerial does not lend itself to ganging with closed circuits; moreover, it requires comparatively large variable capacitors and/or inductors to cover so wide a frequency range as that of the medium-wave broadcast band. It would, therefore, be impracticable to provide accurate aerial tuning in the conventional broadcast receiver, and in such sets the aerial is accordingly only roughly tuned.

After the pick-up process, the separation of the wanted signal is completed in the tuned circuits of the receiver. These are usually arranged, in part, as input circuits to the first valve of the system and, in part, as couplings between the succeeding valves.

Simultaneously with the process of separation, that of amplification proceeds. The need for magnification of the initial voltage generated in the aerial may be appreciated from a consideration of the fact that the signal in the aerial may be measurable only in microvolts, whereas, to operate a loudspeaker requires appreciable power. The initial signal must be magnified some thousands of times if it comes from a distant station, and it is one of the great advances in radio technique that the major part of this amplification can now be done at radio frequency, thanks chiefly to the valve designer.

Magnified in this fashion, the signals continue to be merely an enlarged copy of the original voltages induced in the aerial by the passing radio-waves; they are, that is, radio-frequency oscillatory voltages rising and falling in amplitude in accordance with the modulation at the sender.

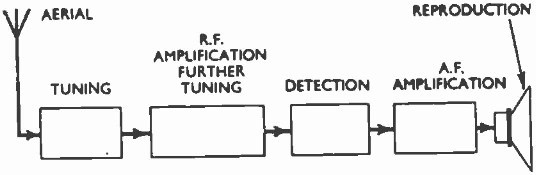


Fig. 20. Schematic representation of the six basic steps involved in the reception of radio signals and the production of sound.

Keeping the signals in radio-frequency form during the major part of the process of amplification offers many advantages, notably the opportunity to include a large number of tuned circuits—with consequent benefits in selectivity (power to select one station and ignore others). Radio-frequency currents, however, will not work a loudspeaker, and at some point in the receiving circuits they must be converted into a form that will do so.

This conversion is the process of detection, and consists in the production of voltages of the frequencies of the actual sounds being carried by the radio-frequency voltages. These audio-frequency voltages are generated from the envelope of the fluctuating radio-frequency signals by the detector valve, whose output consists of voltages as closely similar as possible to those emanating from the microphone in the broadcasting studio from which the transmission originated.

It is not, however, normally practicable so greatly to amplify the signals before conversion to audio frequency that the output of the detector valve can be passed straight to the loudspeaker. In most receivers, the output of the detector is a matter of, at most, a few volts; so further amplification at the modulation frequencies is used to reach the level required by the loudspeaker.

A single valve operating as an audio-frequency amplifier is usually enough to do this, but older receivers sometimes include two such valves, while the more elaborate modern sets may also show several valves performing special functions connected with audio-frequency amplification, their purpose being concerned more with the production of the best possible sound quality than with additional amplification. Fig. 20 shows the basic stages in the reception of sound.

Thus far, stress has been laid on

reception of speech and music, but there are, of course, several other aspects. The field of radio-telegraphic communication, for example, is a wide one. Although the basic principles of reception are the same as those discussed, there are interesting differences in methods. Here the designer does not strive to obtain equal response to a wide range of audio frequencies, so he does not necessarily use similar tuning arrangements.

His tuned circuits, in fact, will probably be planned to respond very sharply indeed to a wanted signal, unlike those of the broadcast receiver which must take in some frequencies on either side of the signal frequency proper in order to ensure faithful reproduction of the modulation which represents the sounds being transmitted.

The communication receiver may indeed be designed to respond principally to one frequency of the audio range, and may have its audio-frequency amplifying circuits tuned to that frequency which will be the musical note of the transmission the receiver is intended to handle. In this way interfering signals can be much reduced.

Most often, a telegraphic receiver has to deal with type A1 signals, which consist of uniform-amplitude waves without any form of modulation to make them audible after amplification and detection. To make them give an audible signal, the receiver usually combines them with a locally generated oscillation of slightly different frequency, whereby there is heard a beat note whose pitch is equal to the difference between the local frequency and the incoming one. The pitch is, of course, controllable by adjustment of the local frequency, and so can be suited to the maximum-response point of the tuned audio-frequency amplifier circuits if these are used.

Much commercial communication work does not aim at audible reproduction of signals at all. The receiving process ends in the production of currents suitable for operating a recording machine of some kind. In this way traffic can be handled many times faster than by the agency of human operators, for machines can send and record at high speeds.

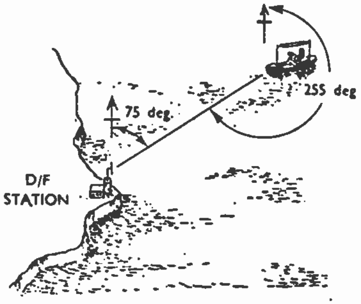


Fig. 21. Example of the meaning of reciprocal bearing: if the bearing of the ship from the direction-finding station is 75 deg., that of the station from the ship is 75 + 180 = 255 deg.

It remains only to add that, in addition to the widely used method of impressing "intelligence" on radio-waves by varying them in amplitude, there is another system of probable future importance in which the modulation is done by appropriate variations of frequency (see FREQUENCY MODULATION). This system calls for special methods of reception.

See BEAT RECEPTION, DETECTION, MODULATION, RESONANCE, SELECTIVITY, TUNING.

RECIPROCAL BEARING. Bearing 180 deg. from the true one. A reciprocal bearing may also be defined as that of the observer's station as seen from the distant point at which he is looking. For instance, if a direction-finder at station A finds that the bearing of station B is 90 deg., the bearing of station A as determined at station B is 270 deg. This is the reciprocal bearing. An example is also given in Fig. 21.

RECORDING HEAD. In any sound-recording system, the device which

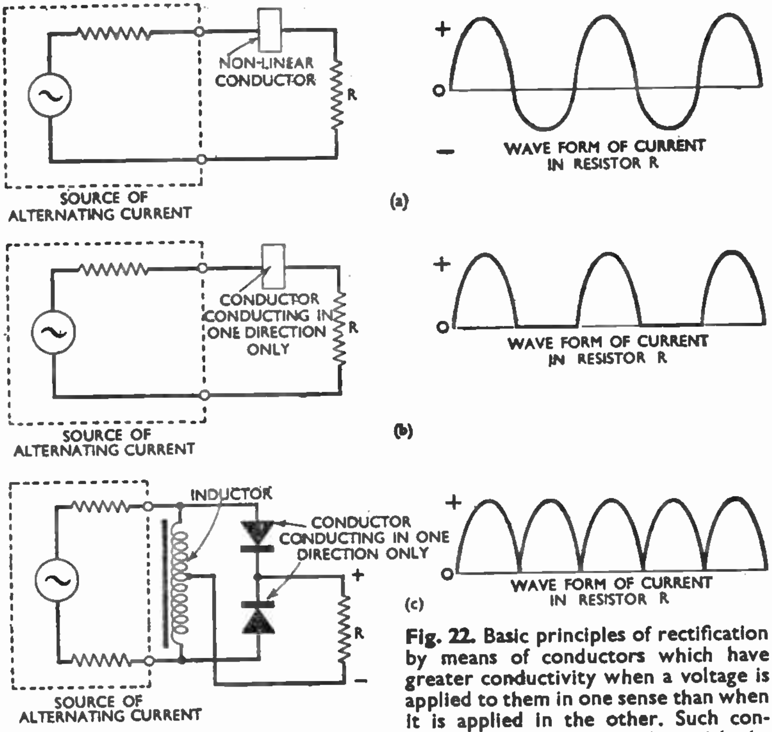


Fig. 22. Basic principles of rectification by means of conductors which have greater conductivity when a voltage is applied to them in one sense than when it is applied in the other. Such conductors, of which three examples (*a*), (*b*) and (*c*) are shown together with the resulting current wave forms, are known as rectifiers.

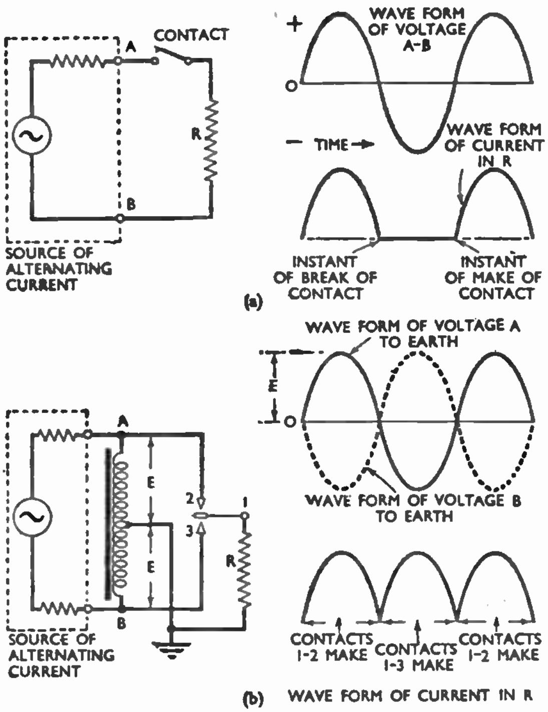
imparts to the recording material the electrical or acoustical variations produced by initial sound waves. See ELECTRICAL RECORDING.

RECORDING SYSTEMS. See ELECTRICAL RECORDING.

RECTIFICATION. Process whereby an alternating current is converted into a unidirectional current. Rectification is produced when alternating current is passed through a non-linear conductor. Alternating current may be rectified also by the use of switches which reverse the circuit path in which the alternating current is flowing. The reversals are made at every half-period of alternation of the alternating current (see COMMUTATION MODULATION, MECHANICAL RECTIFIER).

The basic principles of rectification are shown by the diagrams. In Fig. 22a, a non-linear conductor makes one-half of the alternating-current wave of greater amplitude than the other. This is because the conductor has a higher resistance to voltage applied to it in one direction than it has when applied in the other. Any device with such asymmetrical conductive properties is called a rectifier. In Fig. 22b, the resistance of the rectifier when the voltage is applied to it in one direction is infinite. In Fig. 22c, the circuit of double-wave rectification uses two rectifiers to produce the unidirectional or rectified current.

We can say that single-wave rectification is a process which suppresses



(b) WAVE FORM OF CURRENT IN R

Fig. 23. Rectification of an alternating current by the use of suitable synchronized switches. As shown by the waveform diagrams, the circuit at (*a*) provides half-wave rectification, and that at (*b*) full-wave rectification.

one-half of the wave rectified; thus, in (a), one-half of the wave is shown to be partly suppressed, and in (b) wholly suppressed. Of full-wave rectification we can say that, as a result of it, one-half of the wave rectified is reversed, as in (c).

While it is usual in mains units to use thermionic rectifiers which automatically make circuit interruptions (half-wave rectification) or circuit reversals (full-wave rectification), there is no basic reason why mechanical switches, properly synchronized, should not do the same thing.

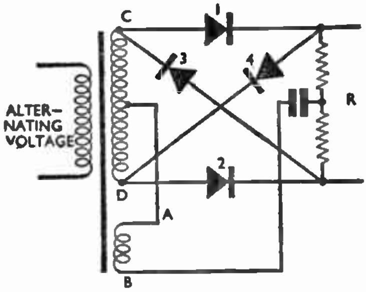


Fig. 24. Use of electronic switches to provide full-wave rectification. When *A* is positive, rectifiers 1 and 2 conduct, and when *B* is positive, rectifiers 3 and 4 conduct; the circuit path from the winding *C-D* to *R* is, in consequence, reversed every half-cycle of alternation of the supply voltage.

To illustrate the principles of rectification, Fig. 23 shows how a switch, if operated at the right time intervals, produces the effects of rectification. These switches are termed mechanical rectifiers. They are not used in mains units for small power, but may be used where very large power is converted from an alternating- to direct-current form. The mechanical rectifier is used also in the form of a polarized relay to rectify feeble alternating current so that these may be measured by sensitive moving-coil instruments (see MECHANICAL RECTIFIER).

In order to see the complete picture, note also how an electronic switch can be used (Fig. 24) to reverse a circuit path and produce the effects of double-wave rectification. The switch shown is a ring modulator.

Rectification is essential to detection. A distinction is that detection is made by means of a non-linear conducting device, usually an electronic rectifier whereas the term rectification has a wider significance. Thus, while rectification is used for detection, it is used also in mains units, mechanical rectifiers, for measuring alternating currents with direct-current meters, and in frequency multipliers.

See FREQUENCY-MULTIPLIER, FULL-WAVE RECTIFICATION, HALF-WAVE RECTIFICATION, RECTIFIER, SMOOTHING CIRCUIT.

RECTIFIED CURRENT. Unidirectional current produced by the process of rectification. The direct-current component in the wave produced by rectification is part of the rectified current. The wave produced contains waves which are harmonics of the fundamental of the wave rectified (see RECTIFICATION) and in half-wave, but not full-wave, rectification a wave having a frequency equal to the fundamental of the wave rectified as well as a direct-current component. To describe this as a unidirectional current is perhaps correct because its wave form indicates that it is pulsating.

The application of the Fourier analysis to any pulsating current shows that it is composed of a direct current and sinusoidal alternating currents. The former is the direct-current component; the latter form the alternating current components of a rectified current.

RECTIFIER. Device for converting an alternating or oscillatory current into a unidirectional current, either by the inversion or the suppression of alternate half-waves of the alternating current (see RECTIFICATION). The foregoing is a general definition and applies to rectifiers used as detectors, or for power conversion, or for measurement purposes.

A rectifier for power conversion is any asymmetrical conducting device suitable for use in circuits designed for the conversion of alternating current to direct current. In the great majority of cases the alternating current is that supplied by the mains network.

The most widely used circuits for rectifying alternating currents such as are commonly distributed through electric mains network (or, in rarer cases, generated by alternators) to unidirectional currents are shown elsewhere under the headings: FULL-WAVE RECTIFICATION, HALF-WAVE RECTIFICATION. We are concerned here, however, with the basic requirements of the rectifier apart from the circuits associated with it (see MAINS UNIT).

Clearly, since the conversion of power from one form to another is in question, efficiency is a paramount consideration. It follows that one of the more important factors governing the choice of a rectifier for efficient use in converting alternating to direct or unidirectional current is the wastage of power in it. We often find, however, that the efficiency of any device is only obtained at the cost of instability or short life, or with high initial cost, and this is equally true of rectifiers.

Many devices and substances may have asymmetrical conductive properties, but far from all are suitable as rectifiers for power conversion. Thus, in practice, owing to a number of factors, we are left with four main types of suitable rectifiers, namely, vacuum-valve rectifiers, mercury-vapour rectifiers, metal rectifiers and mechanical rectifiers.

There is no way to make a comparison between the different forms of rectifier unless the purposes for which they are used are differentiated. Broadly speaking, only the mechanical rectifier and the mercury-arc rectifier (notably in the form of the Ignitron) are suitable when the power dealt with is very large. This is because of the high efficiency of such devices. Metal rectifiers, mercury-vapour (hot-cathode) rectifiers and vacuum-valve rectifiers would all be unsuitable when power of the order of several hundreds or thousands of kilowatts was to be rectified, because such rectifiers would be either relatively inefficient, bulky or unadaptable in one way or another.

For medium-power work, that is, 10 to 100 kW, it would be more practical to use the mercury-vapour (hot-cathode) rectifier, but probably the Ignitron mercury-arc rectifier would still be most suitable because it is automatic in operation and very efficient.

For powers up to 10 kW and greater than 1 kW, the mercury-vapour (hot-cathode) rectifier is suitable because this tube has a high efficiency and a small internal resistance. On the other hand, the metal rectifier, in spite of its higher internal resistance, is very reliable and entails very low maintenance cost.

For small-power installations, notably for domestic receivers of broadcasting, the vacuum-valve rectifier is in almost universal use. This choice of a less efficient device is justified by the combination of reasonable efficiency, small size and reliability under all sorts of external circuit conditions, for example, short circuits.

In judging a rectifier, apart from considerations of basic suitability in relation to use, we must consider also its efficiency, the maximum peak inverse voltage that it will stand and its internal resistance.

Of the high-power types, the mechanical rectifier has notable advantages. It is a question only of balancing the power loss at the contacts and the auxiliary power required to operate it with the power-handling capacity, to judge at what power-handling capacity its efficiency is paramount.

The Ignitron has all the advantages of a low internal resistance, dispensing with any need to supply the cathode-heating power required in the mercury-vapour rectifier, and it scores because no "keep-alive" circuits need be used.

Coming to the lower-power categories, the mercury-vapour (hot-cathode) rectifier has the low internal resistance of the mercury-arc type, and it is reasonably cheap and compact. The reliability of the metal rectifier is its prime recommendation; in addition, it does not involve a serious maintenance cost for replacement provided it is correctly rated.

In the lowest power category, we can again compare the mercury-vapour (hot-cathode) rectifier with the vacuum-tube rectifier, and realize that the former has a lower internal resistance. On the other hand, it is much more sensitive to external circuit conditions, demands a big starting interval, has a lower maximum safe peak inverse voltage, and requires many precautions in operation which make it unsuitable where robustness is essential.

See COPPER-OXIDE RECTIFIER, GAS-FILLED RECTIFIER, IGNITRON, MECHANICAL RECTIFIER, METAL RECTIFIER, MERCURY-ARC RECTIFIER, MERCURY-VAPOUR (HOT-CATHODE) RECTIFIER, RECTIFIER VALVE, SELENIUM RECTIFIER, VACUUM-TUBE RECTIFIER.

RECTIFIER INSTRUMENT. Term applied to a D.C. measuring instrument when used in conjunction with a rectifier for the measurement of A.C. voltages or currents.

RECTIFIER VALVE. Diode used in a mains unit to rectify the alternating current. The term is sometimes used to describe a diode employed as a detector in a radio receiver. It is preferable, however, to use the term *diode detector* to describe a diode used as a detector and to confine the use of the term rectifier valve to mains units.

For half-wave rectification, the rectifier valve has one anode and one cathode, while a full-wave rectifier has two anodes, insulated from one another, and one cathode (see FULL-WAVE RECTIFICATION, MAINS UNIT).

Differentiation is made between the two types of rectifier valve, as one has a nearly complete vacuum but the other contains mercury vapour. The mercury-vapour valve has less internal resistance than the hard-vacuum valve, and is therefore more efficient. The liability to damage is, however, greater when short-circuit of the direct-current output takes place. It is more necessary to maintain constant operating conditions with the mercury-vapour (hot-cathode) rectifier than with the more commonly used hard-vacuum type.

When choosing a rectifier valve for a given set of conditions, it is best to consult the specification of typical valves as regards operating conditions. The valve manufacturers supply graphs showing the relationship between the alternating-current voltage applied to the anode (or anodes) of the valve and the resulting direct voltage for a specified direct-current output. A typical and often specified smoothing circuit is assumed.

In some cases, rectifier valves are designed so that the cathode takes longer to heat up and give emission than do the cathodes of valves used in the equipment energized from the mains unit. This ensures that high tension shall not be applied to valves before their cathodes are giving full emission. See HALF-WAVE RECTIFICATION, MERCURY-VAPOUR (HOT-CATHODE) RECTIFIER, SMOOTHING CIRCUIT, VACUUM-VALVE RECTIFIER.

RECTIFYING DETECTOR. Detector which depends on rectification for its operation. Most practical forms of detector fall into this category.

RED-CONSCIOUS. Term applied to photocells when the chromatic sensitivity increases at the red end of the spectrum. Such cells are particularly sensitive to artificial light, or to light in which there is a large proportion of red rays.

REDIFFUSION SYSTEM. Synonym for RADIO RELAY SYSTEM.

REED LOUDSPEAKER. Moving-iron loudspeaker in which the moving member consists of a metal reed fixed at one end; the free end, to which the cone is attached, is placed near the poles of the magnet and vibrates at the frequency of the signals applied to the coil of the instrument. See LOUDSPEAKER, MOVING-IRON LOUDSPEAKER.

REFERENCE TELEPHONIC POWER. Arbitrarily chosen value of power measured in a specified way. The practical value of using the conventions of definition and measurement is that such a method forms a basis for comparison, even though the basis has little physical meaning. Reference telephonic power (abbreviated to R.T.P.) may be defined as the speech power into 600 ohms, the peaks of which, when measured on the S.F.E.R.T. volume indicator, give a zero reading.

It is very difficult indeed to get any basic physical meaning behind the general conception of speech power because, of course, it is always varying and its variations are irregular. On the other hand, it is important to have means of comparison and, in broadcasting particularly, some means of checking maxima, minima and peaks. R.T.P. was established to give comparisons, and an empirical method of checking to give a reasonable control of "volume" in broadcasting. See CONTROL ROOM, S.F.E.R.T. VOLUME INDICATOR.

REFERENCE VOLUME. Synonym for REFERENCE TELEPHONIC POWER.

REFLECTION. Return of a wave by an impedance discontinuity in a transmission system. Fig. 25a shows a stout piece of rope attached to a firm support held at its free end by a human hand. If the rope is given a single jerk, a hump travels along the rope. Arrived at the far end, the hump then travels back again and jerks the hand. The hand that jerks the rope makes a wave, the wave that hits the firm attachment at the far end is reflected back again.

Fig. 25b shows a transmission line. If the key in the battery circuit is closed and then opened, it gives the sending end of the line an electrical jerk; if means are provided to detect it and if the receiving end of the line is in a condition to reflect it, a reflected wave will be detected at the sending end a fraction of a second after the first wave or electrical jerk was started.

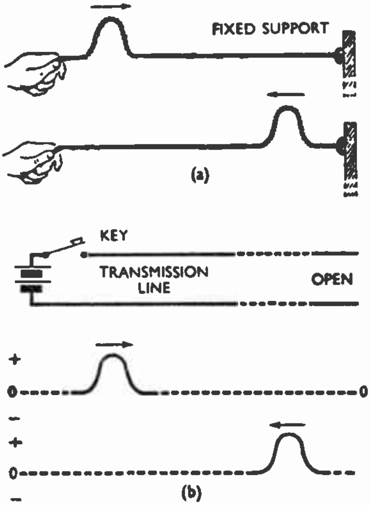


Fig. 25. If a stout rope (*a*), attached firmly at one end, is given a sudden vertical jerk by the hand holding the other end, a "hump" travels along the rope from hand to support, and is then reflected back to the hand. Closing and opening the key in circuit (*b*) sends a pulse along the line; as the receiving end is open the pulse is reflected.

The reflection of the hump, or wave, in the rope will take place only if the energy of the jerk is not absorbed at the far end. If the support were arranged so that the far end could move up and down and, in moving, do some work—if it moved a piston in a cylinder filled with viscous oil, for instance—the reflected wave would be feebler than if the support were solid. The conditions required for the reflection of an electric wave from the receiving end of the line are that it shall be either open-circuited or mismatched with an impedance (see MATCHING, MISMATCHING FACTOR). If the line is terminated by its characteristic impedance, there is no reflection.

Reflection occurs at any junction where there is a failure to match impedances. Any two networks which are joined by an impedance discontinuity produce reflection. The reflected wave modifies the performance of networks and transmission systems.

The term "return" is, in general, associated with reflection because a voltage or current returns to the input terminals. See REFLECTION GAIN, RETURN CURRENT, RETURN LOSS, RETURN VOLTAGE.

REFLECTION COEFFICIENT. Synonym for RETURN-CURRENT COEFFICIENT.

REFLECTION GAIN. Ratio of the power transmitted into a load, whose impedance differs from that of the source, to the power which would be transmitted if impedance of the load were equal in phase angle and in magnitude to that of the source. The ratio is expressed in decibels. See MATCHING, MISMATCHING FACTOR, REFLECTION, RETURN-CURRENT COEFFICIENT.

REFLECTION LOSS. See REFLECTION GAIN.

REFLEX CIRCUIT. Once-popular arrangement in which an attempt is made to induce one valve to function as an amplifier of both radio frequencies and audio frequencies. Signals, after R.F. amplification and detection, are "reflected" back into the grid circuit of the combined-duty valve for amplification at audio frequency. One method of achieving this is shown in Fig. 26.

Much ingenuity was devoted to these circuits when valves were expensive and consumed large filament currents, for it seemed that they offered possibilities of obtaining the work of two valves at the cost of one. Difficult problems of stability usually involved considerable limitation of the amount of gain to be had, but some success was certainly obtained with the simpler

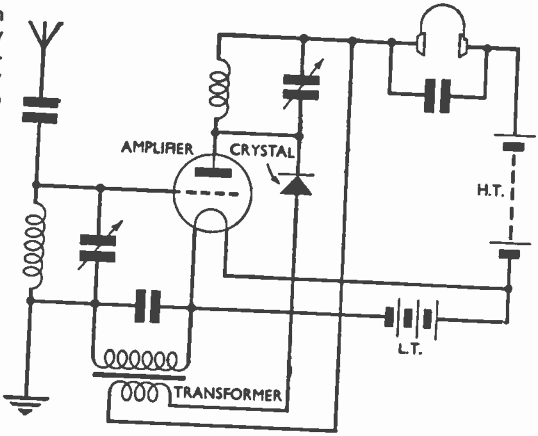


Fig. 26. Essentials of a simple reflex circuit in which audio-frequency currents from the crystal detector are fed by the transformer back to the grid circuit of the valve for further amplification. Thus the valve is seen to operate as both an R.F. and an A.F. amplifier.

circuits. Thus, one valve and a crystal detector did indeed give results little short of those to be expected from a three-valve receiver of equivalent date.

REFRACTION. Deflection of light or radio-waves when they enter a medium of different density from that in which they have previously been travelling. If a rod is partly immersed in water at some oblique angle, the part immersed in the water appears to run in a different direction from that in the air; the rod appears to be shortened and bent. This is because the light waves alter their direction of propagation when they pass from air to water, and vice versa. The waves actually travel with greater velocity in air than in water, and the effect is that the direction of propagation in water is bent towards the normal. The light waves are then said to be refracted; Fig. 27 makes the process clear.

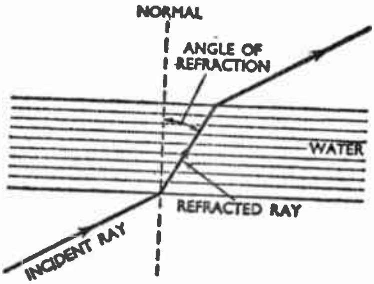


Fig. 27. How a ray of light becomes displaced by refraction as it passes obliquely from air, through a layer of water, and thence into air again.

In a similar manner, radio-waves are refracted when they pass at an oblique angle through an ionized layer; in this case we have the two media of ether and ionized gases. The ratio of the velocity of the waves in free ether to the velocity of the waves in a material medium is known as the refractive index of the medium. The refractive index of water is greater than unity, but an ionized layer has an index less than unity. See IONOSPHERIC REFRACTION.

REGENERATION. Amplification of received signals by means of a controlled amount of positive feedback. See FEEDBACK, SUPER-REGENERATIVE RECEPTION.

REGENERATIVE AMPLIFIER. Amplifier using positive feedback. See FEEDBACK AMPLIFIER.

REINARTZ CIRCUIT. Regenerative circuit for reception in which a continuation of the tuning-inductor winding at the earth end of the coil is used for both feedback and aerial-coupling purposes as shown in Fig. 28. A variable capacitor, usually of about 0·0002 or 0·0003 μF, provides the control feeding an adjustable amount

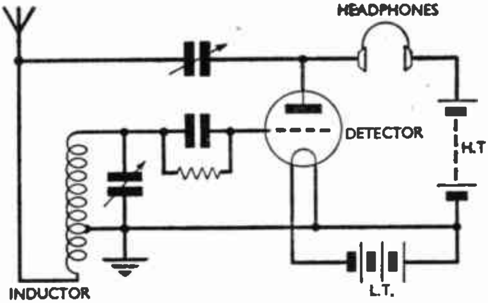


Fig. 28. The classic form of Reinartz circuit, in which the combined aerial and regeneration-coupling inductor is a continuation of the tuning inductor, and the headphones provide the necessary anode-circuit impedance.

of energy to the winding from the anode of the detector valve, where the necessary radio-frequency voltages appear as a result of the inclusion in the anode circuit of a suitable impedance. Originally, this was simply the headphones or the primary of an audio-frequency transformer, but a special inductor is now commonly used.

REIS MICROPHONE. Early type of telephone transmitter in which a contact is attached to the diaphragm. The vibration of the diaphragm causes intermittent interruption of an electric circuit between transmitter and receiver, causing the receiver diaphragm to vibrate at the frequency of the sound waves impinging on the microphone diaphragm.

REISZ MICROPHONE. High-quality carbon microphone developed for use in sound studios. It consists of a marble block with a cavity containing fine carbon granules, which are retained in position by a thin, non-metallic diaphragm.

The principle of operation is that of any carbon microphone; variations in air pressure on the diaphragm produce variations in contact resistance between the granules, thus modulating the direct current flowing in the microphone circuit.

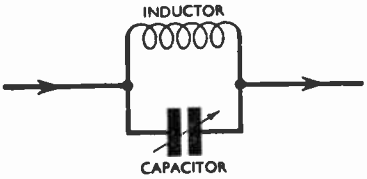


Fig. 29. The parallel inductance-capacitance, or rejector, circuit offers a high impedance to currents at its resonant frequency but allows others to pass.

The current flows in a direction parallel to the plane of the diaphragm, that is, at right-angles to the axis of the microphone. For this reason, it is called a traverse-current instrument. See CARBON MICROPHONE, MICROPHONE.

REJECTOR CIRCUIT. Arrangement of inductance and capacitance in parallel with each other, the whole being placed in series in a circuit as shown in Fig. 29. When tuned to a particular frequency, the rejector offers a high impedance to oscillations of that frequency, and hence "rejects" them. The arrangement is, therefore, of use in reducing or eliminating interference. See IMPEDANCE, RESONANCE, WAVE-TRAP.

REJECTOR IMPEDANCE. Impedance of a rejector at its resonant frequency. See REJECTOR CIRCUIT.

RELATIVE BEARING. Synonym for BEARING.

RELATIVE LEVEL. Ratio of power or volt-amperes (expressed in decibels) at a point in a transmission line to the power at an origin. This origin is arbitrarily chosen, but, of course, has reference to the circuit of which the line forms part. Thus, the relative level between the input of a line and a point on it 20 miles distant would be the ratio of the volt-amperes at the two points specified. The input power is found by calculating what power would be delivered to a resistive load equal to the impedance of the line, the generator having an internal impedance equal to the line impedance. See ACTUAL LEVEL, TEST LEVEL.

RELATIVE PERMITTIVITY. Ratio of electric flux density produced in a dielectric to that produced in free space by the same electric force.

RELAXATION OSCILLATION. Oscillation the frequency of which is governed by a combination of capacitance and resistance. Usually, the wave form of the oscillation is characterized by a relatively slow variation of voltage or current during part of each cycle, followed by a rapid return to the starting point (see RELAXATION OSCILLATOR). It is essentially the output of a circuit which alternates between two unstable states. The output of a linear time-base generator is an example.

Normally, the wave form of a relaxation oscillation is non-sinusoidal and contains numerous harmonics, a valuable feature when the oscillator is used in frequency-measuring equipment. By adjustment of the value of the capacitor or resistor the fundamental frequency can be varied over a very wide frequency band, from one cycle per min. to one megacycle per sec.

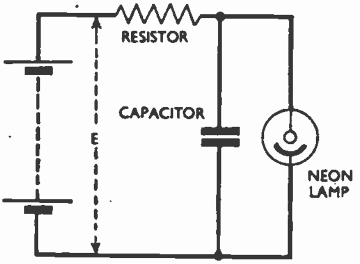


Fig. 30. Simplest form of relaxation oscillator; because the output is a saw-tooth voltage, it is often used as a simple time-base generator.

By restricting the feedback voltage in a relaxation oscillator until it is barely sufficient to produce oscillation, a sine-wave output can be obtained; but normally such a circuit is very unstable under these conditions and is prone to cease oscillating entirely, or to degenerate rapidly into the production of distorted wave forms. By careful design, however, stable relaxation oscillators producing sinusoidal voltages have been developed (see TIME-BASE GENERATOR).

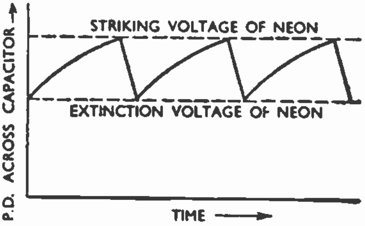


Fig. 31. Wave form of potential difference across the capacitor in the simplest type of relaxation oscillator.

RELAXATION OSCILLATOR. Oscillator the frequency of which is governed by a combination of capacitance and resistance. The simplest type of relaxation oscillator is that illustrated in Fig. 30, a circuit frequently used as a simple time-base generator, since the output voltage is of saw-tooth wave form.

It consists of a neon lamp and a capacitor connected in parallel, both being in series with a resistor and a D.C. supply of voltage E which exceeds the striking voltage of the neon lamp. On connecting up the circuit, the potential difference across the capacitor rises exponentially with time until it reaches the striking voltage of the neon, when the increase in current through the resistor causes it to drop sharply until the extinction voltage of the neon is reached.

The capacitor then begins to charge again and the cycle of events recurs and continues as long as the circuit is connected. The wave form of the p.d. across the capacitor is as shown in Fig. 31. The period of the oscillations can be controlled within wide limits by changing the value of capacitance or resistance. The multivibrator is another example of a relaxation oscillator (see MULTIVIBRATOR). In this, the wave form of the anode currents of the two valves is approximately rectangular in shape.

RELAY. Mechanical switch operated by an electromagnet. The term derives from its early usage in connexion with telegraph systems where, by the use of a relay, weak incoming signals were used to control the release of strong outgoing signals for the next stage of transmission.

The description is usually limited to refer to those types used in telephone and telegraph circuits. The larger and more robust designs for power systems are called contactors.

The term is also applied, by analogy, to an electronic or ionic current switch operated electrically; and to denote the system of line distribution of programmes of sound or vision for general reception. A relay is formally defined as a device by means of which the input power is used to control a local source of energy, and in which there is no proportionality between the magnitudes of the controlling and controlled powers. See ELECTROMAGNETIC RELAY, GAS-FILLED TRIODE, RADIO RELAY SYSTEM.

RELUCTANCE. Property of a magnetic circuit which may be defined as the ratio between the MAGNETOMOTIVE FORCE (q.v.) and the magnetic flux which results. It is analogous to the resistance in an electrical circuit.

REMOTE CONTROL. Means for controlling an apparatus or equipment by switches located at some distance from it. A sender, for example, may be started or stopped by pressing a button in a room some yards, or even miles, away from the sender.

REMOTE CUT-OFF TUBE. Synonym for VARIABLE-MU VALVE.

REPRODUCING HEAD. Device for converting a recorded sound track into electrical or acoustical energy. See ELECTRICAL REPRODUCTION.

RE-RADIATION. Radiation caused by a receiver in which regeneration is applied to the aerial circuit; oscillations produced in the receiver beat with those of an incoming signal.

A receiving aerial may sometimes itself act as a radiator and re-radiates part of the energy it picks up. The term is sometimes incorrectly applied to the process of picking-up and relaying a broadcast transmission.

RESIDUAL GAS. Gas, left in a hard-vacuum valve after degassing, or liberated at any subsequent time. See DEGASSING.

RESIDUAL MAGNETISM. Magnetism which persists in a paramagnetic material after the magnetizing force has been removed. In soft iron, the residual magnetism is comparatively slight; in steel, it is so much greater that the material may become a permanent magnet after a single application of a magnetizing force. See PERMANENT MAGNET.

RESISTANCE. Property of a material which manifests itself as an opposition to the flow of current. The resistance of a material is in inverse proportion to its efficiency as a conductor; good conductors have low resistances; poor conductors have resistances which may be so high that they are better classed as insulating materials.

Sometimes, as in an electric fire, resistance is essential because the opposition to the current generates the heat required; but resistance in supply mains must be minimized because the heat generated in them represents a loss of power.

By inserting the correct amount of resistance in a circuit of known voltage, the desired amount of current can be allowed to flow; by inserting the correct resistance in a circuit in which a known current is flowing, a desired voltage drop can be produced. For details of these calculations, see OHM'S LAW.

The unit of resistance is the ohm, named after one of the early research workers on electricity. The characteristic or specific resistance of a particular material is determined by measuring the resistance between the opposite faces of a cube of unit dimensions of that material; the resulting figure is called the resistivity of the particular substance.

Resistance is inserted in a circuit by breaking the circuit and connecting in it a device called a resistor; this may take a wide variety of forms. A common form consists of a winding of wire of one of the metals (or, more usually, one of the alloys) which has a high resistivity. Variable resistors made in this way may have tappings taken out to a selector switch, to sockets in which a plug may be inserted, or to tags for engagement by clips or for soldered connexion of leads.

Wire-wound resistors are commonly used where considerable currents must be carried; for smaller currents, resistors are often in the form of blocks, rods or tubes of high-resistance material such as carbon, or bakelite containing a proportion of graphite powder. Another type consists of a rod made of an insulating material which is thinly coated with a high-resistance substance like graphite, or even a microscopically thin spray of metal. These are the common methods used to produce resistors of high values and low current-carrying capacity such as those that are widely employed in radio receivers (Fig. 32).

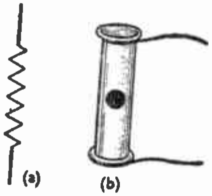


Fig. 32. (*a*) The conventional symbol for resistance, and (*b*) a typical resistor of the kind widely used in radio work, the colours of the body, of one end, and of the spot indicating, in accordance with a code, its ohmic value.

High-value variable resistors and potentiometers are often made with elements consisting of a thin track of resistance material with which a sliding or rolling contact engages. Some types of gain control are made in this way; sliding contacts are also used on some low- and medium-value variable resistors of the wire-wound type. In these, the sliding contact runs on a prepared track on the single-layer winding of special resistance wire (Fig. 33).

Resistance in radio receivers and senders is used for many purposes, but nearly always connected with the development of voltages from currents. Resistance used to limit a current to a desired value is comparatively rare in radio work; the only obvious example is that of the mains-dropping resistor in the "universal" receiver intended to work on either alternating or direct current; there, the resistor serves to limit the valve-heater current to the correct figure. In most other cases, a resistor is inserted for the purpose of developing a voltage from a current and enabling a voltage-operated effect to be produced.

A typical example is the anode-load resistor, which couples successive valves in a resistance-capacitance amplifier. The resistor is connected in series with the anode supply to the valve, and variations in anode current produced when the valve is handling signals cause fluctuations in the voltage drop across the resistor; these fluctuating voltages are communicated to the grid of the next valve. Resistors for such purposes are of some thousands of ohms; values of up to a million ohms or more may be used for grid-circuit resistors in radio receivers, and for convenience in describing them the megohm has been adopted; this unit represents a million ohms, and such values as 250,000 ohms are commonly referred to as a fraction of a megohm (the example would be called 0·25 megohm).

Despite its many practical uses,

resistance remains essentially a loss-producer. When a current is forced through a resistor, work is done and energy lost from the circuit. The energy so lost is converted into heat; a resistor always tends to become warm in use. The heating effect is proportional to the square of the current multiplied by the value of the resistor, and the loss of energy which it represents is often called the I^2R loss.

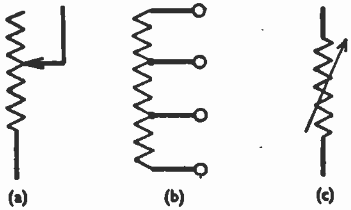


Fig. 33. Conventional symbols representing (*a*) a variable resistor, particularly the type with a sliding contact on a wire winding, and (*b*) a tapped resistor; (c) is a general symbol for a variable resistor without distinction of type.

The heat generated in a resistor is dissipated partly by radiation and largely by the warming of the surrounding air; to get rid of its heat safely, the resistor must provide sufficient surface area for cooling. Thus the minimum size of a resistor is determined by the amount of heat produced, which, of course, depends on I^2R. The surface area determines the power rating of resistors for radio work. A resistor described as a "one-watt" type will safely carry all values of current up to that which, in conjunction with the voltage needed to drive it through the resistor, is equivalent to a power of a watt. Currents above that value represent a power of more than one watt and will be liable to make the resistor so hot that it may suffer damage.

An example may help to show how a suitable wattage rating may be selected for a resistor to perform a particular duty. An anode-load resistor of 10,000 ohms has to carry an anode current of 5 milliamperes. The wattage is given by the expression I^2R. The calculation, therefore, is $\frac{5}{1,000} \times \frac{5}{1,000} \times 10,000$, $= \frac{1}{4}$. A resistor of the small, quarter-watt rating would be adequate, but there would be no margin. See FIXED RESISTOR, VARIABLE RESISTOR.

RESISTANCE ALLOY. Composite material from which fixed resistors are made. Generally, the alloy consists mainly of carbon black or graphite, or both, mixed with silica or other heat-resisting material, together with a binding cement. The whole is then moulded into rods, the resistance value being dependent upon the diameter of the rods.

RESISTANCE ATTENUATOR. Synonym for RESISTIVE ATTENUATOR.

RESISTANCE BOX. Number of resistors arranged in a box, their terminations being brought out to sockets. Selected values of resistance are obtained by inserting plugs into appropriate sockets.

RESISTANCE-CAPACITANCE AMPLIFIER. Amplifier for either R.F. or A.F. in which the anode load consists of a resistor, and coupling to the grid of the following valve is through a capacitor. See AMPLIFIER.

RESISTANCE-CAPACITANCE COUPLING. Method of intervalve coupling which uses resistors to provide the anode-circuit impedances across which the amplified voltages appear; these voltages are passed to the grids of succeeding valves through blocking capacitors, which stop the high-tension voltage from reaching the grids; this would upset the working conditions of the valves. Since the grids are thus isolated, other resistors must be provided to allow the grid bias to reach them. These resistors are the "grid-leaks" of colloquial speech (see AMPLIFICATION).

The resistance-capacitance system is potentially an excellent method of obtaining uniform amplification of a wide range of frequencies; it lacks the voltage step-up effect which can be obtained with inter-valve transformers, but the steep slope of modern valves has made this of little importance.

Although apparently aperiodic, the resistance-capacitance system nevertheless has frequency limitations. Its upper limit is imposed chiefly by the fact that certain of the inter-electrode capacitances of the valves are in effect shunted across the coupling resistors and therefore tend to by-pass alternating voltages. This effect begins to be serious at the higher audio frequencies, and at radio and intermediate frequencies there is a heavy fall in gain. In audio amplification a suitable choice of valves and the use of a coupling resistor of not too high a value (say, under 100,000 ohms) will prevent the effect from being noticeable. Indeed, an excellent upper-frequency response is one of the principal characteristics of a good resistance-coupled audio amplifier.

There is also a lower limit, imposed by the reactance of the grid capacitor. The reactance rises at the lower frequencies and, if it becomes comparable at all with the resistance of the grid-leak, it will cut down the gain on the lower frequencies and there will be a loss of bass. It is the capacitance in relation to the resistance that counts, and in A.F. amplifiers it may be taken that the product of the two quantities should not be less than 0·006, when the capacitance is in microfarads and the resistance in megohms.

The product may be a little greater—say, 0·01—with slight advantage, but it is unwise to increase the figure too much; a larger capacitance and high resistance may cause pronounced "grid choking" if the amplifier should be even slightly overloaded. See AMPLIFICATION FACTOR, AMPLIFIER, AUDIO-FREQUENCY AMPLIFIER.

RESISTANCE-CAPACITANCE FEEDBACK OSCILLATOR. Valve oscillator in which the feedback of power from anode to grid circuits takes place via a network of resistors and capacitors. The frequency of oscillation has the value for which the network gives 180 deg. phase shift between its input and output potentials, and the output wave form may be sinusoidal or irregular, depending on the degree of feedback.

RESISTANCE-CAPACITANCE FILTER. Term sometimes employed instead of "null network," which is a band-stop filter using resistors and capacitors. The term is of doubtful significance, as the Zobel filter uses reactances only. Resistance-capacitance networks are used in various forms of oscillator, and the term could be used in this connexion. A better term would be "resistance-capacitance network," with some qualification as to its form or use, e.g. resistance-capacitance bridge. See NULL NETWORK, PHASE-CHANGE NETWORK, RESISTANCE-CAPACITANCE FEEDBACK OSCILLATOR, WIEN BRIDGE.

RESISTANCE COUPLING. See COMMON-IMPEDANCE COUPLING, RESISTIVE COUPLING.

RESISTANCE DROP. Fall of potential which occurs when a current flows through resistance; the potential drop between the ends of the resistor is equal to the product of current and resistance, and is thus fixed by these circuit constants. The potential drop between a point on the resistor and one end of it depends on the position of the point.

RESISTANCE-STABILIZED OSCILLATOR. Oscillator stabilized by the inclusion of a high-value fixed resistor between the anode and the tuned circuit. This makes the resistance shunting the tuned circuit so high that changes in the anode A.C. resistance of the valve are relatively ineffective in changing the frequency of oscillation. See FREQUENCY STABILIZATION.

RESISTIVE ATTENUATOR. Attenuator for use up to medium radio frequencies and consisting of resistive elements. See ATTENUATOR.

RESISTIVE COUPLING. Common-impedance coupling in which the common impedance is resistive. See COMMON-IMPEDANCE COUPLING.

RESISTOR. Piece of apparatus used in a circuit primarily because of its property of resistance, or because it is capable of dissipating electrical energy. See FIXED RESISTOR, RESISTANCE, VARIABLE RESISTOR.

RESONANCE. Property of an oscillatory circuit which causes it to behave in a special manner at the particular frequency to which it is tuned. This property may manifest itself in several ways. For example, if the circuit is excited by an oscillatory stimulus of the exact frequency to which it is tuned, it will respond strongly, oscillations building up in it to a maximum.

Then, if the frequency of the excitation is altered to either side of the resonance point, the response of the circuit will diminish, dying out as the frequency difference becomes greater. In another case, the resonant frequency may be noticed as the one at which a capacitor and inductor in series tend to become a radio-frequency short-circuit.

Resonance is of fundamental importance in most of the basic processes taking place in radio receivers and senders. It is used to build up the maximum possible voltage and current from the stimulus of a desired signal, and, by abstaining from so doing in the case of signals of other frequency, to pick it out from amongst them. The phenomenon is worthy of detailed study if one wishes to understand the truly fundamental principles of radio.

Resonance effects are best considered in two distinct classes. In the first, the inductance and capacitance of a circuit are connected in parallel, forming an oscillatory system, that is, one in which oscillatory currents of a specific frequency will flow if it is excited by, say, induction effects from a neighbouring circuit wherein currents of that frequency are already flowing.

This form of circuit (the basic tuning unit, as shown in Fig. 34, of most radio apparatus) resonates at a frequency equal to $\frac{10^6}{2\pi\sqrt{LC}}$, L and C being the inductance and capacitance in microhenrys and microfarads respectively. This simple expression neglects the effect of resistance, as may justifiably be done in most cases, since the resistance is, or should be, quite small in comparison with the reactances in the circuit.

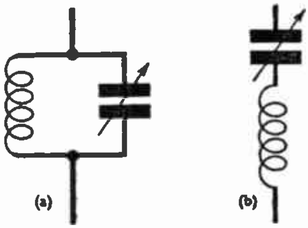


Fig. 34. Two fundamental forms of resonant circuit: (*a*) the parallel and (*b*) the series arrangements.

When tuned to resonance with the excitation, the current circulating in a parallel circuit is at a maximum. On the other hand, if the parallel inductor-capacitor combination is placed in series with, say, the down-lead of an aerial through which signal currents are trying to make their way, those currents will be reduced to a minimum when the circuit is tuned to resonance with them. It is then acting as a rejector, offering a high impedance to its resonant frequency.

It becomes equivalent to a pure resistance, whose value is determined by the "goodness" of the circuit; in a theoretically perfect one, containing only inductance and capacitance but no resistance, the value is infinitely high. In practice, it is equal to $\frac{L}{CR}$, L and C being the inductance and capacitance values, and R the resistance. This expression enables one to evaluate the resistance to which a circuit becomes equivalent at resonance; the resulting figure is sometimes called the circuit's dynamic resistance, or rejector impedance.

It follows that, if a resonating circuit offers a high impedance to the signal currents, they will develop a maximum voltage across it. That is why it is so useful as a means of passing signal voltages from aerial to first valve, and from valve to valve.

The second type of resonant circuit is that wherein the inductance and capacitance are connected in series with each other. This arrangement resonates at a frequency given by the same expression as for the parallel form.

But its behaviour differs in one important respect from that type; its impedance is lowest at the resonant frequency, being, in fact, merely the residual resistance (radio frequency), the inductive and capacitive reactances having vanished. More precisely, they have become equal, and being of opposite sign cancel out. (This leads to another definition of the resonant frequency: it is that at which the inductive and capacitive reactances become equal.)

The property of the series arrangement of becoming a virtual short-circuit to the resonant frequency causes it to be described sometimes as an acceptor, in contradistinction from the rejector. This property is occasionally exploited in dealing with acute interference from a particular sender. The acceptor is then used to form a shunt directly from aerial to earth on the receiver, and tuned to the unwanted signal. To that signal the acceptor provides a low impedance path through which it can leak away to earth, but to all other frequencies it offers a considerably higher impedance, compelling them to enter the receiving circuits much as usual.

In summarizing the properties of the two types of resonant circuits, emphasis must be laid on the fact that both become purely resistive at the frequency of resonance but, whereas the resistance is low in the series circuit, it is high in the parallel circuit. Again, the lower its radio-frequency resistance, the more nearly does the acceptor approach a short-circuit and the more nearly does the rejector approach an infinite resistance.

In conclusion, some mention must be made of two forms of resonance effect in "circuits" which are somewhat difficult to relate in one's mind with the simple and familiar kind containing inductance and capacitance neatly disposed in a coil of wire and the plates of a capacitor.

The first of these is the resonant cavity, used in handling waves of centimetric or millimetric length. It is a space contained by a metallic boundary of suitable size, its resonant frequency depending entirely on its physical dimensions and not at all on the thickness of the metal walls enclosing it. (For strict truth this statement requires slight qualification, but it is correct so far as broad principles are concerned.)

Into such a box, one may inject a received signal from one side, the output of a local oscillator from another, and from a third point extract, after rectification by a crystal, the resulting beat frequency for handing on to an intermediate-frequency amplifier in a superheterodyne receiver. Precise tuning of the cavity is done by small adjustments of its cubic capacity, for example, by adjusting a small plunger so that it projects more or less into the space within. In short, tuning to resonance is a matter of suiting the physical dimensions of the cavity to the length of the waves injected into it.

The second of these special resonance effects also concerns a form of circuit in which physical dimensions are of principal importance; namely, an isolated conductor forming a tuned aerial system. Of this there are many kinds, generally characterized by inductance and capacitance distributed along the length of wires or rods, rather than concentrated in certain places. Given that the distribution is uniform, the resonant frequency is determined by the total length over which the inductance and capacitance are spread.

This often leads, in fact, to a most simple relationship between physical length and resonance properties, as in the case of a single wire or rod, supported on suitable insulators so that it is kept in a straight line and reasonably isolated from other bodies. Such a conductor will resonate freely at a frequency equivalent to a wavelength of twice its physical length, and is what is known as a half-wave dipole. See RESONANCE CURVE, SELECTIVITY, WAVE-TRAP.

RESONANCE AMPLIFIER. Apparatus in which advantage is taken of the special properties of a resonant circuit in obtaining voltage gain and selectivity. The term may denote simply a conventional valve amplifier using tuned inter-valve couplings, but it is sometimes taken to include valveless devices which give an effect of voltage magnification simply by virtue of resonance.

RESONANCE CURVE. Graph showing the response of a tuned circuit to oscillatory excitation of varying frequency. It takes the form of a more or less sharply peaked curve, as illustrated in Fig. 35, the peak occurring when the circuit is tuned to the frequency of the excitation. The precise shape of the curve is often of value in assessing the suitability of a circuit for a given purpose, since it provides information as to the degree of selectivity to be expected. See RESONANCE.

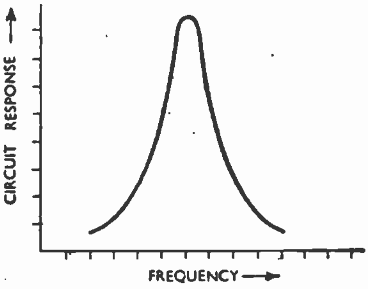


Fig. 35. The shape and height of a resonance curve may be taken as a measure of the "goodness" of a circuit or even of a complete radio receiver.

RESONANT AERIAL. Aerial which resonates at a particularly frequency by virtue of its distributed inductance and capacitance. An example is the half-wave dipole, the resonant frequency of which can be estimated fairly accurately from its physical dimensions. See HALF-WAVE DIPOLE.

RESONANT CIRCUIT. Circuit capable of being set in oscillation at a definite frequency. More precisely, it is a circuit containing inductance and capacitance, but less than critical damping. See DEAD-BEAT.

RESONANT-CIRCUIT DRIVE. Master oscillator, the frequency of which is dependent upon the electrical characteristics of a circuit maintained in oscillation by a valve.

RESONANT FREQUENCY. Frequency to which a circuit responds most strongly when excited by an oscillatory stimulus. The frequency, at which the circulating current is at maximum, is fixed principally by the inductance and capacitance values in the circuit. See RESONANCE.

RESONANT-LINE OSCILLATOR. High-frequency oscillator used in short-wave senders, the frequency stability of which is maintained by a resonant line. The resonant line comprises a parallel wire or concentric transmission cable having a length corresponding to an integral number of quarter-wavelengths.

RESONATOR. Any device possessing inductance and capacitance, and having sufficiently low damping to be capable of resonating. The term is usually limited to special devices in which the resonant frequency is rigidly fixed, as in the resonant cavities so much used in centimetric-wave technique, or in circuits employed for maintaining a frequency calibration of some kind. See RESONANCE.

RESPONSE. Amplitude of power, voltage or current at the output terminals of a source; it is usually considered in relation to its variation with the wave frequency. See RESPONSE GRAPH.

RESPONSE CURVE. Synonym for RESPONSE GRAPH.

RESPONSE GRAPH. Graph plotting response against frequency (see RESPONSE). A filter characteristic may be plotted to show the variation of attenuation with frequency; or, vice versa, it may show the variation of output voltage, current or power with frequency.

The term "response" generally means any quantity which is the greater as power or volt-amperes are greater and it implies the reverse of attenuation. Any source, such as a valve amplifier, radio receiver or oscillator, can have a response characteristic or response graph. See ATTENUATION, FILTER.

RETARDATION COIL. Inductor designed to have a high impedance for voice-frequency currents. Cases occur in which it may be necessary to "block off" a circuit to prevent it being energized by voice-frequency currents, but permit direct current to pass for the operation of relays, for instance. A low-pass filter would be a satisfactory network to assure the attenuation of the higher audio-frequency waves and to pass D.C., but if it is possible to use a simple inductor to get a sufficient selection, the cost of the capacitor or capacitors is saved. See LOW-PASS FILTER.

RETARDED POTENTIAL. In electromagnetic-wave theory, an instantaneous electric potential which is caused by a distribution of charge and current which existed at a source some time before, the lag being due to the finite time taken for the disturbance to travel from the source to the point in question.

RETARDING FIELD. An electric or magnetic field, existing in any interelectrode space in a valve, which acts as a decelerator of electrons travelling therein. See RETARDING-FIELD DETECTOR, RETARDING-FIELD VALVE.

RETARDING-FIELD DETECTOR. Type of detector used in ultra-high-frequency circuits with velocity-modulated valves. A detector valve is employed in which the electrons, in their transit from cathode to anode, come under the influence of a field which alternately accelerates and decelerates them. The electron stream is then said to be velocity-modulated, because some of the electrons are moving faster than the others. In due course the faster-moving electrons will overtake the slower ones, which results in the electrons becoming bunched into groups.

If we introduce into such a velocity-modulated stream a collector electrode at a low or negative potential, this will repel the electrons in the stream. If the potential is suitably chosen, it will have the effect of turning round the slower-moving electrons completely, but it will not be able to stop the faster electrons which will thus be collected by the electrode and withdrawn from the stream.

Since these faster-moving electrons have been introduced into the stream in the first place by the process of modulation, the stream has been effectively demodulated by the use of this retarding field collector, so that, from the velocity-modulated stream, we obtain an electric current varying in intensity.

RETARDING-FIELD VALVE. Valve in which electrons are accelerated from the cathode to a positively charged electrode and, having passed through the electrode, are returned to it by an electric field acting in the opposite direction. A retarding field is produced, for example, between the anode and screen-grid electrodes of a pentode when the anode potential is less than the screen potential. Also, in the cavity magnetron and the klystron, a retarding field acts to bunch electrons. See BUNCHING, VIRTUAL CATHODE.

RETROACTION. Synonym for POSITIVE FEEDBACK.

RETURN CHANNEL. Channel through which messages are received in a two-way communication circuit, as distinct from that through which they are sent. See CHANNEL, DUPLEX OPERATION.

RETURN CURRENT. Current wave which is produced by reflection in any transmission system, and appears at the input terminals of the system (see REFLECTION).

When there exists an impedance-discontinuity in any transmission system, waves are reflected from the unmatched junction (see MATCHING, MISMATCHING COEFFICIENT). These reflected waves appear at the sending end of the system, and their effect is to modify the impedance at the input terminals of the network, transmission line, filter or other system.

The return-current waves can be described as echoes, and may be detected as such. If the level of the input is high enough, a retroactive condition is established and the system may oscillate or sing. See REFLECTION, RETURN-CURRENT COEFFICIENT, RETURN VOLTAGE, SINGING PATH, SINGING POINT.

RETURN-CURRENT COEFFICIENT. Vector ratio of the return current, to the current that would exist at the same point if there were no reflection effects. For instance, if a uniform transmission line is terminated in its characteristic impedance, there is no reflection at its receiving end. Let the characteristic impedance be Z; if the line be terminated by an impedance W, the reflection coefficient is $\frac{W-Z}{W+Z}$, the impedances being expressed by their real and imaginary parts so as to give the vector ratio. See RETURN CURRENT.

RETURN ELECTRONS. In a cathode-ray tube, the electrons which, having struck the screen, move back to the anode under the action of its positive charge.

RETURN LINE. Return channel formed by a line in a two-way communication system using transmission lines. The faint trace shown by the spot on the cathode-ray-tube screen of an oscilloscope when returning rapidly from right to left, usually termed the fly-back trace, may also be called a return line. See EARTH-RETURN CIRCUIT, FLY-BACK, OSCILLOSCOPE, RETURN CHANNEL.

RETURN LOSS. Value of the return-current coefficient expressed in decibels or nepers. See RETURN-CURRENT COEFFICIENT.

RETURN VOLTAGE. Voltage component of the reflected wave. The return voltage is defined in exactly the same way as return current if the word "voltage" is substituted for "current." See RETURN CURRENT.

REVERBERATION. Prolongation of a sound by successive reflections, for example, from the walls of a room.

REVERBERATION-RESPONSE. Response of a microphone to reverberant sound, such sound waves being of differing magnitude, direction and phase as a result of their reflection from surrounding walls, etc.

REVERBERATION-RESPONSE CURVE. Curve showing the response of a microphone to reverberant sound. Such a curve is drawn with a logarithmic frequency scale as its horizontal base and with response in decibels as its vertical scale.

REVERBERATION TIME. As applied to the acoustics of a studio or auditorium, the time taken for reverberant sound to decay 60 db. after the emission of the sound from the source has ceased.

REVERSE COUPLING. Synonym for NEGATIVE FEEDBACK. The term was used in connexion with oscillators or regenerative receivers before the term "feedback" came into use. For example, an oscillator was said to have a reaction coil; this was a coil coupled to the anode-circuit coil to give a 180-deg. phase reversal between grid and anode voltage, thus providing positive feedback. When the coupling was reversed to give an in-phase voltage and negative feedback, this was called reverse coupling. The term is virtually obsolete. See FEEDBACK, OSCILLATOR.

REVERSED IMAGE. Image that has been inverted laterally, the left-hand side of the picture appearing on the right, and vice versa, though the top and bottom are in their correct positions. It is brought about in cathode-ray television reception by incorrect connexion of scanning voltage or direction of scanning current, causing the spot to traverse the line scan in the wrong direction.

REVERSE FEEDBACK. Synonym for NEGATIVE FEEDBACK.

REVERSE GRID-CURRENT. Current which flows from the grid-control electrode as though this were a positive terminal. Normally, if the grid is positive with respect to cathode, it collects electrons and is thus a source of negative electricity. Due to ionization of the gas, be it residual or purposely enclosed by the bulb, positive ions may be collected by a negative grid (Fig. 36). This causes the grid to become positive, and produces reverse grid-current. See GAS-FILLED TRIODE, GRID CURRENT.

R.F. Abbreviation for RADIO FREQUENCY.

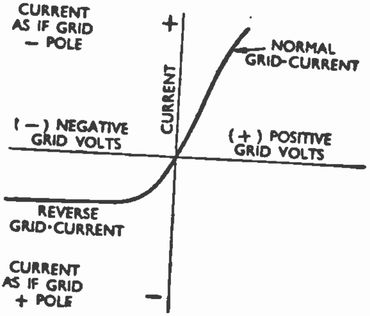


Fig. 36. Example of the shape of grid-current graphs for gas-filled triodes. Reverse grid-current may possibly occur in a hard-vacuum valve owing to traces of residual gas.

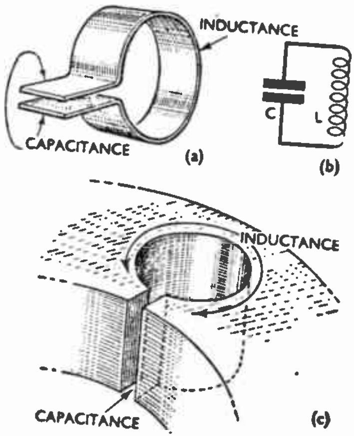


Fig. 37. Principle of the rhumbatron: the shape (*a*) has a natural resonance, as the flat parallel portions have capacitance and the loop has inductance, thus simulating a parallel-tuned circuit (*b*). The rhumbatron cavity (*c*) is formed in a solid conductor.

R.F. PENTODE. Synonym for SCREENED PENTODE.

RHEOSTAT. Term sometimes used for VARIABLE RESISTOR.

RHOMBIC AERIAL. Directive aerial consisting of an equilateral parallelogram of wires, usually horizontal, each element being some definite number of quarter-wavelengths long. The elements meeting at one end of the longer diagonal are connected together through a fixed resistor, and the elements meeting at the other end of this diagonal are connected to the sender or receiver.

RHUMBATRON. Any cavity formed in conducting material and designed so that oscillations may be set up within it by electrical impulses of suitable frequency. A structure such as that shown in Fig. 37a has a natural period of resonance; broadly speaking, the structure can be simulated by a lumped capacitance (that of the two flat ends which are close together) and a lumped inductance (that of the loop joining the two ends). The resonant frequency is very high if the dimensions are small.

A cavity cut out of the solid (Fig. 37c) is similar to the paper-clip shape of Fig. 37a, and it, too, has a natural frequency of resonance. The oscillating currents are of such high frequency that they are confined to the surface of the metal; thus the fact that the block is solid is of no importance.

If a periodic electrical stimulus is applied to the mouth of the cavity, strong oscillatory currents are set up in it. In the Klystron and the multi-cavity magnetron, electrons in alternately large and small concentrations provide the stimulus to set up oscillations in suitably disposed cavities. The field at the mouth of the cavities reacts so as to maintain the concentrations, and sustained oscillations are thus produced. See KLYSTRON, MULTI-CAVITY MAGNETRON, NATURAL FREQUENCY, RESONANCE, SKIN EFFECT.

RIBBON MICROPHONE. Modern type of microphone in which the moving element consists of a corrugated ribbon of metal foil, suspended under light tension between the poles of a permanent magnet, as indicated in Fig. 38. It may be designed to operate as a pressure or as a velocity microphone, or it can operate on the pressure principle over part of the frequency range and on the velocity principle over other parts of the range.

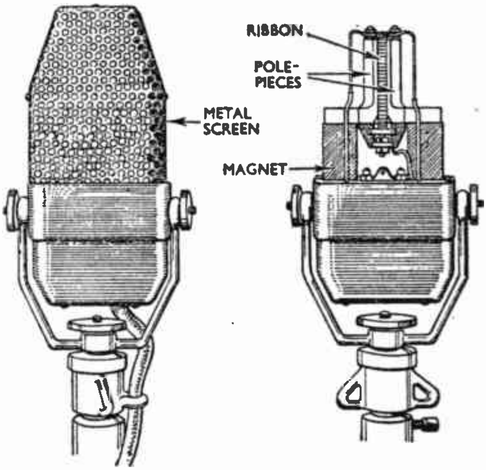


Fig. 38. In a ribbon microphone a corrugated metal-foil ribbon acts as a diaphragm; it is suspended in the field of a permanent magnet and, when the ribbon vibrates under the pressure of sound waves, e.m.f.s are generated at the terminals. The metal screen has an inner lining of fine gauze to exclude dust.

If designed as a pressure microphone, it has little advantage over other types of pressure microphone; if designed for simple velocity operation, the response falls at high audio frequencies because the dimensions of the pole-pieces are comparable with the wavelength. For this reason, the instrument is designed to operate as a velocity microphone over the lower half and as a pressure microphone over the upper half of the normal audio range. See MICROPHONE.

RIFFEL LOUDSPEAKER. Loudspeaker specially designed to give maximum radiation in a horizontal plane, vertical radiation being restricted.

RINGING. Tendency towards self-oscillation, so that free oscillations persist after the stimulus of the signal has ceased; it is a variety of TRANSIENT DISTORTION (q.v.). An example is shown in Fig. 39. Just as a gong will give, when struck, a prolonged note that fades into silence, so will a resonant circuit yield a series of gradually weakening oscillations when excited by a momentary impulse such as the discharge from a capacitor. The rate of dying-away is a function of the decre-

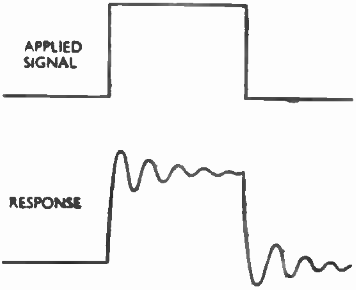


Fig. 39. Graphical example of ringing in an amplifier or a loudspeaker.

ment of the particular circuit. See DECREMENT, RESONANT CIRCUIT.

RING MODULATOR. One of the many types of modulator producing commutation modulation. The reversals of the circuit path of the modulating wave are made by electronic switches (see COMMUTATION MODULATION). The circuit in Fig. 40 shows how the circuit path of the modulating wave is reversed at the frequency of the carrier wave. Transformers are used to balance out any component of the carrier wave in the output from the modulator. The modulating wave cannot find its way to the output because its form is changed in being switched by the rectifiers. In practice, small voltages at the carrier and modulating frequencies may appear in the output due to unbalance effects in the rectifier and transformers. Means are usually provided to balance out these waves.

The amplitude of the carrier wave must be large compared with that of the modulating wave, because pairs of rectifiers must have the same minimum conductance over each half-cycle of the carrier wave, and this must not be affected by the voltage of the modulating wave. The ring modulator has a wide use in carrier-wave transmission over line wires and as a frequency-changer in measuring apparatus. It is essentially an amplitude modulator

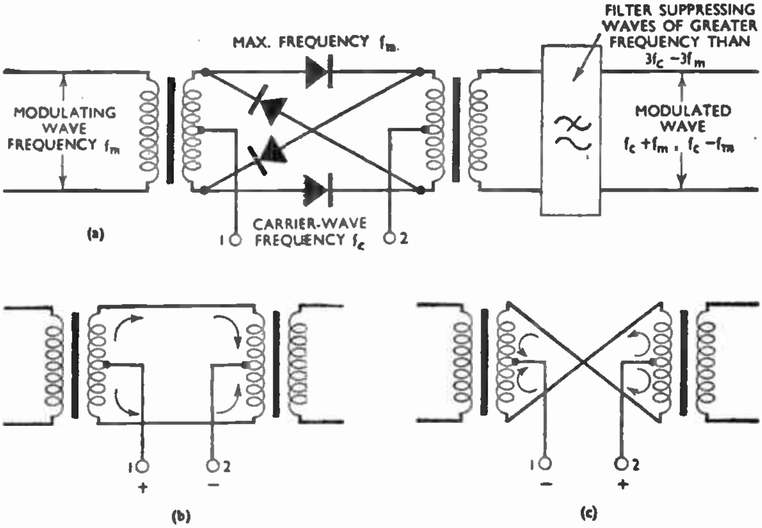


Fig. 40. Connexions of a ring modulator are shown at (*a*); the filter is essential because, in commutation modulation, the output wave is of rectangular form containing waves of frequencies f_c, $3f_c$, $5f_c$ and so on. The lower diagrams show the path of the modulating wave when (*b*) the carrier-wave terminal 1 is positive with respect to terminal 2, and (*c*) when terminal 1 is negative.

which suppresses the carrier wave. See COMMUTATOR MODULATOR, FREQUENCY-CHANGING, SUPPRESSED-CARRIER MODULATION.

RIPPLE. Alternating component or components in a rectified current or in a direct current produced by a generator. Ripple voltages and currents of the latter type are caused by commutation. Thus the term commutator ripple is often used. Suitable smoothing circuits, consisting of a series inductor and shunt capacitor, reduce commutator ripple to negligible proportions.

In some circumstances, the term ripple is employed to describe the residual alternating component appearing at the output terminals of a smoothing circuit used in conjunction with rectifiers to convert alternating to direct current. More usually, such waves are referred to as hum, hum component or hum voltage. See HUM, SMOOTHING CIRCUIT.

r.m.s. Abbreviation for root mean square.

ROBINSON-ADCOCK DIRECTION-FINDER. Adcock type of direction-finder with a rotating aerial system in which an auxiliary aerial can be switched in or out of circuit, as in the Robinson (loop) direction-finder, and with a similar purpose.

ROBINSON DIRECTION-FINDER. Direction-finder in which an auxiliary loop-aerial is repeatedly switched in and out of circuit while a bearing is being taken (Fig. 41). The combined aerial-system is rotated while this is done, until a position is found at which the auxiliary aerial makes no difference to signal strength, whether it be in or out of circuit. At this position the auxiliary must then be in the position of minimum pick-up, that is, at right-angles to the direction of wave travel.

The advantage of the system is that the signals remain audible all the time; and communication need not be interrupted by the taking of a bearing. See LOOP DIRECTION-FINDER.

ROCKY POINT EFFECT. Synonym for FLASH ARC.

ROTARY CONVERTER. Machine for converting alternating current to direct current, or vice versa. The voltages induced in the armature windings of an ordinary shunt- or compound-wound dynamo are alternating, but the current is rectified by the action of the commutator. Consequently, it is possible to inject alternating current into the armature by means of slip-rings connected to suitable tapping points in the armature. A machine in which this is done is known as a rotary converter and in appearance it is exactly like a D.C. generator, except that a set of slip-rings is provided at the end remote from the commutator.

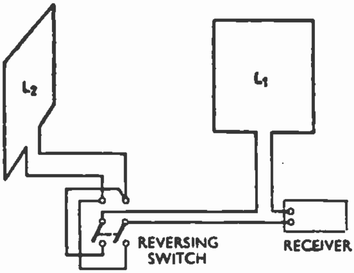


Fig. 41. Robinson direction-finder; loop L_1 is permanently in circuit, and loop L_2 is switched into circuit first one way round and then the other.

A rotary converter works most efficiently with a large number of phases and it is usual, therefore, to arrange for six-phase working, as a supply of this type is easily obtainable from a three-phase source by means of special transformers. As a fixed ratio exists between the A.C. and D.C. voltages, transformers are almost invariably required.

If variation of the D.C. voltage is necessary, some means must be found for varying the voltage of the A.C. input. One method is to provide taps on the transformer, but this varies the voltage in steps. For continuous variation, choke coils or induction regulators may be connected between the transformer and the slip-rings; or the A.C. supply may be taken through a synchronous booster mounted on the shaft of the rotary converter.

Another method consists of varying the voltage ratio between the A.C. and D.C. sides by altering the wave form. This is performed by using split poles for the field, with auxiliary series windings which either assist or oppose the shunt winding.

ROTARY SPARK-GAP. Spark-gap consisting of a studded or toothed disc which revolves between two fixed electrodes. When the studs are opposite the fixed electrodes, the spark jumps from one electrode to the disc stud, current passes through the disc and the spark jumps across the second gap to the other fixed electrode.

If the disc is fixed to the shaft of the synchronous A.C. generator supplying power to the circuit, the spark-gap is said to be synchronous; if the disc is driven independently and at a speed differing from that of the main synchronous A.C. generator, the gap is said to be asynchronous.

ROTARY TRANSFORMER. Synonym for DYNAMOTOR.

ROTATING SCANNER. Method of mechanical television scanning where a disc, scanner, mirror drum or mirror screw is employed. The scanning device rotates, and synchronization is achieved by control of the speed of the rotating mechanism.

R.T. Abbreviation for RADIO TELEGRAPHY.

RUTHERFORD ATOM. Constitution of the atom as imagined by Rutherford in consequence of his experiments. It consists of a central dense nucleus with a net positive charge, and is surrounded at a relatively great distance by planetary electrons having a total negative charge normally equal to the nuclear charge. The normal number of orbital electrons is equal to the atomic number of the element to which the atom belongs and decides its chemical properties. See ATOM, ELECTRON.

S

SADDLE COIL. In a cathode-ray tube, one of the coils used in magnetic deflection; it is usually rectangular in shape and is placed at the narrow end of the tube. See MAGNETIC DEFLECTION.

SAFETY FACTOR. See FACTOR OF SAFETY.

SATURATION. Term which, in general, denotes that the increase in the magnitude of one quantity makes little or no difference to the magnitude of another, the quantities being related. When the state of saturation does not exist, the change of the magnitude of one quantity does alter the magnitude of the other.

As examples, iron is said to be saturated when an increase of ampere-turns produces little change in flux density; and the anode current of a valve reaches saturation when no more electrons can be drawn from the cathode if the anode voltage is increased.

SATURATION CURRENT (of a valve). See EMISSION LIMITATION.

SAUSAGE AERIAL. Synonym for CAGE AERIAL.

SAW-TOOTH VOLTAGE. Voltage having a relatively gradual increment and a very rapid drop to its initial value; so called because, when plotted against time, the resulting graph has the appearance of a saw tooth.

SCALE DISTORTION. Disturbance of the balance of tone when a sound programme is reproduced at a different intensity from the original. For example, reproduction on a reduced scale causes the low tones to be relatively weaker, and subjective harmonics to be reduced. This effect, known as scale distortion, is caused by the relationship between intensity of sound (objective) and loudness (subjective), and the masking of one sound by another, being complex functions of frequency. Although attempts are sometimes made to correct for scale distortion by tone control linked to the volume control, they cannot be completely successful, as the effect is far too complex. See SPEECH AND HEARING, TONE CONTROL.

SCAN. See SCANNING, TRACE. (The line or pattern which is formed by the beam of a cathode-ray tube on the fluorescent screen is called a trace, but the act of making that line is frequently termed scanning and, while the line could be termed a "scan" it is more usual to employ the word as the verb denoting the act of forming a trace.)

SCANNING. Process of dividing a scene or picture into elements each of which can be sent and received over a single radio channel. The number of elements into which the field of view can be divided determines the definition of the system. Each element is sent as a whole, so that gradations of light intensity within the area of one element cannot be taken into account. The light intensity of the element area as a whole decides the amplitude of the signal for that element.

Scanning is a process which selects the elements in regular, controlled order, sends signals from them in that order, and, at the receiver, reconstructs the picture by translating the received radio signals into picture elements again in the same order as that in which they were sent out.

Sequential scanning may be used for the analysis and synthesis of a picture in both facsimile and television. The elements are taken one at a time and, normally, dealt with in rows or lines. In television scanning, two things are essential. The first is that the scanning be carried out at sender and receiver in the same sequence and simultaneously. The second is that the number, shape and relative size of the elements to the size of picture must be the same at both sender and receiver.

It does not matter in what order the elements are scanned, provided that the receiver scanning is carried out in the same order and in synchronism. The simplest method is plain sequential scanning; here the elements are in rows and are scanned in consecutive rows from the top left of the picture, horizontally to the bottom right (see LINE SCANNING).

In mechanical scanning, the analysis into elements is carried out by discs, mirror drums, etc., but in high-definition television the cathode ray is used as the scanning device (see STORAGE CAMERA). In the receiver, a cathode-ray tube is used as the source of light, the ray being modulated by the signals sent as each element is scanned. Thus the receiver cathode-ray tube automatically reproduces the relative light intensity of the original element. For the method of providing the scanning movement of the beam, see LINE-FREQUENCY GENERATOR, TIME BASE.

It has been stated that it does not matter in what order the scene is scanned, and there are, in fact, practical reasons for scanning in a manner other than plain sequential scanning (see INTERLACED SCANNING). In all systems, however, regularity of scan is essential.

SCANNING APERTURE. Diameter, or width, of the spot of light or electron beam that forms the scanning device in television. In the case of a disc scanner, for instance, the scanning aperture is the physical dimension of the hole in the disc. In the lens disc, the aperture is the size of spot of light provided by the lens. In the cathode-ray tube, the aperture is the diameter of the spot of light formed by the cathode-ray beam on the screen of the cathode-ray tube. The aperture is, in every case, the deciding factor in the size of the element and, therefore, in the definition of the picture.

SCANNING BEAM. Beam of light or electron beam that, in being moved regularly across a scene or its image, carries out the scanning process.

SCANNING DISC. See DISC SCANNER.

SCANNING FIELD. Magnetic field for deflecting the cathode-ray beam to provide scanning in television. Many cathode-ray systems employ an electromagnetic field provided by deflector coils through which a saw-tooth current is passed to deflect the stream of electrons. See STORAGE CAMERA.

SCANNING HOLE. Hole in a scanning device, such as a disc, through which the light is directed on to a scene to be televised or on to the screen at the receiver. The size of the hole determines the size of the spot of light on the scene, and thus the size of the picture element. See SCANNING APERTURE.

SCANNING-LINE. Path traversed by the electron beam or beam of light during the process of television. It is applicable only to the line scan and denotes the horizontal line along which the scanning spot travels. The term is not meant to include the fly-back path of a cathode-ray electron beam as it moves back from the end of one line to the beginning of the next.

SCANNING SPOT. Spot of light or focused cathode-ray beam which moves across the scene or the receiver screen of a facsimile or television equipment, analysing the scene into its elements or rebuilding the picture from the signals as each element is scanned at the sender.

SCATTERING. Reflection in all directions of a radio-wave when the incident ray strikes a highly ionized patch in any of the ionized layers. These scattered reflections are usually weak and diffused. Scattered reflections also occur when the ionospheric ray strikes the earth after reflection by the ionosphere. The signals produced by scattering are about 40 db. lower in intensity than the main wave, and are only of importance in the skip area because the only energy received there may be due to this cause. It follows that a direction-finder located where the energy is mainly received by scattering will not indicate a true bearing. Very rapid fading effects are apparent at the receiver if a high proportion of scattered energy is present. See FADING, IONOSPHERIC RAY, IONOSPHERIC REFLECTION.

S.C.C. Abbreviation, in reference to conductors, meaning single-cotton covered.

SCHLENKE LOUDSPEAKER. Loudspeaker with a conventional moving-coil movement which operates a diaphragm consisting of a large stretched sheet of Duralumin.

SCHLOEMILCH DETECTOR. Detector consisting of a fine wire, usually platinum, immersed in an electrolyte. A steady potential difference applied between the wire and the electrolyte causes polarization, but, when a small R.F. voltage is applied, the protective film breaks down and permits conduction of the direct current. See POLARIZATION.

SCHOTTKY EFFECT. Variations in the electrode current of a valve owing to changes of emission. These changes vary with the anode voltage because the anode voltage has an effect upon the work function. See EMISSION, NOISE, SHOT EFFECT, WORK FUNCTION.

SCHROTEFFEKT. Synonym for SHOT EFFECT.

SCINTILLATION. Effect present in the reception of radio signals which is produced by slight changes of frequency of an amplitude-modulated carrier wave when the modulation depth is great. In modern practice, the use of a buffer stage or separator valve between the oscillator and the modulated amplifier prevents scintillation. See AMPLITUDE MODULATION, AMPLITUDE MODULATOR.

SCRAMBLER. Secrecy device used in radio telephony. Speech frequencies contained in the message are transposed, high frequencies being made low, and low ones high. At the receiving end the sounds are unintelligible unless a corresponding de-scrambling process is carried out to restore the correct frequencies. See SPEECH SCRAMBLING.

SCRATCH. Sound produced by the surface roughness of a gramophone record when it is being played. It is a good example of random noise, being distributed fairly evenly over the frequency band, but is more noticeable to the ear at the higher frequencies. Use is often made, therefore, of fixed or variable attenuation of these frequencies, and, with this in view, pre-emphasis may be used in recording. See PRE-EMPHASIS, SCRATCH FILTER, TONE CONTROL.

SCRATCH FILTER. Inductance-capacitance circuit in an electrical gramophone reproducing chain. If, as in Fig. 1a, the filter is designed to cut off all frequencies above 4,500 c/s, most of the needle scratch will be eliminated. Speech quality will be unimpaired but musical records will lack fidelity. Since needle scratch varies with different records, greater uniformity of surface noise can be obtained by making the cut-off frequency of the filter variable.

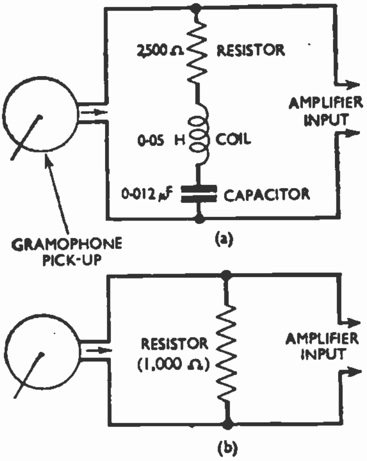


Fig. 1. Two examples of scratch filters for gramophone pick-ups: (*a*) that for a high-impedance pick-up, the values given being those for an amplifier input impedance of 300 ohms; (*b*) arrangement in which top cut increases as resistance value is decreased.

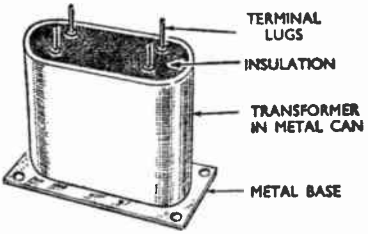


Fig. 2. Appearance of a typical screened transformer. Circuit connexions are soldered to the lugs.

The circuit (a) is particularly suitable for a pick-up having high impedance. A less drastic top cut can be obtained by connecting a resistance of the order of 1,000 ohms across the terminals of the pick-up, as in Fig. 1b. For a low-impedance pick-up, some top-cut may be obtained by shunting it with a resistance of 10 ohms.

SCREEN. Any metallic sheet or wire mesh arranged so as to diminish coupling between circuits as a result of electrostatic or electromagnetic fields. Fig. 2 shows, for example, a transformer which is screened, or "canned." Faraday first demonstrated that there was no electric force within a closed conductor; the "Faraday cage" was a metal container, connected to earth, into which no external electric fields could penetrate.

A circuit in which alternating current flows causes electric fields to vary in the space around it. Any one valve of a multi-valve amplifier, for example, may set up external electric fields which induce voltages in other parts of the amplifier. The coupling may be sufficient to take energy from the output into the input so that the amplifier oscillates; to stabilize the amplifier, screening is used. Thus each valve may have its own metal shield placed around it, while all the components connected to the output circuit of any valve are placed in a copper compartment, so that they are shielded from the components connected to the input circuits of previous valves.

All electronic and other similar apparatus and equipment is constructed with the object of preventing stray couplings between circuits, and each component may be placed in a can which shields it from external fields and thus prevents the escape of fields set up by it. The screen grid of a valve exists to screen the control grid from the anode; cable is screened so that currents may not be induced in it by alternating electric fields. A distinction must be drawn between effects due to electrostatic and electromagnetic fields; the effects due to electromagnetic fields are minimized either by reducing any loops in circuits to negligible dimensions, or by shields of magnetic material.

The smallest loop in the input circuit of a sensitive amplifier may pick up voltages from the alternating electromagnetic fields due to mains wiring, and these induced voltages may be sufficiently strong to produce severe hum at the output. If it is impossible to avoid coupling by diminishing circuit loops, iron screening is essential. For instance, the mains unit of a cathode-ray oscilloscope is conveniently located close to the tube itself. In large tube installations, it is often found that the beam is modulated by the 50-c/s currents flowing in the transformers of the mains unit. Electrostatic shielding is useless, as it is the electromagnetic field which produces the effect.

In this case, ferro-magnetic substances alone are effective for shielding. The higher the permeability of the shield, the more effective it is because the flux passes more easily through the shield if the reluctance of the magnetic path is low. Permalloy shielding boxes are fairly effective, although very expensive. The same arguments apply when audio-frequency transformers (for instance, a transformer of high turns-ratio in the input of an amplifier) become prone to pick up hum voltages. Here again, boxes of iron of very high permeability give good screening, but these are expensive. See ELECTRIC FIELD, ELECTROSTATIC FIELD, INDUCTION, PERMEABILITY, SCREEN GRID, SCREENING, VALVE SHIELD.

SCREEN BURNING. Discoloration of the screen of a cathode-ray tube, causing a reduction in the brilliance of the fluorescence. The effect can be produced by incorrect operation as, for example, by allowing the spot to remain stationary on the screen for some time, but it can also be caused under normal conditions by bombardment of the screen by positive ions; positive-ion burn usually causes a large circular dark patch at the centre of the screen. See CATHODE-RAY TUBE.

SCREEN CURRENT. Steady current which flows between the screen and the cathode of a tetrode or multiple valve when certain specified voltages are applied to the other electrodes.

SCREENED PAIR. Pair of conductors enclosed in an external conducting sheath. A shielded pair of wires may be run in a multi-core cable so that there is less likelihood of cross-talk. The term can, however, apply to any pair of wires with a metal (often lead) sheath surrounding them. See SCREEN, TRANSMISSION LINE.

SCREENED PENTODE. Pentode in which the screen grid is arranged to give the greatest possible screening between anode and control grid. The screen may be extended so that it comes outside the anode electrode. See INTER-ELECTRODE CAPACITANCE, TETRODE.

SCREEN GRID. Grid type of electrode, placed between the control-grid and the anode of a valve with the object of reducing the control-grid-to-anode capacitance. See INTER-ELEC-

TRODE CAPACITANCE, PENTODE, TETRODE.

SCREEN-GRID BIAS. Bias potential of the screen grid. See BIAS.

SCREEN-GRID CURRENT. Current flowing to and from the screen-grid electrode. It is usually substantially constant under operating conditions, because the signal voltages are not applied to the screen grid.

SCREEN-GRID MODULATION. Amplitude modulation obtained by applying the modulating wave to the screen grid, and the carrier wave to the control grid, of a valve; or vice versa. See FREQUENCY-CHANGER VALVE.

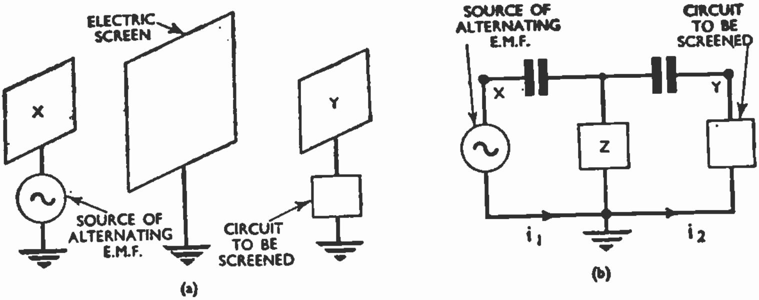


Fig. 3. Diagrams illustrating the principles of screening: (*a*) method of screening *Y* from *X* by an electric screen (conducting plate) as described in the text, and (*b*) the electrical equivalent of such an arrangement.

SCREEN-GRID PENTODE. Synonym for SCREENED PENTODE.

SCREEN-GRID POTENTIAL. Potential or voltage of the screen-grid electrode of a valve. In normal circumstances, this is the screen-grid bias. See SLOPE RESISTANCE.

SCREEN-GRID SLOPE-RESISTANCE. Slope resistance of the screen grid. This is not normally an important quantity, as the screen grid is held at a constant potential. See SLOPE RESISTANCE.

SCREEN-GRID THYRATRON. See GAS-FILLED TETRODE.

SCREEN-GRID VALVE. See TETRODE.

SCREENING. Practice of placing a sheet of material with respect to a magnetic or electric field so as to reduce its penetration into an assigned region. It is necessary to interpose screens between the various stages of thermionic amplifiers in order to prevent the feedback, and consequent possible instability, which may result if the stages are linked by a magnetic or electric field. Screens may be designed to prevent penetration of an electric field, a magnetic field or both.

Screening Against Electric Fields. If electric lines of force can exist between two conductors *X* and *Y*, there is a certain capacitance between them by way of which energy may pass from one to the other. It is the purpose of an electric (or electrostatic) screen to eliminate this capacitance and so prevent the transfer of energy. This problem arose in the development of the tetrode, or screened-grid valve, where it was necessary to minimize the capacitance between the grid and anode of a valve.

The method consists of placing a large conducting plate between *X* and *Y*, as shown at (a) in Fig. 3, and connecting it to the opposite "leg" (usually earth) of the generator which feeds *X*. If the screen is connected to earth through an appreciable impedance *Z*, energy can still reach *Y* from *X*, for the current i_1 in the left-hand loop of Fig. 3b sets up a p.d. across *Z* which drives a current i_2 through the right-hand loop.

For the screen to be effective, Z must be very low, that is to say, the screen must be of highly conductive material, and must be well earthed. Copper and aluminium are the metals most used for electric screens. The screens need not always be solid; a mesh of wires is almost as efficient.

Screening Against Magnetic Fields. An alternating magnetic field, such as that surrounding an inductor carrying alternating current, induces e.m.f.s. in all conductors situated within the field. If such an inductor is surrounded by a screen of conducting material, circular currents flow in the latter and set up a new alternating field which effectively neutralizes the effect of the original field outside the box. For effective magnetic screening, the screen should be a good conductor and solid so as to present a low-resistance path to induced currents. By contrast with an electric screen, a magnetic screen need not be earthed.

Sometimes a screen is required to prevent the spread of both electric and magnetic fields (for example, the screens surrounding the tuning coils of a radio receiver), in which case a well-earthed can of copper or aluminium is used. Radio-frequency currents tend to flow on the surface of conductors (skin effect) and very thin metal can make an effective screen; at radio frequencies the thickness which gives adequate mechanical strength to the screen is usually more than adequate to make the box an effective electric and magnetic screen.

An aluminium or copper screen surrounding a coil may be regarded as a loosely coupled and short-circuited secondary winding of a transformer, the coil forming the primary. This is a useful viewpoint since it shows that the effect of the screen on the coil is to reduce its inductance and increase its electrical resistance at radio frequencies.

To avoid considerable changes in the coil constants, the screen should not be placed very close to the windings. A cylindrical screen surrounding a solenoid should have at least twice the diameter of the solenoid. If the coil is iron-cored the effect of the screen is not so marked, because the field of the coil is more concentrated.

Screening at Audio Frequencies. As frequency is reduced, the induced current that must flow in a screen to provide the necessary external field increases. Large induced currents can be obtained only by the use of thick screens of low-resistance material. For example, if the same technique were used for screening at audio frequencies as that employed at radio frequencies, a copper screen would require to be at least 1 cm. thick to provide adequate protection at 1,000 c/s.

This is an impracticable thickness, however, and, for magnetic screening, it is customary to use a different principle; that of surrounding the source by a closed box of high magnetic permeability such as Mu-metal or Permalloy. The magnetic field surrounding the source confines itself almost entirely to the magnetic material and very little of it escapes into the space outside. As audio-frequency inductors are usually iron-cored, their magnetic field is very concentrated, and magnetic screens may be placed very close to the windings without appreciably affecting either their inductance or resistance.

SCREEN MODULATION. See SCREEN-GRID MODULATION.

SEARCH COIL. Electrical device having a detective or probing function. A search coil is inserted into an electrostatic or magnetic field to determine its intensity and direction. A voltmeter, ammeter or any other form of detector is connected to the coil to register the energy induced in the coil when there is relative motion between coil and field.

The commonest use of a search coil is in the measurement of flux density; the coil is inserted in the field to give maximum coupling and either the field is suddenly reduced to zero, or the coil is quickly withdrawn from the field. In either case, it is arranged that all the flux lines shall cut the coil.

Galvanometers are made which integrate the total energy in the search coil and register a permanent deflection representing the energy, until mechanically set back to zero. Thus, the rate at which the field collapses or builds up, and the speed at which the search coil is withdrawn from the steady field, are of no importance—always assuming that all the flux lines are cut by the search coil. A search coil may also be used to determine the direction of a field, since the flux lines are parallel to the plane of the coil for zero voltage induced in the coil.

If the field is alternating, the search coil is positioned so as to give a maximum deflection on an r.m.s.-reading instrument; from the deflection the flux density can be calculated.

The rotatable coil of a radiogoniometer is called the "search coil." See ELECTRIC FLUX DENSITY, ELECTROMAGNETIC INDUCTION.

SECONDARY CELL. Synonym for ACCUMULATOR CELL. The term is used when distinguishing between a secondary cell and a primary cell. A secondary cell or accumulator may be recharged (rendered active again after the chemical action has ceased due to discharge of current) by passing a current through it in a direction opposite to that of the flow when the cell discharges, whereas a primary cell cannot be recharged. See ACCUMULATOR CHARGING, PRIMARY CELL, VOLTAIC CELL.

SECONDARY ELECTRONS. Electrons produced by secondary emission. See PRIMARY ELECTRONS, SECONDARY EMISSION.

SECONDARY EMISSION. Electron emission from metal owing to the bombardment of the metal by electrons. When an electron travelling with sufficient velocity strikes the surface of a metal even at a normal temperature, it may knock off electrons from the neutral molecules or atoms of the metal.

Secondary emission varies with the velocity of the bombarding electrons and the nature of the bombarded metal. Secondary emission is produced at minimum electron velocities of from 25 to 75 volts, depending on the metal (see ELECTRON VELOCITY). Surfaces treated to give secondary emission produce ten electrons for one bombarding electron; those treated to prevent the effect need ten bombarding electrons to release one secondary electron. See ELECTRON MULTIPLIER, ORBITAL-BEAM VALVE, TETRODE.

SECONDARY-EMISSION MULTIPLIER. Synonym for ELECTRON MULTIPLIER.

SECONDARY-EMISSION VALVE. Synonym for ELECTRON MULTIPLIER.

SECONDARY RADAR. Radio system in which a radar pulse triggers a further device, such as a beacon. See RADAR BEACON.

SECONDARY WAVE. Wave formed when the main wave used for communication is partly spread, refracted or reflected.

SECONDARY WINDING. Winding of a transformer from which power is withdrawn or across which voltage appears when the primary winding is energized. See PRIMARY WINDING, TRANSFORMER.

SECOND-CHANNEL INTERFERENCE. Reception by a superheterodyne receiver of a second transmission which happens to be at a frequency difference from the desired one of just twice the intermediate frequency of the receiver.

Suppose the I.F. is 100 kc/s. To receive from a sender working on 600 kc/s, the superheterodyne oscillator may be set to 700 kc/s, giving the required beat-frequency of 100 kc/s. This, however, will also give the same beat-frequency with a sender working on 800 kc/s, and the latter will tend to be heard as an interfering signal.

Practical remedies are found partly

in wise choice of intermediate frequency, and partly in provision of adequate selectivity in the early circuits of the receiver. See SUPERHETERODYNE RECEPTION, PRE-SELECTION.

SECOND-CHANNEL RATIO. Ratio of receiver sensitivities at the two frequencies when, in superheterodyne reception, signals having frequencies either greater than or less than the frequency of the local oscillator combine with it to give the intermediate frequency. It is the duty of the R.F. or pre-selector circuits to accept only one of these, so that the signal on that channel may be received without interference from the other.

The effectiveness of pre-selection is expressed by the second-channel ratio. For example, suppose a receiver having an I.F. of 465 kc/s is tuned so that the local oscillator is 1,200 kc/s. The pre-selector would then normally be tuned to 1,200–465 = 735 kc/s, at which frequency suppose the sensitivity is 10 microvolts. If, with the receiver tuning unaltered, it is found that its sensitivity on the second channel, 1,200 + 465 = 1,665 kc/s, is 6,000 microvolts, the second-channel ratio is 600 : 1. See PRE-SELECTION, SENSITIVITY, SUPERHETERODYNE RECEPTION.

SECOND-CLASS BEARING. Direction-finder bearing which is accurate to within + 5 deg. See FIRST-CLASS BEARING, THIRD-CLASS BEARING.

SECOND DETECTOR. In a superheterodyne receiver, the detector following upon the intermediate-frequency amplifier and which provides the audio-frequency input to the audio amplifier. It is called *second* because the frequency-changer in such receivers was once known also as the first detector. See SUPERHETERODYNE RECEPTION.

SECOND INTERMEDIATE FREQUENCY. Second frequency to which incoming signals are converted in a superheterodyne receiver employing more than one such change. It is rarely used in broadcast reception, but is very often used in special receivers for extremely high frequencies.

S-EFFECT. Synonym for SURFACE-CHARGE EFFECT.

SELECTANCE. Synonym for SELECTIVITY.

SELECTIVE FADING. Fading of the sidebands of any type of modulated wave whilst the carrier remains at constant strength, or vice versa. When short-wave signals that have travelled along any one particular path to the receiver fade, carrier and sidebands usually fade in and out together. But if a signal is received by two or more ionospheric paths at approximately equal strength, the resultant signal is the vector sum of all the signals arriving by different paths. This vector sum at any particular instant depends upon the frequencies concerned, differences of as little as 200 c/s having a noticeable effect. This causes selective fading of the resultant signal, and causes, for example, a broadcast programme to be reproduced with considerable distortion. See FADING, IONOSPHERIC REFLECTION.

SELECTIVE RESONANCE. That property of a tuned circuit which enables it, by resonating at a particular frequency, to select that frequency from among others and to exclude those of differing frequency. See RESONANCE, SELECTIVITY, TUNED CIRCUIT.

SELECTIVITY. That property of a tuned circuit (or group of circuits, as in a receiver) which enables it to respond strongly to a particular signal and disregard others of different frequency. Selectivity is a natural product of the phenomenon of resonance, for the ability to respond most strongly to the resonant frequency implies a power to select it from among others.

The actual degree to which a circuit builds up oscillatory currents at its resonant frequency and declines to do so in response to excitation of other frequencies is the measure of its selectivity, and to this quality the resonance curve is the best guide; it shows the rapidity with which the response of the circuit falls off on either side of the resonant frequency. A narrow, sharply peaked graph with steep sides indicates high selectivity, and a broad one with gently sloping sides the reverse.

The selectivity of a circuit depends on its damping. Heavy damping means low selectivity and flat tuning. More precisely, the sharpness of the resonance curve varies in proportion to the ratio of inductive or capacitive reactance to resistance. For a given reactance value, the lower the circuit resistance the higher becomes this ratio, and the sharper the resonance.

Circuit resistance mostly resides in the inductor, the R.F. resistance of a good modern capacitor being extremely small. Designers, therefore, devote much attention to securing suitably low resistance in the coils of a receiver.

They do not, however, necessarily strive for the lowest possible resistance; too little damping in a circuit may produce so sharply peaked a resonance curve that there will be attenuation of the higher modulation frequencies in speech and music. Even when the circuits are arranged in band-pass fashion, excessively low damping causes difficulties in obtaining exactly the desired shape of flat-topped resonance curve.

Damping may also be affected by the connexion of components across the tuned circuit. For example, the connexion of a valve across a tuned circuit lowers its Q-factor, but the effect of the valve types now in use is not marked, except in the case of the detector. This valve draws power from the circuit to which it is connected and, therefore, adds appreciably to the damping, unless it is of the anode-bend type.

On the other hand, if the aerial is very tightly coupled to the input circuit of a receiver, it can widen the resonance curve disastrously. For this reason and others, the aerial is usually coupled rather loosely to the first tuned circuit, and has very little effect on its Q-factor.

Another factor affecting the selectivity of a circuit is the ratio of inductance to capacitance. In a parallel, or rejector, circuit, the larger the capacitance and smaller the inductance, the higher the selectivity. It would, therefore, seem expedient to tune with large values of capacitance and small ones of inductance, and this is done in special cases.

Unfortunately, in most applications of the circuit it is required to act as a high impedance and develop the largest possible voltages across its ends from some oscillatory current flowing through the circuit, or induced in it by coupling from another circuit. Thus it is evident that there are two conflicting requirements: to obtain a high impedance at resonance, the inductance must be large and the capacitance small, for the resonant impedance (or "dynamic resistance") is actually proportional to the inductance divided by the product of the capacitance and R.F. resistance of the circuit; whereas, for high selectivity, inductance should be small and capacitance large.

In a series, or acceptor, circuit, the opposite is true. Maximum selectivity calls for a high ratio of inductance to capacitance. Unfortunately, there is little application for this type of circuit in modern receivers.

It has been remarked that a too sharp and peaky resonance curve has undesirable effects on the quality of sound reproduction. Nevertheless, extremely high selectivity is an essential attribute of any receiver with pretensions to high sensitivity. The medium-wave broadcast band is crowded with stations working on frequencies a bare 9 kc/s apart in most instances, and to receive one of these clear of powerful neighbours demands a resonance curve with very steep sides, bearing in mind that the top must be sufficiently wide and flat to ensure a reasonably satisfactory standard of reproduction.

Such a curve cannot be obtained from a single circuit because the necessary steepness, in that case, would also mean a sharp peak, even were it possible to design a circuit with such selectivity as this. The only feasible method of getting the kind of curve required is to use a group of circuits through which the signal must pass in succession.

The first pair of the group may well be arranged to form a band-pass filter, and later ones may be coupled with radio- or intermediate-frequency amplifying valves. If still higher selectivity without loss of audio fidelity is wanted, then couplings between amplifying valves may be transformers with separately tuned primaries and secondaries, each transformer making up a band-pass filter. Set out in this fashion, an elaborate superheterodyne receiver may contain as many as seven or eight tuned circuits.

When a chain of tuned circuits is thus built up, the addition of each one steepens the sides of the over-all resonance curve; but if due care is taken with the coupling arrangements, a suitably broad and flat top can be maintained. With a sufficient number of circuits in the chain, selectivity becomes adequate to meet reasonable demands, and, with proper use of the band-pass principle, the quality of reproduction remains good enough to satisfy all except the most critical listeners.

The fact must be faced, however, that selectivity sufficiently good to deal successfully with station frequencies only 9 kc/s apart does involve sacrifices. The necessary resonance curve must show a sharp cut-off at about 4·5 kc/s on either side of the precise frequency; and this means that there will be attenuation of modulation frequencies higher than about 4,500 c/s.

Opinions differ somewhat as to the upper limit of audio frequencies necessary for really high fidelity reproduction, but it is certainly above
4,500 c/s. For this reason, some
the more elaborate receivers are pr
vided with an adjustment of some ki
for the band-pass coupling effects,
that the resonance curve can
widened when a strong station is bei
received. Gain being then compar
tively low, no interference is expe
enced from the weaker stations wor
ing on the channels to either sid

In conclusion, it must be added th
selectivity is affected to some degr
by the efficiency of screening in
receiver. If screening is poor, signa
may be induced directly into the lat
tuned circuits of a receiver; suc
signals are not subjected to the fu
selectivity and may spoil the perform
ance of the receiver. It is essentia
therefore, that screening should b
good, so that signals are able to trav
along only the intended paths.

When a poorly-screened receiver
used near to a powerful sender, th
radiation is then picked up direct o
the inductors and wiring of all th
tuned circuits, and may evade ever
precaution to keep it out. See BAND
PASS TUNING, DAMPING, RESONANC
TUNING.

SELENIUM CELL. An early form o
photocell in which the light-sensitiv
material was selenium. It is slow i
action and not very sensitive. It has
therefore, been replaced by th
caesium type of cell in a gas-filled bul
or in vacuo.

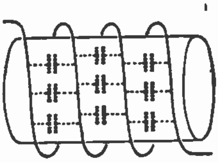
SELENIUM RECTIFIER. Metal rec
tifier in which the rectifying actio
takes place between the inner surfac
of a selenium coating and the surfac
of the iron with which it is in contact
A counter electrode exists to mak
contact with the selenium.

The selenium rectifier is similar i
its action to all metal rectifiers, but it
internal resistance is less, for a give
power-handling capacity, than that o
the copper-oxide rectifier. It has
however, a larger capacitance than ha
the copper-oxide type and is therefor
not so suitable as an electronic switc
when the frequency of the wave

passed through it is high. See COPPER-OXIDE RECTIFIER, METAL RECTIFIER, RECTIFIER INSTRUMENT, VOLTAGE-DOUBLER.

SELF-CAPACITANCE. Capacitance effect between parts of the same component or circuit. A common example is the capacitance between the turns of an inductor winding. Fig. 4 suggests this effect by showing dotted capacitors between turns.

Fig. 4. Capacitance between the turns of an inductor is an example of self-capacitance.



SELF-CAPACITY. Synonym for SELF-CAPACITANCE.

SELF-EXCITING OSCILLATOR. Oscillator in which grid-circuit excitation is obtained by means of the alternating current in the anode circuit.

SELF-EXCITING SENDER. Radio sender in which the frequency-determining oscillator generates the R.F. power.

SELF-HETERODYNE. Synonym for AUTOHETERODYNE.

SELF-INDUCTANCE. See INDUCTANCE.

SELF-INDUCTION. Process in which electromagnetic induction produces a voltage in the circuit in which the inducing current is already flowing; self-induction is the phenomenon which gives a circuit the property of inductance. See ELECTROMAGNETIC INDUCTION, INDUCTANCE.

SELF-OSCILLATING SENDER. See SELF-EXCITING SENDER.

SELF-RESTORING COHERER. Coherer in which the signal itself operates the tapper which re-sensitizes the filings (see COHERER). The term has also been applied to the LODGE-MUIRHEAD COHERER (q.v.).

SEMI-CIRCULAR ERROR. Error in a direction-finding system which reaches a maximum twice in 360 deg.

SENDER. Sending equipment for radiocommunication. The first commercial apparatus to be used for this purpose was the spark sender, a development from the induction-coil circuits on which the early experiments had been conducted. This sender radiated type B waves which were keyed in the long and short periods of a dash-and-dot code. The Morse code, already in use for telegraphic communication over wire circuits, was adopted.

Two other systems were introduced: the arc, and the high-frequency or Alexanderson alternator. Although experiments and demonstrations had been carried out on what are now known as the short-wave bands, the frequencies which were used for long-distance communication were generally at the low-frequency end of the spectrum, that is to say, on the kilometric waves.

This was due mainly to the low attenuation at these frequencies, together with the difficulty of producing higher frequencies with the arc and Alexanderson alternator systems. The potentialities of short waves as a medium for long-distance communication were not appreciated.

It was not until the introduction of the three-electrode valve, a device which was capable of generating, amplifying and detecting oscillations, that widespread applications in the use of senders began. Hitherto they had been employed almost exclusively for commercial purposes between high-power land stations for inter-continental communication, and also for ship-to-ship and ship-to-shore liaison.

With the inception of broadcasting, the use of radio senders for conveying entertainment represented a new function which has led to many developments, particularly with regard to methods of modulation.

The principal fields in which much research work in the design of senders has been carried out in the last twenty-five years have been in respect of: (1) the generation of stable radio frequencies; (2) the utilization of a wider range of radio frequencies; (3) the development of modulation systems, and (4) the use of progressively higher powers.

With increasing congestion of the bands of frequencies allocated to various services, it soon became obvious that a greater degree of stability of the carrier-wave frequency was very necessary. This was particularly noticeable on the medium-wave broadcasting band.

Many of the senders had simple oscillatory circuits in which positive feedback between anode and grid circuits was used to maintain the oscillations. The frequency was only approximately determined by the elements of the tuned circuits, and other factors, such as the variation of temperature, output loading and the D.C. operating voltages, were such as to cause random changes of the carrier frequency.

Thus it became necessary to treat the valves in the sender as R.F. amplifiers and to drive them from a low-power source of oscillations the frequency of which was stabilized.

One of the first methods was to use an electromechanical device called the tuning-fork oscillator. This consisted of an accurately pitched tuning fork in association with an oscillator valve. The fork vibrated at an audio frequency and the required radio frequency was obtained by the use of doubler amplifiers.

The tuning fork was enclosed in a thermostatically controlled oven and, to guard against variations of loading on the oscillator circuit, a buffer stage was placed between the oscillator and doubler stages. This scheme had the disadvantage that any large change of frequency involved the replacement of the fork by one tuned to a suitable sub-multiple of the carrier frequency.

Another method was to place all the tuning elements of a low-power oscillatory circuit in an oven the temperature of which was closely controlled. The supplies to the oscillator valve were stabilized. This method gave a relatively high degree of frequency stabilization, and is in common use today, particularly where rapid changes of frequency may be required.

A third method was to control the frequency of the oscillatory circuit by means of a plate cut from a quartz crystal. It was found that, by cutting the plate at certain angles with respect to the main axes of the crystal, a very low temperature-frequency coefficient could be obtained. The crystal, too, was enclosed in an oven; by using circuits in which any tendency to change of operating conditions caused little frequency drift, and by stabilizing power supplies, the crystal drive equipment now has a very high degree of stability.

As an instance, the B.B.C. has designed its own crystal-oscillator drive equipment which keeps its standard-frequency transmissions within the limits of plus or minus one part in a million. It is now common practice to use frequency-stabilized oscillators with frequency multipliers or dividers to obtain carrier frequencies up to at least 30 Mc/s.

In the years following 1900, the results to be expected on frequencies up to about 2 Mc/s became fairly well known, but the higher frequencies were comparatively neglected as they appeared to have no practical value. In the early 1920's, however, there were a few professional engineers engaged in experimenting on the frequencies above 2 Mc/s, but the high-power inter-continental communications were still using low radio frequencies.

The low-power senders operated by amateurs had been assigned to frequencies above 1·5 Mc/s, and it was largely due to the remarkable results obtained by them that attention was drawn to the possibilities of the short-wave band for long-distance communication.

Senders were built for use as telegraphy and telephony channels on frequencies ranging between about 1 and 20 Mc/s. Broadcasting on frequencies of this order soon followed.

It became necessary to design special valves for use at these frequencies, and many materials which were quite suitable for use in senders working at lower frequencies had to be rejected in favour of those which were found to have a low loss factor. In addition, the sender had to be designed so that rapid changes of frequency could be made in order to take advantage of the daily changes in propagation conditions. This resulted in the production of senders in which pre-set tuning circuits could be rapidly switched into the R.F. amplifiers.

The inauguration of a television service in 1936 brought another band of frequencies into use. The sender on the vision frequency of 45 Mc/s had to be capable of sending sideband frequencies up to about 2·5 Mc/s, that is, about 5 per cent of its carrier frequency. On medium waves, a sender radiating sound requires only about 1 to 1·5 per cent of its carrier frequency for the sidebands.

For short-distance point-to-point communication, senders operating on centimetric waves (above 300 Mc/s) are very often used. At frequencies of this order it becomes necessary to abandon the conventional valve-oscillator circuits, because of the transit-time effect (see TRANSIT TIME), and circuits such as the electronic oscillator and the cavity magnetron are used.

Several modulation systems are available, but that most generally used is amplitude modulation. The aim in this type of modulation is to vary the amplitude of a carrier wave so that it corresponds to the amplitude of the signals fed into the modulator circuit. Thus the modulation envelope of the carrier wave is a replica of the modulating signal wave form.

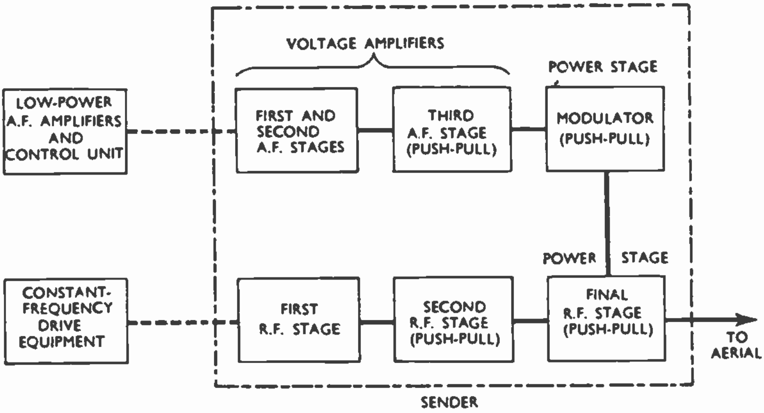


Fig. 5. Schematic diagram of a high-power broadcast sender using push-pull modulation; class-B valve operation with negative feedback is employed.

The main problems in designing the modulator stages are to keep attenuation distortion, amplitude distortion and harmonic distortion as low as possible whilst maintaining as high a conversion efficiency as possible. The conversion efficiency is the ratio of the A.C. (A.F. or R.F.) output to the D.C. power input.

Anode modulation, which may be applied to one of the R.F. amplifying stages of the sender, is commonly used.

If modulation is effected in one of the earlier stages of the R.F. chain, it is referred to as low-power modulation. The following R.F. stages must have their valves operated in a class-AB or B condition with a consequent reduction of the conversion efficiency. To offset this loss the valves and coupling components in the modulator stage are of low power rating and relatively cheap (see CLASS-AB VALVE OPERATION, CLASS-B VALVE OPERATION).

Alternatively, by operating the R.F. stages in class C and modulating the final amplifier, a high conversion efficiency is obtained from the R.F. amplifiers. This will necessitate the use of a series of audio-frequency amplifiers, culminating in the modulator stage in which high-power valves and coupling components will be needed (see CLASS-C VALVE OPERATION).

Another method which is of interest is series anode modulation. Two valves are connected in series, the filament of one valve being connected to the anode of the other. The audio signal is applied to the grid of one valve whilst the other is a driven R.F. amplifier. The H.T. is applied across the combination. Although this method has the merit of not requiring iron-cored coupling components such as A.F. inductors or transformers, the filament circuit of the valve operating above earth potential has to be highly insulated. Also, a high value of H.T. is required in order to provide suitable anode voltages for both valves.

Push-pull modulation circuits are employed in high-power broadcast senders, and a useful saving of power is effected by operating the modulator valves in a class-B condition and applying negative feedback to the modulation chain to cancel distortion. Fig. 5 shows the sequence of amplifiers in a modern high-power broadcast sender.

Among other methods of modulation are suppressor-grid modulation, which is used with pentodes, grid modulation and the single-sideband and quiescent-carrier systems. Apart from amplitude modulation, there are also phase, frequency and pulse modulation, the latter two systems finding application on frequencies above 30 Mc/s.

The progressive increase in the power radiated by senders has been accompanied by a demand for valves capable of dissipating larger anode powers. At first, the only valves available were little more than receiving valves and groups of them had to be paralleled in order to obtain an increase of power.

Larger glass-envelope valves and the silica valve were produced, and were capable of dissipating about 500 to 2,000 watts. Air-blast cooling was provided by conducting air from a blower and discharging it over the envelope of the valve.

These types were followed by the water-cooled valve, now in general use in modern high-power senders. This type of valve is of radically different design as, by the discovery of reliable methods of making a copper-to-glass seal, it has been possible to make the anode a part of the external surface of the valve. The anode of such a valve is cooled by placing it in a metal jacket through which water is circulated to carry the waste heat away. In addition, the points where filament connexions enter the valve are also cooled, by either air or water. When operating on short waves, it is necessary to cool the grid connexion by air blast.

The de-mountable valve is another type used to a limited extent on high-power senders. This valve is unique because it can be dismantled; but a drawback is the need for continuous evacuation by exhaust pump whilst it is in service.

Filament supplies to these large valves are by means of transformers to give an A.C. supply, or by motor generator to give a D.C. supply, the required filament voltages lying between about 15 and 35, according to the power rating, and currents between about 50 and 450 amperes.

Elaborate protection circuits are associated with water-cooled valves, as a loss of cooling leads to almost immediate destruction of the valve. The protection circuits are connected so as to trip the power supplies from the sender should a failure of cooling occur. Thermometers, meters for measuring the flow of cooling water, and air-pressure gauges are also fitted so as to give visual indication of the adequacy, or otherwise, of the cooling.

The modern sender may have anode voltages ranging up to 20,000 and, in order to provide protection for personnel, the high-voltage units are fitted with mechanical and electrical interlocks.

See AIRCRAFT RADIO EQUIPMENT, ARC SENDER, BROADCAST SENDER, RADAR, SHIP'S RADIO, SPARK SENDER, SPARK SENDING SYSTEM, TELEGRAPH SYSTEM, TELEVISION SENDER.

SENSE-FINDING. Process of resolving the 180-deg. ambiguity inherent in direction-finders which depend on the directive properties of loops and other spaced-aerial systems used to determine the direction of arrival of a radio wave. To take a simple example, when a loop-aerial is swung to locate the position of minimum signal the operator knows that it has been set broadside on to the wave, but he does not know from which side the wave is approaching.

In a practical case, the approximate direction will often be known and the operator has no difficulty in deciding which of the two alternative bearings to choose, but some form of sense-finding is provided on most direction-finders to deal with exceptional cases. In one generally used arrangement, sensing is done by combining an open aerial of some convenient type with the loop or other spaced-aerial system, so producing an asymmetric polar diagram which will indicate the true bearing. See CARDIOID DIAGRAM, DIRECTION-FINDER.

SENSITIVITY. Of a radio receiver; in general terms, the least input required to give a specified output. It is usually expressed as the least R.F. input modulated to a specified percentage by tone of a certain frequency which will give a particular signal-to-noise ratio at the output. See DEFLECTION SENSITIVITY, LOCAL SENSITIVITY, ZERO-LEVEL SENSITIVITY.

SEPARATELY HEATED CATHODE. Synonym for INDIRECTLY HEATED CATHODE.

SEPARATOR. Synonym for BUFFER STAGE.

SEPARATOR CIRCUIT. Synonym for BUFFER CIRCUIT.

SEPARATOR STAGE. Synonym for BUFFER STAGE.

SEPARATOR VALVE. Synonym for BUFFER VALVE.

SEQUENTIAL SCANNING. Process of scanning successively the elements of a scene to be televised, the signals thereby produced being sent in succession over a single channel. In sequential scanning the lines are traversed consecutively 1, 2, 3, etc. Interlaced scanning is, however, more widely used in practice because it has certain advantages over sequential systems. See INTERLACED SCANNING, SCANNING.

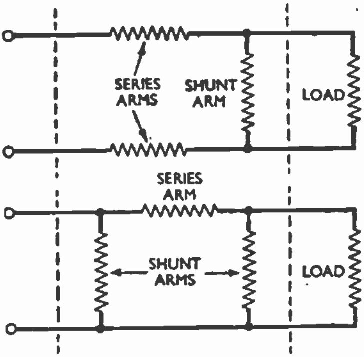


Fig. 6. Diagrams which clearly distinguish between the series arms and the shunt arms of a network.

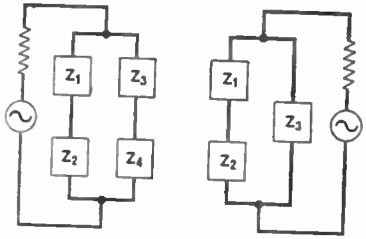


Fig. 7. Two simple examples of what is meant by series-parallel connexion.

SERIES ARM. Arm which carries the input current of a filter network less any current taken by the shunt arm or arms. Fig. 6 shows the distinction between series arms and shunt arms. See FILTER, FILTER SECTION, NETWORK, SHUNT ARM.

SERIES CONNEXION. Arrangement of circuit elements, components or conductors so that the same current flows in each. See PARALLEL CONNEXION.

SERIES-GAP CAPACITOR. Capacitor used in spark-sender circuits and connected in series with the spark gap and aerial inductor. See SPARK SENDER, SPARK SENDING SYSTEM.

SERIES-GAP CONDENSER. Synonym for SERIES-GAP CAPACITOR.

SERIES-PARALLEL CONNEXION. Connexion of a group of series-connected circuit elements or apparatus in parallel with other similar groups; or the connexion of such a group in parallel with a single circuit element or apparatus (Fig. 7). See PARALLEL CONNEXION, SERIES CONNEXION.

SERIES-PARALLEL SWITCH. Double-pole, two-way switch for connecting two components either in series or in parallel.

SERIES-VALVE ANODE MODULATOR. Amplitude modulator in which a valve is connected in series with the anode supply to a modulated amplifier. The modulating wave is applied between grid and cathode of the series valve. Thus the high-tension current to the modulated amplifier is varied as in anode modulation, but by a different circuit arrangement (Fig. 8). The system is used in broadcasting senders, notably that operated by the B.B.C. at Droitwich.

The advantages of the system are the same as those claimed for high-power modulation: namely, that the modulated wave need not be amplified, and, by contrast with anode modulation at high power, the modulating-wave amplifier need not handle more power than is required to vary the grid–cathode voltage of the series valve. This is obviously a very small power provided grid current does not flow. The insulation of the transformer producing the variations of grid–cathode potential of the series valve must be very good, however, since the cathode of the series valve is at a considerable positive potential with respect to earth. See ANODE MODULATOR, HIGH-POWER MODULATION, MODULATION.

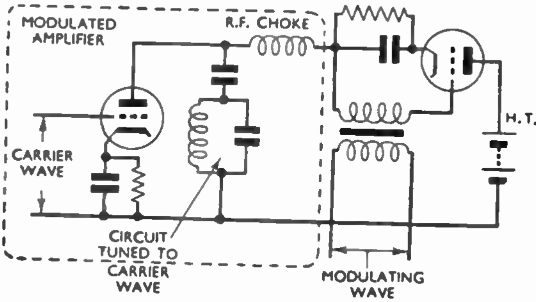
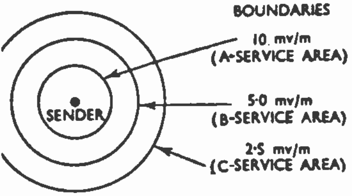


Fig. 8. Circuit of a series-valve anode modulator; the modulating wave is applied between the grid and cathode of the series valve.

RIES WINDING. Field winding ich is connected in series with the mature of a motor or generator.

RVICE AREA. Area surrounding a dio-broadcasting sender within which e field strength set up by the sender greater than a specified value. A



ig. 9. Formal diagram which shows e service-area boundaries of a broad-st sender; it assumes that radiation d attenuation are the same in all directions from the aerial.

ood broadcasting service allows any stener to receive programmes by day nd by night which can be clearly eard and easily tuned-in. These two onditions of good reception depend pon the SIGNAL-TO-NOISE RATIO (q.v.) eing high. In general terms, service is etter as the field set up by the sender greater; thus a service area may be efined as an area in which the signal as, or exceeds, a certain value.

There are three grades of service rea known as the A-, B- and C-grades. n A-service area is bounded by a ield contour of 10 mV per metre; a B, y 5 mV per metre; and a C-service rea is one in which the field is greater han 2·5 and less than mV per metre. These igures are arbitrary, nd were chosen long go. It has been maintained that 1 mV per meter is a satisfactory field for reception where the noise level is low.

The noise level is not constant; disregarding atmospherics, it is worst in industrial areas and least in rural or country areas. As a very general rule, A-service areas should be established in densely populated industrial areas, B-service areas in suburban districts and C-service areas in rural districts.

The formalized diagram (Fig. 9) shows circular boundaries of service areas, for which it is assumed that the radiation from the aerial is the same in all directions and that the attenuation of the ground wave is the same throughout the areas. The latter condition implies that the ground conductivity is everywhere constant. In practice, however, the radiation is not uniform, nor is the ground conductivity, and these two factors produce irregularly shaped service areas. A typical service-area map (Fig. 10) shows that the attenuation is least over water and greatest over mountainous country.

It is possible, in certain circumstances, to increase the field strength at some places at the expense of reducing it in others, by the use of directional aerials at the sender (Fig. 11). But the size of a service area is determined chiefly by the power of the sender and the frequency, or wavelength, of the

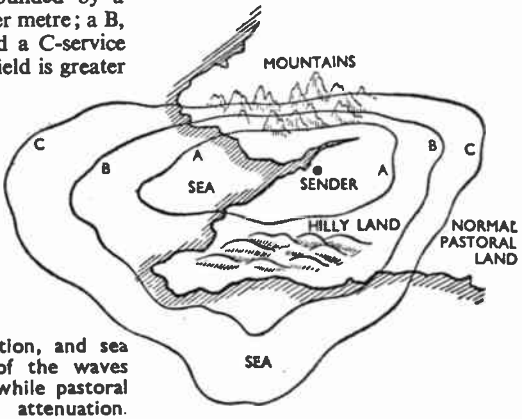


Fig. 10. Variations in he nature of the earth's surface affect he shape of service reas. Mountains ause the most attenuation, and sea he least attenuation, of the waves adiated from a sender, while pastoral land produces medium attenuation.

carrier wave. The higher the frequency of the carrier wave, the greater the attenuation over ground of given conductivity.

The size of a service area is proportional to the power radiated from the aerial. This means that a field-contour line will be established twice as far away from a given station if the power is increased to 2^2 (i.e. four times). The intensification of radiation by three times is tantamount to an apparent increase of power of 3^2 (i.e. nine times), in the direction of field intensification. See BROADCASTING, BROADCAST SENDER, WAVE PROPAGATION.

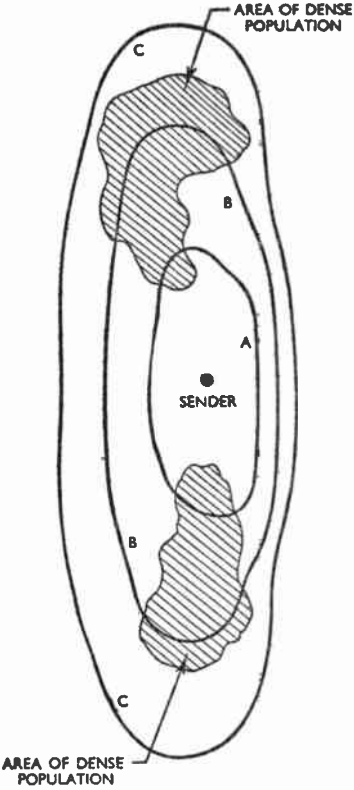


Fig. 11. Directional aerials may be used to extend the A-, B-, and C-service areas in certain directions to include populous districts and so to provide, with only one sender, better reception for a greater number of listeners.

SERVICE BAND. In radiocommunication, a specific band of carrier frequencies allotted to a particular branch of the radio service. See WAVE BAND.

SERVICING. Process of subjecting equipment to overhauls at regular intervals, whether or not it has developed specific faults. In order to obtain the most reliable service from an amplifier or a receiver which is in regular use, it should be withdrawn from service periodically and examined to detect the faults which inevitably develop with age. Such faults are valves with low mutual conductance, electrolytic capacitors with low capacitance and noisy volume controls.

Even though the performance of the apparatus is apparently quite normal, any components showing signs of age should be replaced since they may cause serious trouble before the next routine examination takes place. While the equipment is out of service, the opportunity should be taken to remove all dust and clean the chassis. Radio apparatus in general—and high-tension leads in particular—have a marked tendency to collect a considerable amount of dust.

The presence of ageing components in an amplifier or a receiver may be determined by means of measurement (see TESTING). If the equipment has specific faults, these may be traced according to the methods set out under FAULT-FINDING.

SET NOISE. Random noise at the output of amplifier or receiver, from causes within the amplifier, which fixes the limit of useful sensitivity. These causes are thermal-agitation voltage in circuits, and shot effect and flicker effect in valves. Avoidable noise, such as microphony and hum, may also be included. See NOISE FACTOR, SIGNAL-TO-NOISE RATIO.

SEVEN-ELECTRODE VALVE. Synonym for HEPTODE.

S.F.E.R.T. VOLUME INDICATOR. Instrument used for the measurement of comparative speech levels in telephone systems. S.F.E.R.T. are the initials of Système Fondamental Européen de Référence pour la Transmission Téléphonique, and indicate that the instrument has internationally agreed electrical and mechanical characteristics. It is calibrated in decibels with reference to a zero level of 6 milliwatts. See REFERENCE TELEPHONIC POWER.

SHARED-CHANNEL BROADCASTING. Broadcasting made by senders using the same, or nearly the same, carrier-wave frequency and transmitting the same programme. The shortage of available channels for use by broadcasting senders prompted the study and eventual use of a scheme whereby several senders, forming part of a national broadcasting system, use the same carrier-wave frequency. The result is of considerable benefit because each sender establishes service-area conditions around it, although the extent of the area is limited because of the sharing of a channel by two or more senders.

Two senders of equal power, transmitting waves of exactly the same frequency, will produce waves of approximately equal strength at points somewhere about halfway between the locations of the two senders. Depending upon the relative phase of the waves, the resulting field may be nearly zero; or nearly twice the strength of the field due to one. The relative phase of the waves will vary according to the geographical position at which the phase is compared. In other words, an interference pattern will be set up with nodes and antinodes. This interference pattern will change according to the frequency of the waves.

When two similar modulated waves are radiated, where the waves have much the same amplitude, there will be cancellation of some waves and an increase in the amplitude of others. The resulting wave is one in which sideband waves are reduced or increased in amplitude depending upon their frequency; the carrier wave is similarly made artificially greater or lesser in amplitude.

There is thus an intolerable distortion of the envelope of modulation, if two or more senders share the same channel, at places (Fig. 12) where the strengths of the radiated waves are comparable, and reception conditions will be bad even though the signal-to-noise ratio is large. On the other hand, if the field due to one sender is predominantly strong, the effect of the other will be negligible.

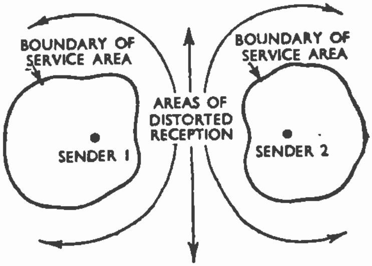


Fig. 12. In shared-channel broadcasting, even with perfect synchronization, there will be distorted reception in all areas other than those in which the field strength of the nearer sender is two to three times greater than that of the more distant sender.

The service areas of senders using the same carrier-wave frequency are limited by field contours at which the field due to the nearest station is so many times greater than the combined fields due to others. Obviously, if senders are located in the centre of dense population, good service is given to a large number of people and yet only one channel is used.

The extent of the service area depends upon the degree to which the carrier waves are maintained at the same frequency. If true synchronism is established, the service-area boundary is established when the field due to the nearer station is two to three times greater than the interfering field. If the senders are not phase-synchronized, but keep to the same mean frequency, the ratio is about five. If a difference of frequency less than, say, 30 c/s is maintained, the service-area boundary is that given by a field ten times the interfering field. See SERVICE AREA, SYNCHRONIZATION OF BROADCAST SENDERS.

SHARED-WAVELENGTH BROADCASTING. Synonym for SHARED-CHANNEL BROADCASTING.

SHARPNESS OF DIRECTIVITY. Extent to which the radiating or receiving efficiency of an aerial is concentrated in a particular direction, or within a particular solid angle. See DIRECTIVITY.

SHARPNESS OF TUNING. Relative degree to which a circuit or complete receiver responds selectively to its resonant frequency, and fails to respond to others differing from it. When sharpness is to be expressed in figures, it is commonly done by indicating the percentage of detuning needed to reduce the output from a given signal by some arbitrary amount such as 2 db.

SHIELD. Magnetic screen placed around electrical apparatus to protect it from electrostatic or electromagnetic interference (see SCREEN). When in reference to a cathode-ray tube, see MODULATOR ELECTRODE.

SHIELDED PAIR. Synonym for SCREENED PAIR.

SHIELD-GRID VALVE. Synonym for SCREEN-GRID VALVE. See TETRODE.

SHIELDING. Synonym for SCREENING.

SHIFT. Abbreviation for PHASE-SHIFT.

SHIP'S RADIO. Radio apparatus installed on board ship for the purposes of (1) safety of life at sea, (2) commercial communications, and (3) aids to navigation.

Since its inception, one of the most important applications of radio communication has been the installation of sending and receiving apparatus on ships. It provides the ship with a ready means of calling assistance when in distress, enables the owners to communicate instructions to the master and, by means of direction-finding apparatus (see DIRECTION-FINDER, DIRECTION-FINDING), gives valuable aid to navigation.

Other advantages are: telegraphic or telephonic communication between passengers and crew with their friends on shore, weather reports and news service; and operational instructions in naval and fishing services.

For safety of life at sea, the minimum apparatus to be carried by merchant ships is laid down by inter-

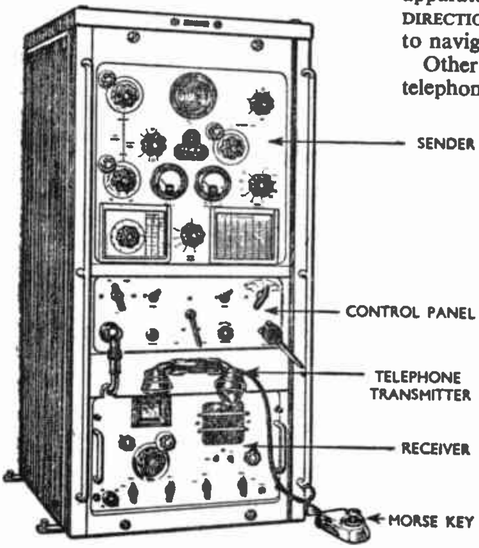


Fig. 13. Modern example of ship's radio equipment, this battery-operated Marconi combined sender and receiver for telephony and telegraphy was designed primarily for use in trawlers and coastal vessels.

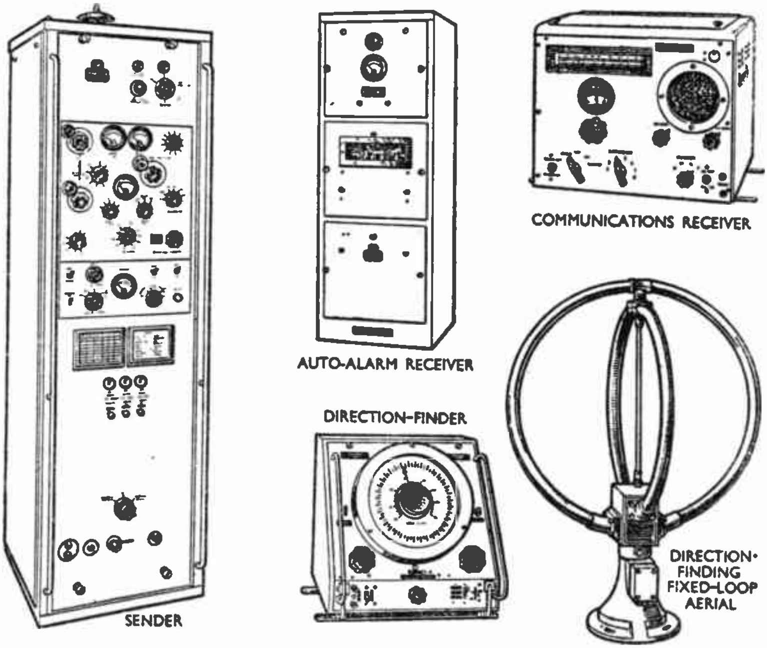


Fig. 14. Group of Marconi marine equipments, which constitutes a medium-power adio installation for an ocean-going vessel. The sender covers nine marine high-frequency bands in addition to the medium-frequency band.

national convention. The essential requirement is that every ship above a certain tonnage shall have a sending-and-receiving range of at least 100 miles, and that emergency apparatus shall be carried which is independent f the ship's main electrical installa-ion.

For many years the majority of hips' radio installations consisted of a park sender (see SPARK SENDING YSTEM) and a crystal receiver. Mini-num sending power was ¼ kW, the verage being 1½ kW. The average vorking range was 200 miles by day nd 500 miles by night (see DIRECT AY, IONOSPHERIC RAY). With the evelopment of senders and receivers sing valves, the spark sender and rystal receiver have gradually fallen into disuse and are now almost obsolete.

For the purposes of safety of life at sea, the ship's operating wavelength is 600 metres, and a constant watch for distress signals is maintained on this wavelength by all large vessels, and by land stations around the coasts of maritime countries. Where valve senders are employed for safety communications, type A2 waves are invariably used, since these can be received on crystal receivers.

For long-distance communication, both long and short wave bands are used with type A0 waves (see WAVE BAND).

The most important aids to navigation are the direction-finder and the depth-sounder (see DEPTH-SOUNDING).

By means of the former, a ship is able to obtain its bearing from any shore station within a range of approximately 100 miles to an accuracy of one or two degrees and, by taking bearing from two or more such stations in quick succession, it can obtain its actual position. For obvious reasons, the depth-sounder is invaluable when navigating shallow water.

The radio equipment installed on modern ships varies extensively with the size of vessel and the trading route over which it operates. Thus, a small compact unit, comprising a sender and receiver (Fig. 13), provides adequate service for a trawler or coasting vessel.

The apparatus shown is designed for radio telegraphy or radio telephony, and can be tuned instantly and precisely to any one of seven wavelengths. When used for telephony only, it can be operated without skilled personnel, and there are arrangements for remote control. Such apparatus is used extensively for communication between trawlers and their shore base.

For ocean-going vessels, a longer radio range is necessary. This involves the use of equipment giving greater power and occupying more space. A typical installation is illustrated in Fig. 14.

The medium-power sender operates on either medium or short waves and can be used for type A0 (C.W.) or type A2 (M.C.W. or I.C.W.) transmission (see TYPE A0 WAVE, TYPE A2 WAVE). The medium-wave band extends from 365 to 540 kc/s (550–820 metres), there being pre-selected operating frequencies. The 500-kc/s frequency (600-metre wavelength) can be switched to either a main or emergency aerial.

In addition, there is provision for the use of 30 crystal-controlled high-frequency bands covering a range of 3–23·0 Mc/s. The aerial current in the medium-wave band is approximately 5 amperes, and on the short-wave band the radiated power is approximately 100 watts.

Power supply may be taken from either generated A.C. or D.C. or from emergency batteries; there is, therefore, no necessity for an emergency sender. The tuning controls are simplified, precise frequencies being selected by click switching.

The aerial arrangements for a ship's sender must inevitably depend upon the distance between masts, the disposition of superstructure, etc. In the sender illustrated in Fig. 14, matching circuits are provided for both medium- and high-frequency bands, the circuits being variable to suit different aerial characteristics.

The communications receiver shown in Fig. 14 has a frequency range of 15 kc/s—25 Mc/s (20,000—12 metres) thus covering the whole range required in marine communication. Like the sender, it can be operated from the ship's mains or from an emergency battery.

The automatic-alarm receiver is permanently tuned to 600 metres for the reception of distress signals. For the purpose of automatic alarm, a special international distress signal is used; it comprises twelve four-second dashes with a one-second interruption between dashes.

The output of the receiver operates an electromechanical device which, on the reception of the distress signal described, causes alarm bells to ring at strategic points on the ship. By this means, the attention of the ship's radio officer is at once called to the emergency and a listening watch kept on the communications receiver. The selector device is critically adjusted to prevent false alarms from combinations of signals which may resemble the twelve-dash group.

The direction-finding instrument indicated in Fig. 14 operates on the Bellini-Tosi system (see BELLINI-TOSI AERIAL). The fixed loops are enclosed in screened tubing and are normally installed on an upper deck forward of the funnel and clear of the superstructure. Where superstructure is interposed between the aerial and the radio beacon, the signal is deflected and a false reading given. To compensate for such errors, however, each direction-finder is calibrated after installation.

The instrument incorporates both receiver and goniometer and, with accurate calibration, is capable of obtaining bearings correct to ± 1 deg. up to a 300-mile range.

In addition to the apparatus shown in Fig. 14, many ships carry depth-recording apparatus (see DEPTH-SOUNDING), public-address equipment and radar. See RADIOGONIOMETER, RADIO RECEIVER, RADIO TELEGRAPHY, RADIO TELEPHONY, SENDER.

SHOCK EXCITATION. Excitation of transient currents at natural resonant frequency in an oscillatory system by the sudden application or removal of an e.m.f. from some external source and of different frequency.

SHORT-CIRCUIT ADMITTANCE. Reciprocal of SHORT-CIRCUIT IMPEDANCE (q.v.).

SHORT-CIRCUIT IMPEDANCE. Impedance of a network or transmission line at the input, or sending-end, terminals when the output, or receiving-end, terminals are short-circuited. The characteristic impedance of a network or transmission line is given by the square root of the product of the short-circuit and open-circuit impedances. See CHARACTERISTIC IMPEDANCE, OPEN-CIRCUIT IMPEDANCE.

SHORT WAVE. Synonym for HIGH-FREQUENCY WAVE.

SHOT EFFECT. Variations in the space current of a valve caused by variations in the number of electrons carrying the current between electrodes. The current passing between valve electrodes is carried by millions of electrons accelerated from the space charge. Even if the electrode voltages are constant, the number of electrons arriving at an electrode varies from instant to instant. Thus the space current must also change, however slightly, from instant to instant. A valve amplifier with a large gain will amplify the variations of current of a valve in the input stage. These variations are irregular and a loudspeaker or telephone will give a sound which resembles shot striking a hard surface; hence the term "shot effect." The effect is less pronounced when the electrons are drawn from a space charge, which levels out the variations.

A noise similar to shot effect is SCHOTTKY EFFECT (q.v.). There is also FLICKER EFFECT (q.v.). See also NOISE, THERMAL-AGITATION VOLTAGE.

SHOT NOISE. Synonym for SHOT EFFECT.

SHROUD. Extension to metal portions of electrical devices, such as valves, which are subjected to high voltages; the purpose of the shroud is to avoid excessive stress on the insulating material.

SHUNT. Circuit in parallel with another so that current is "shunted" from one circuit to another. The term "in shunt" can be synonymous with "in parallel," but there is often a suggestion of by-passing a current to earth when the former term is used. See SHUNT ARM, SHUNT-EXCITED AERIAL, SHUNT-FIELD RELAY.

SHUNT ARM. Circuit formed between the non-earthed side of an unbalanced quadripole (sometimes called the "line") and the earth connexion. See FILTER SECTION, QUADRIPOLE, SERIES ARM.

SHUNT-EXCITED AERIAL. Vertical aerial or radiator earthed at one end and supplied with radio-frequency power at a point along its length. At medium frequencies, vertical quarter-wave aerials are usually built in the form of a lattice-work tower to give strength and rigidity. The tower may be several hundred feet high and constitutes the aerial itself. The shunt method of exciting the aerial is illustrated in Fig. 15.

It can be considered as consisting of an aerial *a–b*, in which the exciting voltage between *b* and *e* (earth) is developed across the section *b–c* of a single-turn inductance *b–c–e–d*, formed by the inclined wire *b–d*, the aerial section *b–c*, and the earth-return system *c–e*. The inclined wire is connected to the aerial-tower, and the resistance, as viewed from the feeder looking towards the aerial, is equal to the characteristic impedance of the feeder line. The reactive component of the impedance at point *e* is always inductive and may be balanced out by the capacitor *C*. Point *b* is usually about one-fifth of the tower height. The shunt method of exciting vertical aerials is particularly useful when concentric feeder lines are to be used. See AERIAL, QUARTER-WAVE AERIAL.

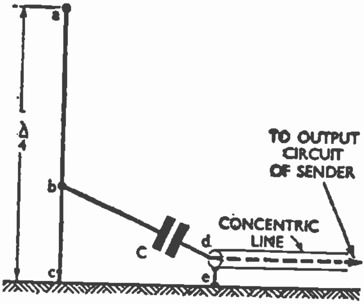


Fig. 15. Diagrammatic representation of a shunt-excited earthed aerial-system with concentric feeder line.

SHUNT-FIELD RELAY. Form of polarized relay having a second electromagnet for polarizing purposes instead of a permanent magnet.

SHUNT WINDING. Field winding which is connected in parallel with the armature of a motor or generator.

SIDEBAND. Band of frequencies containing sideband waves produced by the modulation of a carrier wave. Sidebands with frequencies higher than that of the carrier wave are known as upper sidebands; those with frequencies lower than that of the carrier wave are known as lower sidebands. See ASYMMETRICAL SIDEBAND MODULATION, LOWER SIDEBAND, SIDEBAND WAVE, SINGLE-SIDEBAND MODULATION, UPPER SIDEBAND.

SIDEBAND FREQUENCY. Frequency of one of the new components produced when a carrier wave is amplitude-modulated by a sinusoidal wave. See AMPLITUDE MODULATION, SIDEBAND.

SIDEBAND INTERFERENCE. Interference due to the sidebands of an unwanted transmission, as distinct from its carrier wave. From the character of its sound, it is sometimes called "monkey chatter" or sideband "splash." See INTERFERENCE, SIDEBAND.

SIDEBAND SHRIEK. Effect peculiar to very selective receivers with automatic gain-control and resulting in very distorted reproduction when the receiver is slightly mistuned. When the A.G.C. voltage is obtained from a point such as the detector anode which follows a number of highly selective tuned circuits, even a small amount of mistuning causes an appreciable fall in A.G.C. voltage and a corresponding increase in gain. Thus the sideband to which the receiver is now tuned is subjected to greater gain than the carrier and remoter sidebands, resulting in the distorted reproduction referred to.

The remedy for this is to derive the A.G.C. voltage from a point earlier in the amplifying chain, for example, from the anode of the final I.F. amplifier, which follows less tuned circuits. See AUTOMATIC GAIN-CONTROL, INTERMEDIATE-FREQUENCY TRANSFORMER.

SIDEBAND SPLASH. Synonym for SIDEBAND INTERFERENCE.

SIDEBAND WAVE. Wave resulting from modulation and having a frequency which is different from, but related to, the frequencies of the carrier and modulating waves (see MODULATION, MODULATOR). The fact that modulation produces sideband waves is all-important when considering carrier-wave transmission in particular, and communication technology in general.

An amplitude-modulated wave is one in which the amplitude of the carrier wave rises above its mean value and falls below it in a manner determined by the wave form of the modulating signal. An amplitude-modulated wave with sinusoidal modulation can be obtained by combining with an unmodulated carrier wave two additional unmodulated waves, known as sideband waves, both of the same amplitude. The frequency of the two sideband waves is given by $f_c + f_m$ and $f_c - f_m$, where f_c is the carrier frequency and f_m is the modulating frequency.

The amplitude of the sideband waves is directly proportional to the amplitude of the modulating wave; for 100 per cent modulation by a sinusoidal wave form, each sideband wave has an amplitude equal to one-half of the carrier wave. If the modulating wave has a complex form, there is, for each component present in it, a pair of corresponding sidebands, their amplitude being directly proportional to the amplitude of the component.

A frequency-modulated or a pulse-modulated wave can also be synthesized by adding pairs of sidebands of suitable frequency and amplitude to the carrier wave, but for a sinusoidal modulating wave there are many pairs of sidebands (excepting amplitude modulation, for which, under the same circumstances, there is only a single pair of sidebands). These numerous pairs are symmetrically disposed about the carrier wave in frequency, and the frequency difference between sideband waves and carrier wave is an integral multiple of the modulating frequency.

The foregoing is not a mathematical conception; the sideband waves are, in fact, physical waves and one or the other can be selected by a filter with the required characteristics from the carrier wave and the other sideband wave of the pair (see FREQUENCY-CHANGING).

Mathematical analysis proves that there is, in theory, an infinite number of sideband waves in frequency and phase modulation, but those far removed in frequency from the carrier are of such small amplitude that they can be filtered out without introducing appreciable distortion.

It is obviously impossible to send intelligence by carrier-wave transmission unless a free channel is provided to accommodate the sideband waves. The sideband—that is, the frequency band occupied by sideband waves—is much greater in phase and frequency modulation than in amplitude modulation. That is why, in the former systems, a high carrier frequency must be used. Nevertheless, the advantages claimed for frequency and phase modulation as against amplitude modulation often miss the concomitant disadvantages of the wider sideband. Also, as frequency modulation systems must use very high-frequency carrier waves, and amplitude-modulation systems generally use medium-frequency waves, and because very high-frequency carrier-wave broadcasting has notable advantages, it would appear that those who claim the superiority of frequency modulation are claiming only the advantages of very high-frequency carrier waves. See MODULATION, SIDEBAND.

SIDE CIRCUIT. Synonym for SHUNT.

SIDE FREQUENCY. See SIDEBAND FREQUENCY.

SIDETONE. In a two-way communication system, the reproduction of the signals transmitted by the local sender in the earphones or loudspeaker used to receive signals from the distant sender. Telephone users hear their own speech when talking over the system to another person; this reproduction is called sidetone. The loudness of the sidetone is determined by the adjustment of the hybrid coil in the instrument, and is, in fact, an effect due to slight unbalance of the hybrid coil. Some sidetone is usually present, whether duplex or simplex systems are in use. See HYBRID COIL, RADIO TELEPHONY.

SIDE WAVE. See SIDEBAND WAVE.

SIGNAL. Characteristic of a complex wave representing intelligence conveyed through a transmission system or the complex wave itself. The term is widely and variously used. Thus an operator of a commercial radio-receiving station may say that signals are strong, weak or fading; he refers to what he hears as signals. In another sense, a description of a circuit may say that "the signals are applied between" certain terminals.

In telegraphy, the reproductions of dots and dashes on a tape by an inker are called signals; "the signals are badly shaped," means that the tape recording is difficult to decipher. In the term signal-to-noise ratio, the signal is that part of the sound received which is required to be heard, as distinct from the unwanted sounds which may spoil clear reception. Again, a sender is said to "send out signals" and a receiver to "receive signals."

SIGNAL GENERATOR. Apparatus for producing a voltage or current of known wave form, amplitude and frequency. The wave form is generally sinusoidal; the amplitude and frequency are usually variable over a certain range. For the testing and alignment of receivers, signal generators giving modulated waves are available.

SIGNAL PLATE. Synonym for MOSAIC ELECTRODE.

SIGNAL RECTIFIER. See DETECTION, DETECTOR.

SIGNAL-SHAPING NETWORK. Network (in telegraphy) designed to improve the shape of the code units recorded upon a tape or otherwise. Code signals consist of rectangular waves of different duration, that is to say, rectangular pulses. Such pulses are made up of sinusoidal waves of different, harmonically related frequencies (see FOURIER ANALYSIS). A transmission line may seriously attenuate the higher frequencies, so that the pulse at the receiving end, composed as it is of the lower-frequency sinusoids. becomes rounded.

Any network which attenuates the lower frequencies in the pulse in favour of the higher tends to improve the shape of the pulse; such a network is called a signal-shaping network. It should be noted that a quick-acting relay tends to shape a pulse into a square form, but its efficiency increases as the pulse becomes squarer. See MORSE CODE, TELEGRAPH SYSTEM.

SIGNAL-TO-NOISE RATIO. Ratio of the power in a received signal to the power in waves which mask or interfere with the received signal. The efficiency of a communication system is, in the final analysis, determined by the signal-to-noise ratio at the receiver.

In the early days of radio, before the invention of the valve, the strength of the signals available to energize a transducer such as an earphone or Morse-printer was determined by the strength and the length of the waves sent out by the sender. Short waves, no matter what the power of the sender, were too feeble to energize a transducer for long-distance communication. Thus longer and longer waves were used to cover greater distances because the longer the wave, the stronger were the received signals.

The difficulty was that reception was frequently spoiled by atmospheric interference. This was often so strong as to make reception of these long waves impossible. Thus radio was but small use for world communication; it was chiefly used on ships for communication with other ships and the land.

The invention of the valve provided receivers with the power to amplify signals; but this facility was of very little value practically, because the valves amplified the atmospherics or noise equally with the wanted signals. Thus, in spite of the improved amplification of the received signals, the signal-to-noise ratio was as low as ever, and still prevented efficient communication by long waves over world distances.

Atmospheric interference decreases

as the receiver is tuned to a higher frequency; thus a valve amplifier may be used to improve the intelligibility of short-wave signals, because the noise is so much less in the short-wave band that it is almost negligible.

Thus radio gained a new lease of life as a means of world communication when short-wave signalling became possible. The use of the valve on the one hand, and the fact that a high signal-to-noise ratio was obtainable by use of short waves on the other, were responsible for a revolution. If the signal-to-noise ratio had been small, whatever the wavelength, then in spite of the introduction of the valve the use of radio for long-distance communication would have been as restricted now as it was thirty years ago.

This example is one among a vast number. Broadcasting is of no interest if the reproduction is masked by noise; the signal-to-noise ratio is the determining factor of good service. Noise may interfere with a telephone conversation, spoil a television picture or mar a facsimile reproduction; and, in fact, such services are of value only if the signal-to-noise ratio is satisfactory.

It is now clear that different systems of transmission give effectively different signal-to-noise ratios—an important aspect of the subject. As a generalization, if noise is solely due to the varying amplitude of waves, a frequency-modulated receiver would not reproduce noise at all and would reproduce only the frequency-modulated signal. Frequency-modulation does, in fact, score in respect of signal-to-noise ratio.

Pulse-code modulation systems give a signal-to-noise ratio tens of decibels greater than ordinary amplitude-modulation systems; the end of this century may mark the end of the trunk telephone cables and their replacement by radio links using pulse modulation and centimetric waves. See CARRIER-WAVE TRANSMISSION, FREQUENCY MODULATION, PULSE MODULATION, RADIO TELEGRAPHY, RADIO TELEPHONY, SERVICE AREA, TRANSMISSION.

SIGNAL VELOCITY. See PHASE VELOCITY, WAVE VELOCITY.

SILICA VALVE. Valve with a bulb made of silica glass. Silica glass can be raised to a higher temperature than can ordinary glass without fear of damage, thus the silica valve may be operated at higher temperatures. In some cases, air is blown on to the bulb to assist cooling. Silica valves are designed for rated anode dissipations in the 3–7-kW range. See ANODE DISSIPATION, COOLED VALVE.

SIMPLEX OPERATION. In telecommunication, a method of working in which communication between two stations takes place in one direction at a time. See SIMPLEX SYSTEM.

SIMPLEX SYSTEM. In telegraphy, a system in which the circuit is arranged for transmission in one direction at a time. If two such systems are worked conjointly, each transmitting in opposite directions, the system is called a two-way simplex.

SIMULTANEOUS BROADCASTING. Term describing the conditions when two or more senders radiate the same programme, the necessary linking together of the senders being made by telephone lines. The output of a single microphone is taken through local and trunk telephone lines and is distributed, via control rooms, to a number of senders (Fig. 51 on page 124).

Thus an announcer in London, reading the news, is clearly heard by listeners throughout England from their local station. Without simultaneous broadcasting, the news would have to be read by different announcers in different studios to enable the majority of listeners to hear it in service-area conditions. This was done, *circa* 1922–23, before the trunk-line system was adopted for broadcasting.

The lines that link the senders together run along the same routes as those used for the normal trunk-line traffic of the public-telephone system. Such lines normally have a cut-off around 3–4 kc/s and are not therefore suitable to carry high-fidelity transmissions having a frequency range of from 50 to about 8,000 c/s. Thus, for the special purposes of broadcasting, certain trunk lines are treated to give the wider transmission band, and the repeaters are designed for a wider band response. By the application of well-known principles, it is possible to get lines giving a flat response up to the higher audio frequencies, even though the lines are hundreds and (in America) thousands of miles long. See BROADCASTING, CONTROL ROOM, EQUALIZER, TRANSMISSION LINE.

SINE CURVE. Synonym for SINE GRAPH.

SINE FUNCTION. Function related to a quantity and equal to the sine of the angle which represents that quantity. For example, the current or voltage of an alternating supply is a sine function of the angle which represents the particular instant in the cycle at which the current or voltage is to be specified.

SINE GRAPH. Graph representing a quantity which is proportional to the sine of the angle representing another quantity. An example is the graph representing an alternating current or voltage; in this the current or voltage values are proportional to the sine of the angle which specifies each point in the cycle. See PHASE ANGLE.

SINE WAVE. Wave having the form of a SINE GRAPH (q.v.).

SINGING. Undesired self-oscillation caused by excessive positive feedback. The greater the gain and the higher the frequency, the greater is the difficulty in preventing an amplifier from singing. The term is used mainly in telephony; in other branches it is known as spurious or parasitic oscillation, or instability. See HOWLING, PARASITIC OSCILLATION.

SINGING PATH. Circuit path which permits oscillation or singing to take place in a system in which there is reflection. See REFLECTION.

SINGING POINT. In general, the maximum gain which a two-wire repeater can have before oscillation occurs. Consider the two-way repeater circuit in Fig. 16. If the lines are accurately balanced by their respective balancing networks, and if the hybrid coils are also accurately balanced, there can be no transfer of power from the output of A_1 to the input of A_2, nor from the output of A_2 to the input of A_1, and oscillation is impossible no matter what the gains of A_1 and A_2. In practice, however, owing to inevitable unbalance, this transfer of power from the output of one amplifier to the

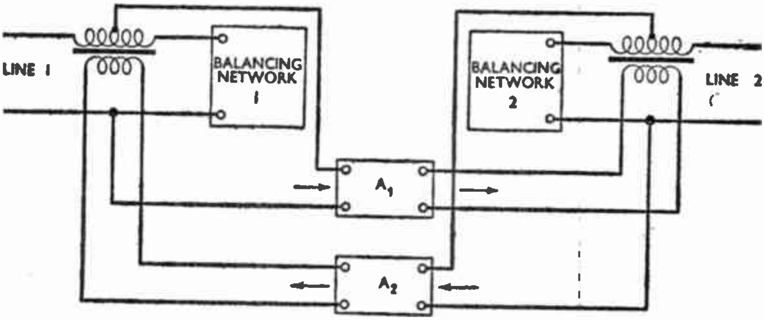


Fig. 16. Two-wire repeater circuit; the singing point may be measured by the maximum gain that the repeater can have without oscillation when one hybrid coil is terminated by the line on one side and the balancing network on the other, while the second coil is terminated by 600 ohms and an open circuit.

input of the other can occur, and oscillation results unless the gain of the amplifiers is limited to a certain value. This value is the singing point. The singing point is usually measured by the maximum gain that the repeater can have without oscillation when one hybrid coil is terminated by the line on one side and the balancing network on the other, while the second coil is terminated by 600 ohms and an open circuit. See SINGING, SINGING PATH.

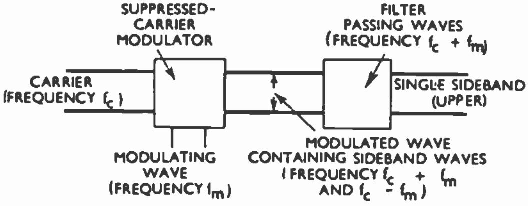


Fig. 17. Single-sideband modulation in which the filter passes only the upper-sideband waves. The filter may instead be used to transmit waves of frequency $f_c - f_m$ to produce a modulated wave containing lower-sideband waves.

SINGING SPARK SYSTEM. Spark system, used in radio telegraphy, in which the spark discharges occur at regular intervals and at such frequency that the signals heard at the receiving point have a musical note.

SINGING-SUPPRESSOR. Device used in telephone systems for preventing oscillation (and, incidentally, echo) in repeatered circuits. In the absence of speech currents the device introduces losses into one or both directions of transmission to prevent oscillation; when speech currents are present they operate the suppressor, which removes the loss from the forward transmission path and maintains or increases the loss in the opposite direction of transmission. See SINGING POINT.

SINGLE CHANNEL. Transmission system carrying only one communication channel.

SINGLE-CURRENT SYSTEM. Telegraph system in which signals are transmitted by means of unidirectional currents.

SINGLE-LAYER WINDING. Method of winding a coil, usually on a cylindrical former, in which the turns of wire are laid side by side to form a layer of close turns. It is commonly employed in inductors and transformers for use at the higher radio frequencies.

SINGLE-NEEDLE SYSTEM. Telegraph system in which the transmitted signals are indicated at the receiver by a deflection of a needle to the right or left.

SINGLE-PHASE RECTIFIER CIRCUIT. Circuit suitable for converting electric power from alternating-current to direct-current form, the input to the device being in single-phase. The term is used when it is necessary to differentiate between circuits used for single-phase and polyphase rectification. See MAINS UNIT, POLYPHASE-RECTIFIER CIRCUIT.

SINGLE-PIVOT INSTRUMENT. Instrument which has its moving part mounted on a single pivot placed at the centre of gravity of the moving part. See MEASURING INSTRUMENTS.

SINGLE-POLE SWITCH. Switch for making and breaking only one path of a circuit. See SWITCH.

SINGLE-SIDEBAND MODULATION. Generation of a modulated wave in which the carrier wave and all the lower sidebands, or the carrier wave and all the upper sidebands, are suppressed. The first process in single-sideband modulation is to use a suppressed-carrier modulator. The output contains sideband waves, one group of which has a higher, and the other a lower, frequency than the carrier wave. A filter is used to separate one group of sideband waves and suppress the other, as shown in Fig. 17.

Modulation must be performed at a low carrier frequency in order that a practical filter may have a sharp enough cut-off to separate the groups of sideband waves. The resulting modulated wave may be frequency-changed to a higher frequency for transmission. The carrier wave of the modulator might well be a few thousand cycles per second in frequency, as, in carrier-wave transmission over line wires, a frequency of tens or hundreds of kilocycles per second is added after one sideband has been removed. In practice, the use of filters prevents the transmission and reproduction of the lower-frequency components of the audio spectrum, as the reproduced modulating wave does not contain waves of a frequency much lower than 300 c/s. See FILTER, GROUP MODULATION, SUPPRESSED-CARRIER MODULATION.

SINGLE-SIDEBAND SYSTEM. System of radio transmission in which one sideband is wholly or partially suppressed. See SINGLE-SIDEBAND MODULATION.

SINGLE-SIDEBAND TRANSMISSION. See SINGLE-SIDEBAND MODULATION.

SINGLE-WAVE RECTIFICATION. Synonym for HALF-WAVE RECTIFICATION.

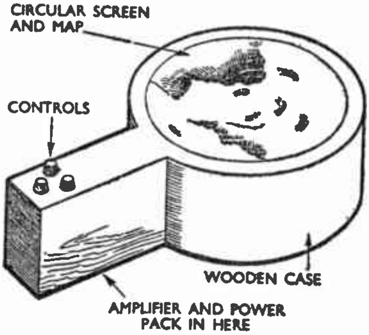


Fig. 18. Skiatron, in which the image on a small but brilliant cathode-ray tube is enlarged and reflected on to a large horizontal screen.

SINGLE-WIRE FEEDER. Feeder, usually used as a connexion between a sender and an aerial, in which the circuit is completed by an earth return. See FEEDER.

SINUSOID. Curve having the general shape of a SINE GRAPH (q.v.).

SITE ERROR. Error in direction-finding caused by peculiarities of the site of the equipment. The error may be due to reflections from neighbouring objects, irregularities in underlying strata, and the like.

SIX-ELECTRODE VALVE. Synonym for HEXODE.

SKIATRON. Name given to a cathode-ray tube providing a dark trace which can be projected on to a ground-glass screen. The skiatron was used a great deal in the latter stage of the Second World War to enable radar plots to be projected on to large maps (each about 2 ft. 6 in. in diameter) so that a number of aircraft and naval controllers could see plots simultaneously.

The cathode-ray tube is housed in a wooden cabinet, together with a lens system which enables the end of the tube (about 4 in. in diameter and illuminated by powerful lamps) to be enlarged to 2 ft. 6 in. in diameter. The enlargement is thrown on to the underside of a horizontal glass screen on which is placed a translucent map of the area under survey as indicated in Fig. 18. The light from the lamps is bright enough to show clearly the revolving trace of the skiatron tube (P.P.I. system—see RADAR).

Owing to the high wattages used to achieve the necessary intense illumination, considerable heat is generated within the cabinet of the equipment, and careful ventilation of the system is necessary. A similar system is under investigation for home television projection.

SKIN EFFECT. Phenomenon in which high-frequency currents become more closely confined to the surface of a conductor as the frequency becomes higher (see DEPTH OF PENETRATION).

Skin effect is of importance in the design of high-frequency circuits, especially of inductors; it is so pronounced at the higher frequencies that a metal tube is just as good a conductor as a solid wire or rod of the same surface area.

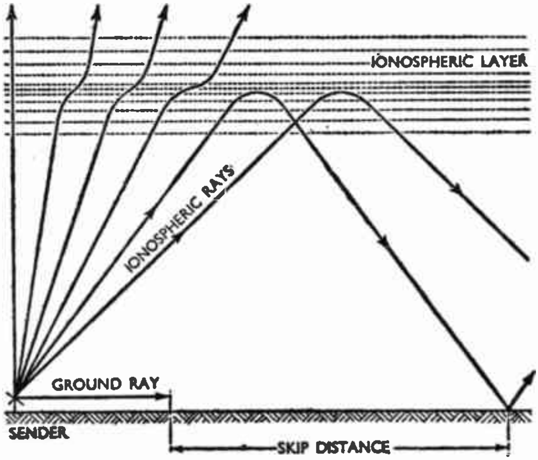


Fig. 19. Diagram showing that the skip distance is the distance between the point at which the ground ray is completely absorbed and the point at which the first ray is returned to earth by reflection from the ionosphere.

SKIP DISTANCE. That distance between the point where the ground ray is completely absorbed and the point where the first ionospheric ray is reflected to earth (Fig. 19). Energy radiated horizontally from a short-wave sending aerial is quickly absorbed due to heavy earth losses; the higher the frequency the more quickly is absorption completed. Energy radiated towards the ionosphere at an angle within the critical angle of the F-layer will be reflected, and will return to earth.

Between the distance at which the ground ray becomes negligible and the distance at which the first ionospheric ray returns to earth, there is a zone where no signals are received. This zone is known as the skip zone, and the distance across it is the skip distance.

In practice, however, very low-level signals may be received in the skip zone because of the process known as scattering.

The skip distance will obviously depend upon the angle of elevation of the ionospheric rays, and to ensure reflection from the F-layer this angle has to be reduced as the frequency is increased. If the angle is too great, the ray enters the F-layer too sharply and is not reflected. For longer high-frequency waves of about 100 metres there may not be any skip distance at all; but with wavelengths of 12 metres the skip distance may be several thousand miles. This explains why the B.B.C. short-wave transmissions are not normally receivable in the British Isles, although reception is good in places as far distant as Australia and New Zealand. See ABSORPTION, GROUND RAY, IONOSPHERIC RAY, SCATTERING.

SKIPPING-LINE SCANNING. Synonym for INTERLACED SCANNING.

SKY WAVE. Synonym for IONOSPHERIC WAVE.

SLIDE-BACK. Method of measuring the peak value of a varying voltage by connecting it to the grid of a valve which is biased so as to cut off anode current, and increasing the bias until the anode current is again zero, the increase in negative bias measuring the required peak value.

SLIDE-BACK VOLTMETER. Valve voltmeter measuring the peak value of the applied voltage and operating on the principle of SLIDE-BACK (q.v.).

SLIDING RESISTANCE. See POTENTIAL DIVIDER, VARIABLE RESISTOR.

SLOPE. Gradient of a curve. In radio, the term is often used instead of MUTUAL CONDUCTANCE (q.v.). Thus there may be confusion between mutual conductance and slope resistance. See SLOPE RESISTANCE.

SLOPE CONDUCTANCE. Inverse of slope resistance. Anode slope-conductance is the slope of the anode-volts/anode-current characteristic graph of a valve.

SLOPE RESISTANCE. Rate of change of the resistance of a non-linear conductor. The term "non-linear" means that the resistance of the onductor changes with the current lowing through it. In other words, it is conductor which does not obey HM'S LAW (q.v.). A typical example of hose conductors which do not obey Ohm's law is the diode rectifier. The anode-volts/anode-current characteristic of a diode rectifier is shown in Fig. 20. The scale numbering is arbitrary, but suffices to illustrate a principle (see DIODE).

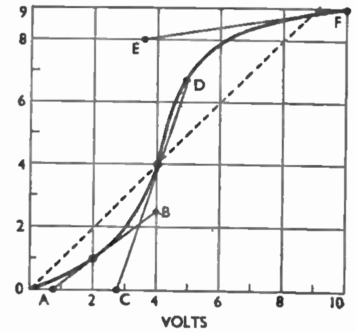


Fig. 20. Voltage/current graph of a onductor that does not obey Ohm's aw, for example a diode; the slope esistance of the conductor is given by the reciprocal of the slope of the raph at any point. The dotted line is he equivalent graph of a conductor which obeys Ohm's law.

With a voltage 2, there is a current 1, so that the resistance is $\frac{2}{1} = 2$. With a voltage 4 the resistance is $\frac{4}{4} = 1$; and with a voltage 10 the current is 9, making the resistance $\frac{10}{9} = 1{\cdot}1$. Thus the resistance varies as the current varies, and the diode is a conductor which does not obey Ohm's law. The dotted line shows the characteristic of a conductor which does obey Ohm's law; the resistance is always $1 = \frac{1}{1}, \frac{2}{2}, \frac{3}{3}, \frac{10}{10}$, etc.

The slope resistance of the conductor is given by the inverse or reciprocal of the slope of the graph of volts plotted against current flowing for any specified current or voltage. In Fig. 20, at 2 volts, it is the inverse of the slope of *AB*; at 4, the inverse slope of the line *CD*; and at 10, the inverse of the slope of *EF*. These slope resistances are approximately $\frac{3{\cdot}2}{2{\cdot}5} = 1{\cdot}28$, $\frac{2{\cdot}2}{6{\cdot}5} = 0{\cdot}34$ and $\frac{6{\cdot}5}{1{\cdot}0} = 6{\cdot}5$ respectively.

Fig. 21a shows a circuit which may be used to measure slope resistance. The object is to find out what small change of current is caused by a small change of voltage. If, as in Fig. 21c, the changes taken are too large, a wrong result is obtained. The slope of the graph alters rapidly, and to get its true slope at a point, the changes in voltage and current must be very small. In the extreme and for perfect accuracy, the changes must be infinitesimal; but in practice small finite changes must be used.

It is necessary to know the slope resistance of a non-linear conductor for two reasons; the first, pertinent to valve amplifiers, is that the anode slope-resistance is the internal resistance of the valve considered as a generator of power. The second reason, following logically on that just given, is that anode slope-resistance, mutual conductance and amplification factor are all related quantities.

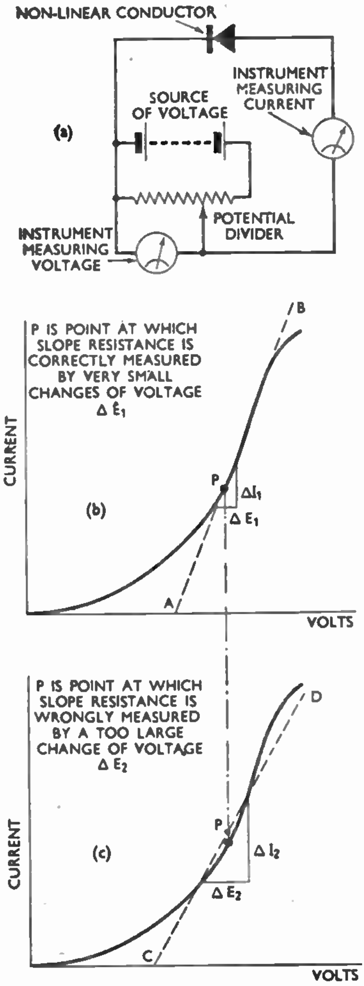


Fig. 21. At (*a*) is shown a circuit for measuring the slope resistance of a non-linear conductor. The graph shows how the value at *P* may be (*b*) correctly measured and (c) wrongly measured when change in voltage ΔE or the change in current ΔI is too large.

Any valve with a constant alternating voltage V_g applied between the grid/cathode terminals will supply power to a load connected in the anode circuit. The power supplied to the load is the same as if it were fed from a generator with an e.m.f. of μV_g volts and with an internal resistance of r_a, where r_a is the anode slope-resistance of the valve. It must be remembered that the generator resistance is given by the slope, that is, the value of $\Delta V_a / \Delta I_a$ for the valve, and thus varies, depending on the operating conditions. As shown in Fig. 22, the generator resistance for a pentode can be small or large depending upon whether the anode voltage is small or large. See AMPLIFICATION FACTOR, ANODE-VOLTS/ANODE-CURRENT CHARACTERISTIC, MUTUAL CONDUCTANCE, NON-LINEAR RESISTANCE.

SLOT AERIAL. Radiator sometimes used on extremely high frequencies, consisting of an elongated opening cut in a metal sheet, and usually voltage-fed at the middle points of the longer edges. The slot is of the order of a half-wave in length.

SLUDGE. Deposit which slowly forms in oil-filled transformers and capacitors as a result of oxidation of the oil.

SMALL-SHOT EFFECT. Particular form of shot noise. The sound resembles small shot hitting a hard surface. See SHOT EFFECT.

SMOOTHING CIRCUIT. Circuit arranged so that a pulsating current or voltage applied to its input terminals appears as a substantially direct current or steady voltage at its output terminals. The output from a rectifier which rectifies alternating current is in the form of pulsating currents. These currents contain a direct-current component and alternating-current components (see RECTIFICATION).

The function of a mains unit is to produce a direct current. That part of a mains unit which attenuates the alternating current and transmits the direct-current components of the rectified current is called the smoothing circuit. The term is used because the circuit smooths out the variation of current or voltage supplied from the rectifier and leaves a sensibly direct current.

A smoothing circuit consists essentially of a capacitor and inductor. A capacitor is connected between the output of the rectifier and earth to form a shunt path of low reactance for the alternating-current components (Fig. 23a). The inductor is connected in series with the direct-current circuit to form a low-resistance path to the direct, and a high impedance path for the alternating, component. In another form of smoothing circuit, the inductor is in series with the output from the rectifier and is then terminated in a shunt capacitor (Fig. 23b). A development of the smoothing circuit, when more units are added, is shown in Figs. 23c and 23d.

A great many factors are involved in the design of smoothing circuits. Most engineers who require results quickly use electrolytic capacitors of the order of 4–32 μF and an inductor of 20 H or so, and judge the result aurally. If the smoothing is insufficient another capacitor is added. A few of the basic pointers in the design of a smoothing circuit may be useful, however, to those requiring a more planned approach to the solution of design problems.

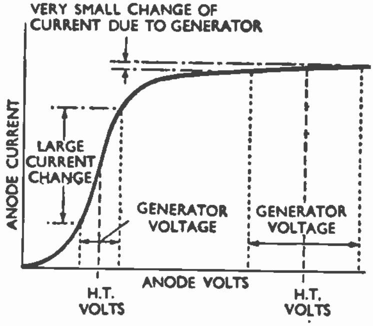


Fig. 22. If an alternating voltage is applied between the grid and cathode terminals of a pentode, and the H.T. D.C. voltage is high, change of current produced by a change in applied voltage is small. But with reduction in the D.C. voltage, the current change produced by the generator becomes large; this shows that the slope resistance of the valve is much smaller with a low than with a high H.T. voltage.

Taking first the circuit using the so-called "swinging choke" (Fig. 23b), the minimum inductance value of the inductor is given roughly by $= \frac{R}{1{,}000}$, where R is the load resistance in ohms and the supply frequency is that of the mains (50 c/s). This condition is not always easy to satisfy if R is variable and may have very high values. A bleeder resistance may be used to make the minimum value of R suitable. Also, the choke may be designed so that the incremental inductance is high for small currents and lower for large currents.

The smoothing circuit of Fig. 23c is more commonly used, possibly because it is not always easy to meet the conditions required in that of Fig. 23b. In this case, the best approach to the problem is to consult the manufacturers of rectifier valves who will supply all the necessary data, both as regards the smoothing circuit and the valves to use with it. We may note that the inductance of an inductor depends upon the current flowing in it. If so many henrys inductance are specified for an inductor in a smoothing circuit, this is the value which exists when the load current flows.

The greater the current taken from a mains unit, the larger the hum voltage compared with the direct voltage. This is because the capacitor produces a reverse voltage which prevents the rectifier from conducting except for a fraction of a half-cycle of alternation. The larger the direct current taken from the unit, the longer the time the rectifier conducts and the greater the alternating component in the rectified current.

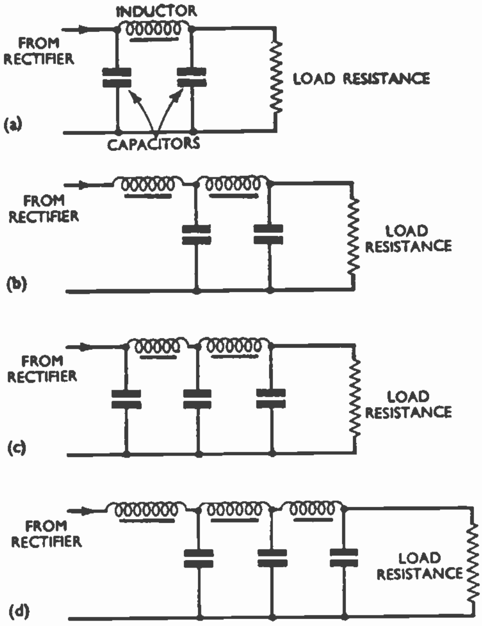


Fig. 23. Various forms of smoothing circuit are shown: (*a*) the essentials, and typical of the arrangement used for radio receivers; (*b*) with an inductor in series; (c) and (*d*) the development of the smoothing circuit when more units are added.

In a typical smoothing circuit, as used for a radio receiver, the circuit of Fig. 23a is used. The inductor has an inductance of the order of 10–20 H and the capacitors (usually the electrolytic type) a capacitance of 8–32μF. See MAINS UNIT, RECTIFICATION, RECTIFIER.

SOCKET. See PLUG AND SOCKET.

SOFT-VACUUM VALVE. Valve in which the amount of gas is sufficient to affect appreciably the electrical characteristics of the valve.

In modern practice, valves are either hard-vacuum or gas-filled types. A soft-vacuum valve (colloquially, a soft valve) describes a valve which was manufactured as a hard valve and has gone soft. Soft valves are not generally manufactured as such; a valve goes soft because gas has been released inside the bulb. The effect is to produce instability in performance. A valve that has gone soft shows a blue glow. The de Forest audion was a soft valve. See BLUE GLOW, GAS-FILLED VALVE, HARD-VACUUM VALVE.

SOFT VALVE. Synonym for SOFT-VACUUM VALVE.

SOLENOID. Coil wound on a cylindrical former the length of which is greater than the diameter. The term is applied more particularly to coils of this type used in electromagnets, and also for producing, or being acted upon by, a magnetic field for purposes of measurement.

The term is also used to describe a particular type of electromagnet in which a soft-iron rod is drawn into the coil when the latter is energized by the passage of a current of sufficient magnitude.

SOUND ARTICULATION. Percentage of speech-sounds correctly received over an electrical transmission or reproducing system, or in an auditorium when logatoms are transmitted. See LOGATOM.

SOUNDER. Electromagnetic device used in reception of Morse. It gives a click at the beginning and end of each dot or dash, thus producing audible sounds from which the message can be derived.

SOUND-MODULATED WAVE. Wave produced when a carrier wave is modulated by waves with the frequencies of voice, music or other sounds.

SOUND PROGRAMME. Term used to distinguish programmes which are reproduced as sound, from those which give a moving visual picture of an event. See BROADCASTING.

SOUND RECORDING. See ELECTRICAL RECORDING.

SOUND WAVES. Waves set up in a medium having elasticity and mass, such as air or water, by vibration within that medium, and detectable by the ear.

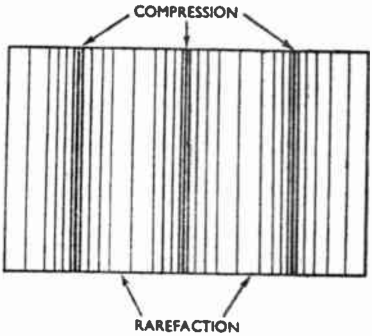


Fig. 24. Diagram which illustrates how regions of compression and rarefaction are formed as a sound wave travels from its source into space.

When a vibrating body moves in a given direction, the air is compressed in the same direction. Such compression relieves the body of the original air pressure from the reverse direction. When the body moves in the opposite direction, it leaves behind it a region of reduced pressure. Thus a state of compression is followed by a state of rarefaction, as shown by diagram in Fig. 24.

These conditions of compression and rarefaction are transmitted outward into space as the body continues to vibrate, and the length of the sound wave is the distance between two succeeding points of maximum compression. The velocity at which the wave travels in air is 1,120 ft. per sec. Therefore, if the body vibrates at a frequency of f c/s, the length of the sound wave is $\frac{1,120}{f}$ ft.

When the sound wave impinges upon the ear diaphragm, the latter vibrates at the frequency of the original vibration, producing the physical sensation that we term hearing. See SPEECH AND HEARING.

SOURCE ERROR. Error in direction-finding due to the manner of radiation of the energy from the sending aerial, or caused by peculiarities at the sending site generally.

SPACE. In telegraphic codes, the period of time which separates two successive characters; or the time between two successive letters; or that between two successive words. The interval increases in the order given.

SPACE CHARGE. Electric charge resulting from a concentration of electrons between the electrodes of a valve and, notably, around the cathode of a valve. The term is often used to describe the concentration of electrons, as distinct from the charge due to the concentration; for example, "electrons are drawn from the space charge."

The charge due to a concentration of electrons round the cathode profoundly influences the electrical characteristics of valves of all kinds, and it is a basic principle of the valve that the anode current is determined by the potential gradient at the cathode. Thus a con-

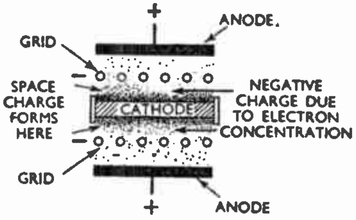


Fig. 25. Section through a triode showing the formation of the space charge. If the potential gradient at the cathode is small, the electrons concentrate around the cathode and exert a negative charge, thus reducing the potential gradient and limiting anode current.

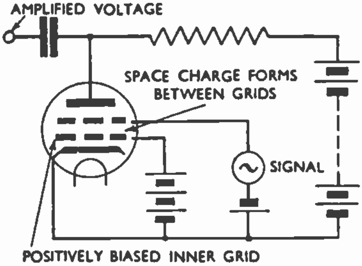


Fig. 26. Operation of the space-charge-grid valve. The inner grid is biased strongly positive with respect to the cathode so that a space charge forms between the two grids. As this space charge is very close to the outer grid, it provides a high mutual conductance between grid and anode.

centration of electrons round the cathode, in producing a negative charge near the cathode, may profoundly affect this gradient and modify the anode-volts/anode-current characteristic of valves at low anode voltages (Fig. 25). See SPACE-CHARGE-GRID VALVE, SPACE-CHARGE LIMITATION, VALVE, VIRTUAL CATHODE.

SPACE-CHARGE-GRID VALVE. Valve in which the grid nearest to the cathode (normally the control grid) is given a strong positive bias; while a second grid, next to, and embracing, this positively biased grid, is negatively biased and used as a control grid. The arrangement gives the valve a high mutual conductance but, on the other hand, the valve characteristics are markedly non-linear.

The action of the valve is explained with reference to Fig. 26. The strong positive bias on the inner grid accelerates electrons from the cathode and these shoot past the inner grid, and meet the retarding field due to the negatively biased control grid. Thus a concentration of electrons forms between the first and second grids. The difference between the conditions set up by the space-charge-grid valve and in a normal valve is that in the former the control grid is much closer to the concentration of electrons (or space charge) than in the latter. The mutual conductance of the space-charge-grid valve is thus relatively great.

Considerable current (30–50 per cent of the anode current) is drawn by the inner grid. The grid volts-anode current characteristics are far more curved than those of a normal valve. See PENTODE, SPACE CHARGE, SPACE-CHARGE LIMITATION.

SPACE-CHARGE LIMITATION. Limitation of the anode current of a valve (occurring at low anode voltages) due to the negative charge produced by a concentration of electrons round about the cathode (Fig. 27).

When the cathode is energized, electrons are emitted from it, even when there is no anode voltage. In other words, the emitted electrons are not "pulled out" of the cathode by the positive anode potential but are thrown off the cathode owing to its heat. With zero anode potential, the electrons form into a cloud, or concentration, round the cathode. The negative charge (see SPACE CHARGE)

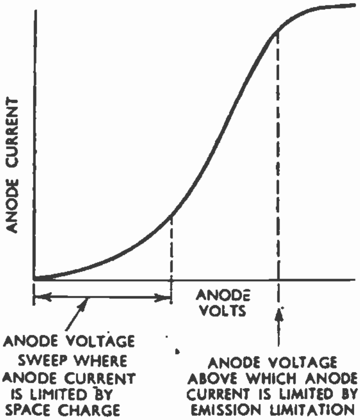


Fig. 27. Anode-volts/anode-current characteristic of a hard-vacuum valve, which illustrates the space-charge limitation of the anode current at low anode voltages.

tends to prevent any more electrons from escaping from the cathode.

If a small anode voltage is now applied, only the electrons at the edge of the concentration move away; the remaining electrons shield the cathode from the field due to the anode. A small anode current flows, but its value is limited because the negative charge prevents the potential gradient at the cathode being as large as it would be in the absence of the space charge.

Increase in the anode voltage creates a condition in which electrons are drawn away from the concentration as fast as these are replenished by the cathode. In this condition, the anode-volts/anode-current characteristic is nearly linear. With a very high anode voltage, each electron rushes straight to the anode as soon as released; and the anode current is constant and independent of anode potential, being limited by EMISSION LIMITATION (q.v.).

The basic difference between the hard-vacuum and gas-filled valve is that, in the latter, positive ions move towards the cathode and so cancel the space charge; thus the anode current quickly rises to its maximum value because there is no space-charge limitation owing to space charge.

The three conditions already described (in which (1) the anode current is limited by space charge when at low anode voltage; (2) the current and voltage are related in a more linear manner; and (3) the current reaches its maximum possible value) are illustrated by the anode-volt/anode-current characteristic of a hard-vacuum diode shown in Fig. 27. See DIODE, EMISSION LIMITATION, GAS-FILLED VALVE, TRIODE, VALVE.

SPACE CURRENT. Current flowing to and from the cathode of a valve. In a hard-vacuum valve the space current is carried by free electrons, supplied from a space charge round the cathode. In a gas-filled valve or glow-tube, space current is carried by both positive ions and electrons. An explanation is given diagrammatically in Fig. 28. See ELECTRODE CURRENT, EMISSION, GAS-FILLED VALVE, HARD-VACUUM VALVE.

SPACED AERIAL. Aerial-system in which certain elements are spaced apart but connected to a single receiver for direction-finding purposes. Such aerial elements may be complete half-wave dipoles in themselves, open aerials of almost any type, or loops (the two vertical sides of a single loop can be regarded as spaced aerials). See SPACED-AERIAL DIRECTION-FINDER.

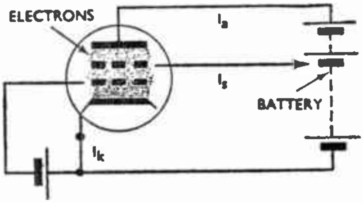


Fig. 28. Space current is the current carried by the electrons within the valve; it is here represented by I_k and is equal to the anode current I_a, plus the screen current I_s.

SPACED-AERIAL DIRECTION-FINDER. Direction-finder in which the wave direction is determined fundamentally by the phase difference between the voltages induced in two aerials or parts of the same aerial. This phase difference depends on the angle at which the waves cross the pair of aerials.

If the aerials are separated by a distance equal to half the wavelength of the signals and are situated along the direction of travel of the waves, the voltages induced in one aerial will be at 180 deg. to that induced in the other. If the two lower ends of the aerials are connected together—via the input circuit of a receiver—maximum current will flow and the receiver will give maximum signals. If, on the other hand, the wave direction is at right-angles to the line joining the two aerials, each wave front will cut across both at the same instant and there will be no phase difference in the voltages induced in them. No current will flow in the receiver input circuit and no signals will be heard in the receiver connected between the aerial bases.

Waves crossing at angles other than 0 deg. or 90 deg. naturally produce signals and, if the aerials could be mounted on some rotating base, the signal strength would vary from zero to maximum as the aerials were turned from the broadside-on to the in-line position. This is, in fact, a practical method of direction-finding in its simplest form: the swinging of a loop-aerial to find the minimum-signal orientation (the two upright sides of the loop represent the two separate aerials previously used for purposes of explanation).

The theoretical optimum spacing of half a wavelength is, of course, impracticable except on the higher frequencies. At other frequencies smaller spacings and correspondingly reduced pick-up efficiency must be accepted for practical reasons. Indeed, before highly sensitive receivers became available for direction-finding, it was considered that the smallest aerial capable of giving the minimum standard of pick-up efficiency was too unwieldy to be conveniently rotated, and other methods were devised for ascertaining the direction of wave travel (see BELLINI-TOSI DIRECTION-FINDER).

Modern receivers have made possible the use of comparatively small rotating-loop aerials, and this type of direction-finder has found wide use in consequence. For fixed stations, however, where space is not a consideration, the non-rotating, spaced-aerial direction-finder has advantages and is not likely to be superseded. See ADCOCK DIRECTION-FINDER, RADIOGONIOMETER.

SPACE DIVERSITY. Radio reception in which a number of receivers with aerials are situated at a distance of several wavelengths from each other and in which a single signal is derived from a combination of or selection from the receiver outputs. See DIVERSITY SYSTEM.

SPACED-LOOP DIRECTION-FINDER. Direction-finder in which the spaced aerials are loops rather than open aerials. The principle of operation is the same as that of the more usual arrangement with open aerials. See SPACED-AERIAL DIRECTION-FINDER.

SPACE WAVE. Component part of the ground wave. The ground wave can be divided into two components, a surface wave and a space wave. The surface wave travels along the surface of the earth. The space wave, as illustrated in Fig. 29, is the result of two component waves; a direct wave and a ground-reflected wave. At all except very high frequencies, the sending and receiving aerials are only a small fraction of a wavelength above the surface of the earth and, under these conditions, the two component parts of the space wave are of equal amplitude and opposite phase, thereby cancelling each other out and leaving the surface wave as the only component of the ground wave.

At very high frequencies, where the aerials may be raised several wavelengths above the earth, the space

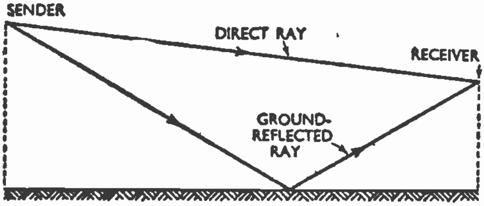


Fig. 29. Direct and ground-reflected components of a space wave where the sending and receiving aerials are several wavelengths above ground, as is usually the case at very high and ultra-high frequencies.

wave rapidly increases in relative strength, because, in practice, the angle of incidence of the ground-reflected wave increases, reflection becomes less perfect and the path length increases over that of the direct wave. There is thus less over-all cancellation of the two waves. At extreme optical ranges, this can cause fading in the same way that interaction of ground wave and ionospheric waves causes the fading experienced on medium frequencies. See FADING, GROUND WAVE, SURFACE WAVE.

SPACING. Extent of the separation between neighbouring elements in a spaced-aerial system of a direction-finder, usually expressed as a ratio of the working wavelength. See ANGULAR SPACING, SPACED-AERIAL DIRECTION-FINDER.

SPACING WAVE. In radio telegraphy, the wave radiated by the sender during the spaces in the code. See MARKING WAVE.

SPARK. Filamentary conducting path formed in a gas by ionization of the gas in the path. When two conductors are brought close to one another, and a sufficient difference of potential is established between them, a spark forms and tends to equalize the potential difference between the conductors.

A flash of lightning is an extremely large spark, and the two conductors in this example are the clouds (or a cloud) and the earth. The electric strain set up in the gas between the conductors causes it to be ionized, and therefore conductive. The rush of current heats the gas and causes the ionized path to appear as a brilliant streak of light.

An arc is different from a spark in that it forms when a conductor carrying a current is broken; the current persists, in spite of the break in the metallic circuit, and is conducted over the gap by ionized gas. Thus a spark jumps between conductors between which a large potential is established, while an arc forms at a break in a circuit which is carrying a large current.

Sparking is associated with voltage, and arcing with current, but the terms are often used synonymously; the sudden change of conduction in a glow-tube when the striking voltage is exceeded may be called an arc; and in mercury-arc rectifiers, the initial spark

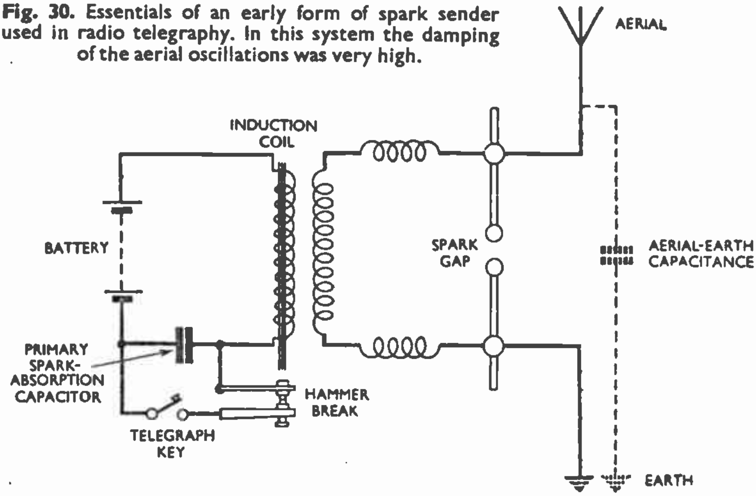
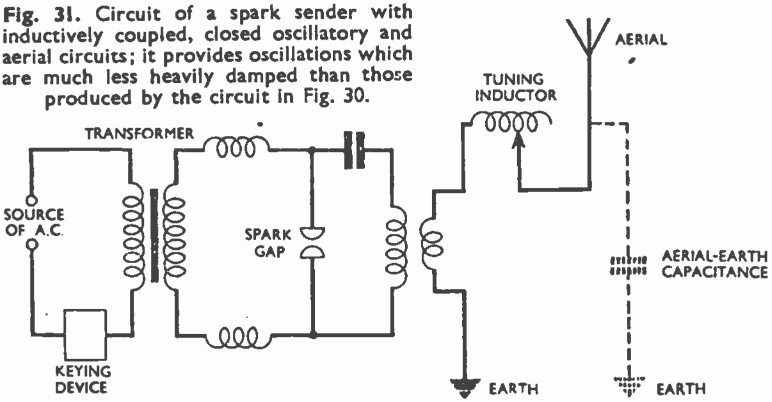


Fig. 30. Essentials of an early form of spark sender used in radio telegraphy. In this system the damping of the aerial oscillations was very high.

Fig. 31. Circuit of a spark sender with inductively coupled, closed oscillatory and aerial circuits; it provides oscillations which are much less heavily damped than those produced by the circuit in Fig. 30.



which starts the arc is sometimes itself called an arc. See ARC, IONIZATION, SPARK-QUENCH, SPARK SENDER, SPARK SENDING SYSTEM.

SPARK COIL. Induction coil used to generate a high voltage for a spark sender. See INDUCTION COIL.

SPARK FREQUENCY. Rate at which sparks occur in a spark system, expressed in terms of the number of sparks per unit time. In radio-telegraphic communication with spark senders, the spark frequency determines the pitch of the signal note heard in the receiving headphones.

SPARK-GAP. Apparatus for the production of repeated spark discharges between the two or more electrodes forming the system.

SPARK-QUENCH. Electrical network connected across two contact points to reduce or prevent sparking between them. The network usually consists of resistance and capacitance in series.

SPARK RESISTANCE. Resistance between electrodes once spark discharge has begun.

SPARK SENDER. Type of radio-telegraph sender employing the spark system for the generation of the R.F. oscillations. The simplest form of low-power sender, used in the early days of radio telegraphy, had a circuit somewhat similar to that shown in Fig. 30. An induction coil was used to charge the capacitance existing between an aerial and the earth. Since an aerial-system possesses distributed inductance as well as distributed capacitance, the discharge across the spark-gap was of an oscillatory nature, at the natural frequency of the aerial-system (now grounded through the gap). The damping of the aerial oscillations was very high with this system.

The need for the production of less highly damped oscillations and, at the same time, greater power led to the system illustrated basically in Fig. 31. Here the oscillations were generated in a closed oscillatory circuit coupled to the aerial circuit which was tuned by an inductor to resonate at the natural frequency of the closed oscillatory circuit.

When using any form of non-quenching spark-gap, it was necessary to employ very loose coupling between the closed oscillatory and aerial circuits to avoid double-frequency effects arising from interaction between the two circuits during the spark-discharge period.

The audio-frequency note heard in the headphones of a receiver had a pitch corresponding to the spark frequency of the sender. Higher spark frequencies than that obtainable with a simple fixed spark-gap were desirable for reception through atmospherics, and the earlier spark-gap senders gave place to senders employing rotary and quenched spark-gaps.

With a quenched spark-gap, tighter coupling was employed between the closed oscillatory and aerial circuits, and the best conditions were secured with slight mistuning between the two circuits. See QUENCHED SPARK-GAP, QUENCHED SPARK SYSTEM, ROTARY SPARK-GAP, SINGING SPARK SYSTEM, SPARK SENDING SYSTEM.

SPARK SENDING SYSTEM. Original system of radio telegraphy, now almost obsolete, in which radio-frequency oscillations are produced in the sending aerial by coupling it to an oscillatory circuit containing a spark-gap.

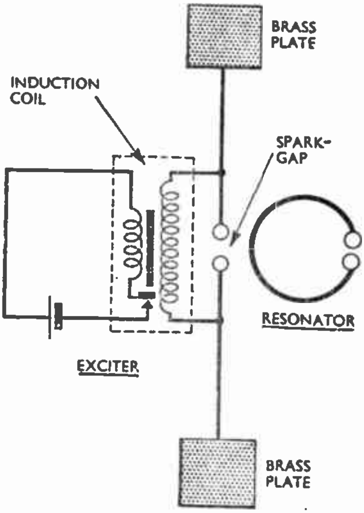


Fig. 32. Fundamentals of a spark sending system are demonstrated by Hertz's apparatus, shown in the diagram, for producing and detecting electromagnetic waves. In both the exciter and the resonator two brass balls form the necessary spark-gap.

The production of electromagnetic waves by means of an electric discharge across a spark-gap was first discovered by Hertz in 1888. His apparatus comprised an exciter and a resonator (Fig. 32). The exciter consisted of a Leyden jar or an induction coil, to the terminals of which were attached two brass rods, each having a brass plate at one end and a small brass ball at the other. The balls were placed a short distance from each other and an electric discharge from the Leyden jar or the induction coil caused a spark across the gap.

The resonator consisted of a loop of wire carrying a small brass ball at each end, and when this was placed near the exciter a spark occurred between the ends of the resonator, the energy being transmitted by radiation of electric waves from the plates of the exciter.

Experiments with this apparatus provided the foundation of the spark sending system, and the detection of electric waves in space. The experiments were continued and developed by various scientists, notably Lodge in Britain, Branly in France, Tesla in U.S.A. and Righi in Italy. Branly made the important discovery that the electric waves could be detected by a tube containing iron filings (see COHERER); this device was developed to form the basis of the first radio receiver.

In 1890, Marconi proceeded to turn the laboratory experiments of his predecessors into practical application. By using an aerial–earth system with both induction-coil exciter and coherer detector (Fig. 33), the range was increased to a few miles. The aerial comprised a sheet of wire netting suspended from a mast and was called the *capacity aerial.*

It was soon found that efficiency depended not so much on the netting area as on the length of wire leading to it; a longer aerial produced better results. Signals were transmitted across the Bristol Channel in 1896, and across the English Channel in 1899.

In these demonstrations, no tuned circuits were used; hence there was no selectivity, and most of the energy was quickly expended because of the heavily damped waves (see TYPE B WAVE).

The next stage was the introduction of tuning coils, based on experiments previously carried out by Lodge. This had two important results. First, greater energy was radiated for a given length of spark; and second, the waves decreased in amplitude more slowly, increasing the range.

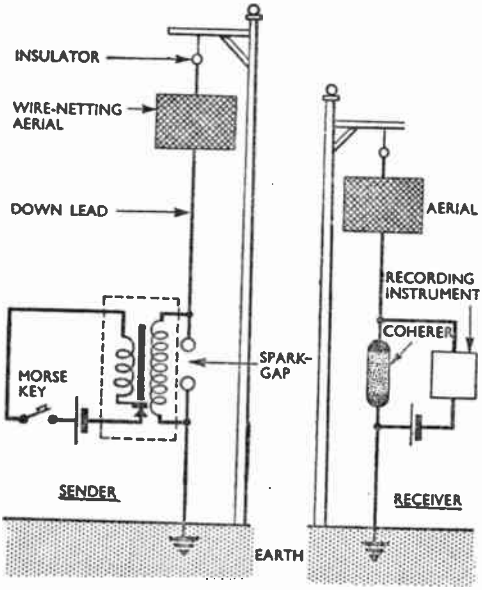


Fig. 33. Diagrammatic representation of the original apparatus used by Marconi as a spark sending system. Aerial-earth systems were included in the circuits of both exciter (sender) and coherer detector (receiver).

Moreover, by calculating component values for the tuned circuits, sending and reception took place on a predetermined wavelength (see OSCILLATORY CIRCUIT, WAVELENGTH), and the sending and receiving circuits then took the form of Fig. 34. From that time (about 1900), the spark sending system retained the essential features shown. Improvements in the spark-gap were made from time to time (see QUENCHED SPARK-GAP, ROTARY SPARK-GAP), and a new system of detection called the magnetic detector (see MAGNETIC DETECTOR) was introduced in 1901.

Using the sending system of Fig. 34 and the magnetic detector, signals were sent from Cornwall to Newfoundland in 1902. The magnetic detector was later replaced by the crystal receiver (see CRYSTAL DETECTOR, CRYSTAL RECEIVER). Finally, the valve was used as a detector, with the additional and all-important development of amplification.

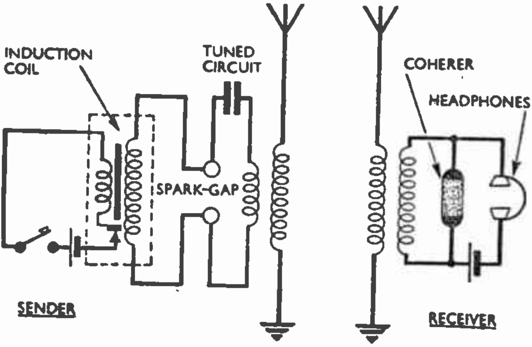


Fig. 34. Circuits of the tuned sender and receiver forming the system by which Marconi sent signals across the Atlantic in 1902.

Within a few years of its inception, the spark system had wide applications. It was installed on ships, and coastal radio stations were erected. Ships were thus able to communicate with each other over long distances and also with the shore (see SHIP'S RADIO). In addition, high-power stations were built for transatlantic communication, supplementing the cable services. The system was also used on military aircraft in the First World War.

The chief drawback of the system is that, however well developed, it produces heavily damped waves which cannot be sharply tuned; this brings about mutual interference between stations using the system and, more important, causes serious interference on radio-broadcast receivers in coastal areas. For these reasons the system is being gradually superseded by the more efficient type A0 and type A2 sending systems.

See CARBORUNDUM DETECTOR, ELECTROMAGNETIC WAVE, OSCILLATORY DISCHARGE, RADIO TELEGRAPHY, SPARK-GAP, TUNING CAPACITOR, TUNING INDUCTOR.

SPARK TRANSMITTER. Synonym for SPARK SENDER.

SPEAKER. See LOUDSPEAKER.

SPECIFIC GRAVITY. Measure of the density of a substance, liquid or solid, which may be expressed as the weight of unit volume; more conventionally, it is the ratio of the weight of a given volume to the weight of the same volume of water at a temperature of 4 deg. C.

SPECIFIC INDUCTIVE CAPACITY. Synonym for PERMITTIVITY.

SPECIFIC RESISTANCE. Synonym for VOLUME RESISTIVITY.

SPEECH AND HEARING. Oral expression and the perception of sound. The human brain can distinguish three qualities in any sound wave to which the ear responds. First, it is able to decide whether the sound has a high or a low pitch; that is to say, it can make an estimate of the fundamental frequency of the sound. Secondly, the brain can tell us whether the sound is loud or soft; that is to say, it can make an estimate of the power contained in the sound. Thirdly, the brain can give us some indication of the quality, or "richness," of the sound; that is to say, it can give some indication of the wave form of the sound and hence of its harmonic content.

These three physiological aspects of sound will now be considered in greater detail.

Frequency. The pitch of a sound, that is, its position in the musical scale, depends only on the fundamental frequency and is not influenced by the number or relative intensities of any harmonics which may be present (see HARMONICS). When various musical instruments play the same note, say middle C, the wave forms of the sounds they produce vary enormously, some having practically no harmonics, others having a wealth; but all the wave forms have the same fundamental frequency, namely, 256 c/s.

It is interesting to note that some instruments, played under certain conditions, give notes in which the fundamental frequency is not present as a discrete component; nevertheless, the pitch is still decided by the value of the fundamental frequency.

The frequency limits of the human ear vary with the age of the listener. Very young children can hear sounds with frequencies between 16 c/s and 20,000 c/s or even higher, but, as age increases, the upper frequency limit falls. At 30 years the average ear does not respond to sounds with a frequency in excess of 15,000 c/s, and people 60 years old are fortunate if they can hear a note of 10,000 c/s. The lower limit does not vary very much with age and is, in fact, rather indeterminate: it is very difficult to decide whether very low-pitched sounds are heard or *felt*.

When sound is reproduced by electromechanical means, say, from the output of a radio receiver or a

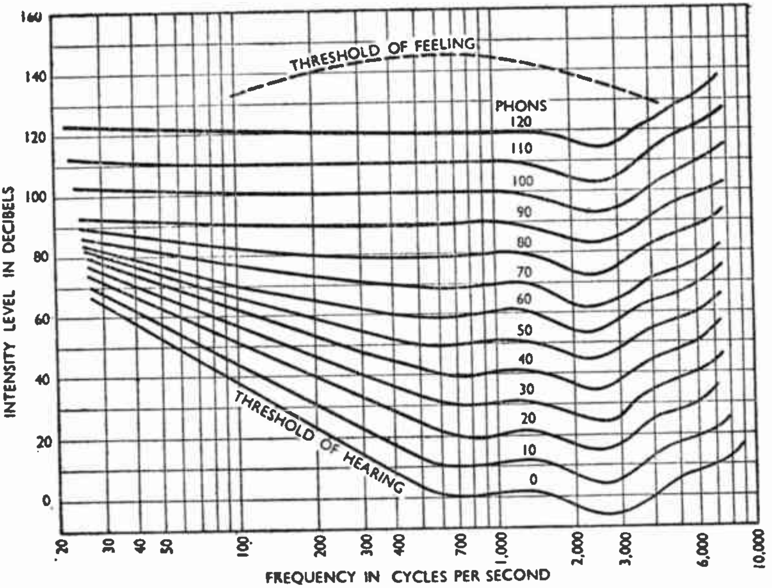


Fig. 35. Contours of equal loudness expressed in phons above a threshold value (zero phons) as a function of frequency and sound power, or intensity, the latter being expressed in decibels relative to the acoustic zero level.

gramophone, it is desirable to reproduce, as far as possible, the full frequency range of the human ear in order to create a faithful copy of the original sound. For many reasons, this is not normally possible and the frequency range is curtailed at both ends.

The mechanism of the ear is, however, non-linear and the frequency range is effectively extended by the difference in tones and harmonics introduced in the hearing process. Hence the reproduced frequency range can be reduced very greatly without unduly impairing the quality. For example, speech is quite intelligible when the reproduced frequency range is restricted to between 250 c/s and 2,500 c/s, the range of the average telephone instrument.

The average radio receiver, with an audio-frequency range of 100 c/s to 4,000 c/s, gives satisfactory reproduction of orchestral music, but the range must be from 50 c/s to 10,000 c/s to give very good reproduction.

Loudness. Experiments have shown that the loudness of a sound depends not only on its power but also on its frequency. For example, the weakest sound at 1,000 c/s that can be heard by the average ear under laboratory conditions has a power, in electrical units, of 10^{-16} watts. This is known as the acoustic zero level. If the frequency is changed to 50 c/s, the power has to be increased to 10^{-10} watts, or one million times as great, to make the sound equally loud as before. Thus the sensitivity of the ear is a function of frequency and power.

If, at a given frequency, the power of a sound is increased by logarithmic steps, that is to say, by repeated multiplication by a constant factor, the ear appreciates the changes as equal increments in loudness. Since the decibel is also a logarithmic unit, the power of a sound expressed in decibels gives a direct measure of loudness.

The unit of loudness is the phon, and a sound is said to have a loudness of *x* phons if it seems as loud as a 1,000 c/s note with a power level of *x* decibels. By definition, therefore, the number of phons and the power level expressed in decibels are numerically equal at and near 1,000 c/s; but this is not true at high and low frequencies because of the variation of sensitivity of the ear with frequency.

The manner in which loudness depends on frequency and power is illustrated in Fig. 35. This shows that, at low volumes, considerably more power is needed to render low notes as loud as 1,000 c/s, but that, as the volume is increased and the equal loudness contours become flatter, the same power tends to give the same loudness irrespective of frequency.

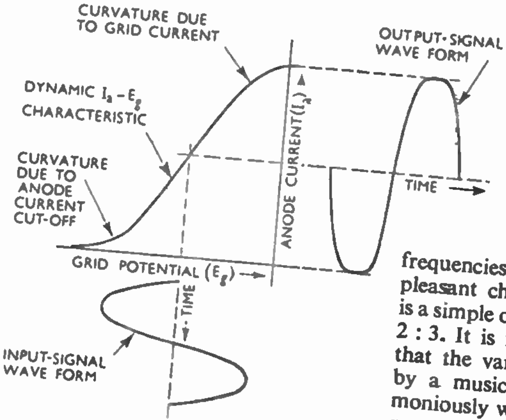


Fig. 36. Diagram which shows how both the positive and the negative half-cycles of the output-signal wave form are distorted when too large an input signal is applied to an amplifier.

Quality. When the ear responds to a sound wave having a complex wave form, the listener can appreciate the presence of all the audible harmonics (see FOURIER ANALYSIS). Thus he is able to distinguish one musical instrument from another, even when both are playing the same note, by recognizing the harmonic content of the sounds produced.

For example, brass instruments produce very strong, odd harmonics, and stringed instruments mostly even harmonics. If some of the harmonics are eliminated by, for example, a radio receiver with a very poor high-note response, it becomes difficult to recognize the various instruments in the reproduced sound. Thus for good reproduction, a wide frequency range is necessary to permit all the harmonics present to be reproduced in their full intensity.

When the ear responds simultaneously to two sounds with different frequencies, the two sounds produce a pleasant chord if the frequency ratio is a simple one such as 1 : 2, 1 : 3, 1 : 4, 2 : 3. It is for this reason, of course, that the various harmonics produced by a musical instrument blend harmoniously with the fundamental component and with each other. If the frequency ratio of the two sounds is not simple, but is, for example, 9 : 10, a discord is produced.

When an amplifier is overloaded by application of too large an input signal, both the positive and the negative half-cycles of the output-signal wave form are distorted as indicated in Fig. 36. The positive peak is "flattened" as a consequence of the flow of grid current and the negative peak by anode-current cut-off. The resulting wave form has a shape similar to that obtained by combining a sine function with odd harmonics.

If the grid-bias value is wrongly chosen, and if the input signal is sufficiently great, flattening of one peak only of the output wave form occurs.

The resulting unsymmetrical wave form can be simulated by combining even harmonics with a sinusoidal wave form. Thus the harmonic content of the signal is increased in both cases—and the ear can detect the presence of the added components.

The additional harmonics produced by the amplifier do not cause audible distortion, but they alter the character of the signal. For example, the sound of a stringed instrument tends to become "brassy" when odd harmonics are added.

More important, however, than the harmonics produced by an overloaded amplifier are the combination tones which are produced at the same time. These are spurious signals having frequencies equal to the sum and difference of the frequencies of any two components present in the input signal and they form discords with the true output signal, producing unpleasant sounds.

SPEECH-BAND. Small frequency band in the audio range which is bounded by frequency limits essential if speech sounds are to be recognizable. For intelligible speech, a range of 250–2,500 c/s is essential. For the perfect reproduction of natural speech, however, the band must include all frequencies between 100 and 4,000 c/s. A speech-band is sometimes also called the "voice-frequency" band.

SPEECH COIL. In a microphone or loudspeaker of the moving-coil type, the coil in which speech currents are generated or to which they are applied.

SPEECH INVERSION. Process used to obtain a measure of secrecy in communication by wire or radio telephony. The speech frequencies are restricted to a certain range (for example, 250–2,750 c/s) by filters, and are then combined with the output of an oscillator of fixed frequency (say, 3,000 c/s) in a modulator or frequency-changer.

The signal output so obtained is in two discrete frequency bands, 250–2,750 c/s and 3,250–5,750 c/s, and the latter is rejected by a filter. The former band occupies the same frequency range as originally but the 250 c/s signal corresponds with the original 2,750 c/s and vice versa. As a result of the modulating process, the original high notes have become low, and the low ones have become high; in other words, the speech is inverted.

The inverted signal can be transmitted along a line or by radio, and is unintelligible if received on conventional telephone or radio receivers. The received signal can be rendered intelligible by a second process of inversion using the same modulating frequency as before. The beat-frequency oscillator of a communications receiver may be adjusted to make inverted speech intelligible. See BEAT-FREQUENCY OSCILLATOR.

SPEECH SCRAMBLING. Process employed to obtain secrecy during the transmission by radio of telephone signals from one country to another. The speech-frequency band is split into a number of smaller bands by filters and each is modulated by the output of a fixed-frequency oscillator.

Inversion of each band occurs (see SPEECH INVERSION) and the separate inverted outputs are combined to form the scrambled signal used to modulate the R.F. carrier at the transmitter. At the receiver, a similar process of band separation and modulation is necessary to restore the original signal.

SPEECH VOLTMETER. Voltmeter calibrated in such a way that zero on its decibel scale represents one volt at 800 or 1,000 c/s, at which frequencies its characteristic impedance is 600 ohms. See VOLTMETER.

SPHERICAL ABERRATION. Electron lens aberration whereby electrons in various regions of the focusing field focus at different points along the axis of the beam. See CATHODE-RAY TUBE.

SPIRAL SCANNING. Movement of a beam of radio waves in spiral fashion from the centre to a considerable angle from the axis through the centre of the spiral. It is used in certain types of radar equipment. In such equipment, frequencies of 3,000 Mc/s or higher are used; the radar beam is thrown out from a rotating parabola which, by virtue of eccentric mounting, describes a cone as it rotates.

The result is to make the radar beam trace a solid figure whose section is a spiral. A rotating P.P.I. trace is geared to the aerial parabola and makes one revolution for each revolution of the parabola. If a target is picked up by the radar dead ahead, that is, when the rotating aerial is following the spiral at its smallest radius, the target will reflect the signal during the *whole* of the rotation of the aerial through its somewhat distorted circle, and a ring appears on the screen of the cathode-ray tube.

If the target is away from the axis of the spiral, that is, not dead-ahead, it will reflect the echo only when the aerial is "looking" at it and, since the aerial will then be tracing a distorted circle (as part of the spiral) of greater radius, the echo will be picked up during a small arc of the circle only, and an arc will appear on the screen. The position of the arc on the tube, that is, its bearing from the centre of the tube, will indicate the bearing of the target from, for example, an aircraft carrying the radar equipment. The distance of the arc from the tube centre will denote the distance of the target from the sender. See RADAR.

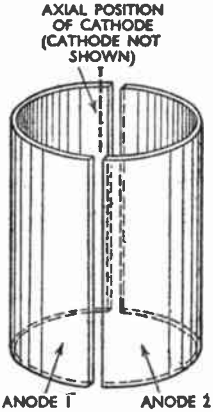


Fig. 37. The two anodes of a split-anode magnetron. The cathode is set on the axis of the cylinder so formed.

SPIRAL TIME BASE. In a cathode-ray tube, a time base produced by the spiral rotation of the spot at constant angular velocity, thus giving a base line longer than that with the normal linear method. See TIME BASE.

SPLIT-ANODE MAGNETRON. Magnetron with two anodes insulated from one another. The two anodes form a cylinder with cuts in opposite sides (Fig. 37). The cathode lies on the axis of the cylinder. The valve can be arranged to produce a negative slope-resistance and can thus be used to generate oscillations in a tuned circuit. The electrons in a magnetron are acted upon by magnetic and electrical fields at right-angles. This causes the electrons to have a rotational component of motion around the cathode (see MAGNETRON).

In a split-anode magnetron, increasing the voltage on one anode decreases the current taken by that anode; and decreasing simultaneously the voltage on the other anode increases the anode current taken by that other anode. This is a consequence of the orbits of electrons; these may terminate on the anode with less voltage on it and avoid that with the greater voltage. In this condition, each anode has a negative slope-resistance.

In Fig. 38 a tuned circuit is connected between the two anodes. As each of the anodes has a negative resistance, the circuit is set into oscillation. See NEGATIVE RESISTANCE, OSCILLATOR.

SPOOL. Hollow former, usually of insulating material, on which may be wound a coil of wire; it has end-flanges, or cheeks, to support the coil. The cheeks may also serve to carry connecting tags. For resistors and air-cored inductors, the section is usually

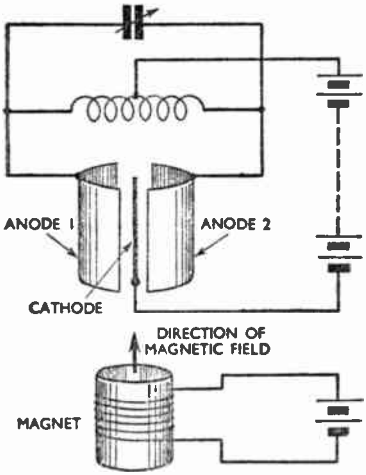


Fig. 38. How a split-anode magnetron may be used as an oscillator because each anode has a negative resistance.

circular but, for iron-cored inductors and transformers, the section is often square or rectangular. See FIXED INDUCTOR, FIXED RESISTOR.

SPRAY-SHIELDED VALVE. Valve in which the outside of the bulb is sprayed with metal. This forms a conductive surface and acts as an electrostatic shield. The shield is sometimes connected internally to the cathode, and sometimes terminated on one of the pins. See METALLIZED VALVE, SCREENING, VALVE SHIELD.

SPREADER. Device which maintains the intended spacing between the parallel wires or rods of an aerial structure. An example of a spreader is a wooden spar, with an insulator at each end to carry the conductors of a twin-wire aerial span (Fig. 39); another is a circular hoop supporting and positioning the wires of a cage aerial. See CAGE AERIAL.

SPUTTERING. Effect in which the cathode of a vacuum or gas-filled valve is disintegrated and deposited on the other electrodes or the walls of the valve. See CATHODE SPUTTERING.

SQUARE-LAW CAPACITOR. Form of variable capacitor so constructed that the capacitance is proportional to the square of the movement of the control. For example, if the total capacitance is 400 μμF, then, at half-scale, the capacitance would be $(\frac{1}{2})^2 \times 400 = 100$ μμF and at quarter-scale it would be $(\frac{1}{4})^2 \times 400 = 25$ μμF.

When used as one element of an ideal resonant circuit, the wavelength at resonance is proportional to the movement of the control; so that a dial marked with wavelength and attached to the control knob would have equally spaced divisions. See VARIABLE CAPACITOR.

SQUARE-LAW CONDENSER. See SQUARE-LAW CAPACITOR.

SQUARE-LAW DETECTOR. Detector in which the output is proportional to the square of the applied voltage, so that if the input voltage is doubled the output will increase four times. For certain types of use, as, for example, in heterodyne detection, a square-law detector is preferable to a linear detector.

A thermal detector is a true square-law detector, while most valve rectifiers exhibit a square-law characteristic over some part of their curve. Valves can be made for use as anode-bend rectifiers, which exhibit a good approximation to the square-law characteristic over quite wide ranges of input.

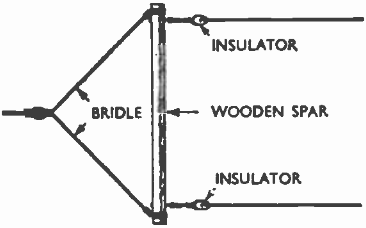


Fig. 39. Wooden spar commonly used as a spreader in twin-wire aerials.

SQUEGGING OSCILLATOR. Valve oscillator the output of which consists of radio-frequency oscillations modulated by relaxation oscillations. See OSCILLATOR.

S.S.C. Abbreviation, in reference to insulated wire conductors, meaning single-silk covered.

STABILIZED-FEEDBACK AMPLIFIER. Amplifier in which the gain is kept almost constant despite changes in working conditions, by the use of a considerable amount of negative feedback.

STABILIZED MAINS UNIT. Mains unit, including valves or neon tubes, for maintaining a constant output voltage in spite of variations in load and mains-supply voltage. See MAINS UNIT, VOLTAGE STABILIZER.

STABILIZER. Synonym for VOLTAGE STABILIZER.

STACK. Synonym for TIER.

STAGE. Complete unit of an amplifying or receiving chain of valves, comprising a valve and its ancillary components.

STAGE GAIN. Amount of amplification given by a single stage (see STAGE). A useful measure of the efficiency of any given system of radio-frequency or audio-frequency amplification, or, in particular, of the performance of some combination of valve and inter-valve coupling.

STAGGERED AERIAL. Synonym for END-FIRE ARRAY.

STAMPING. Thin sheet of metal of any size the shape or form of which is determined by a tool, shaped along a horizontal plane. When the tool is pressed against the sheet, it cuts out a stamping of the same shape as the face of the tool. Transformer laminations are sometimes, for this reason, called stampings.

STANDARD BEAM APPROACH. See BEAM APPROACH, LORENZ BLIND-LANDING SYSTEM.

STANDARD CABLE. Uniform transmission line having certain specified constants. The standard is chosen as a basis for comparison of other uniform transmission lines. The standard cable used in Great Britain for telephone measurements has the following constants per loop mile: resistance, 38 ohms; capacitance, 0·054 μF; inductance, 1 mH. Networks can be made which simulate the electrical characteristics of the standard cable or other cables.

STANDARD FIELD GENERATOR. Instrument used for calibrating field-strength measuring equipment. It consists of an oscillator feeding an aerial and, properly adjusted, produces a known field strength at a certain distance from the aerial.

STANDARD SIGNAL GENERATOR. Modulated oscillator the output of which is variable and calibrated in frequency, amplitude and (sometimes) modulation depth; it is used for testing radio apparatus, particularly receivers. The modulation frequency is usually 400 c/s, and the depth of modulation, when fixed, is 30 per cent.

STANDARD-WAVE ERROR. Extent of the error shown by a direction-finder when dealing with a wave having certain assumed properties as to the direction of polarization. Certain errors are calculable if a wave of given polarization characteristics is assumed; for such purposes there is a conventional standard wave, in which there are equal horizontally polarized and vertically polarized components.

STANDING WAVE. Non-uniform distribution of current and voltage in a conductor which may occur when a reflected wave, travelling in the opposite direction, is superimposed on the forward-travelling wave. Such a condition is characterized by the presence of nodes and antinodes along the conductor. The term is also applied to a similar distribution of electromagnetic fields or sound intensity.

STANDING-WAVE AERIAL. Aerial along which there is a stationary pattern of voltage and current nodes and antinodes, spaced half a wavelength apart. This is the normal condition of an aerial in which there is an impedance mismatch to the energy source; it may be explained as the result of an interference pattern between wave energy travelling to the aerial from the generator, and a second set of current and voltage waves reflected back from the aerial.

START-STOP SYSTEM. In telegraphy, a system by which a "start" signal is transmitted prior to the transmission of the signal representing a character or letter, and a "stop" signal is transmitted at the end of the character or letter. The start signal trips the printing apparatus so that it may be capable of correctly scanning the character or letter transmitted; and the stop signal restores the apparatus to rest.

STATIC. See ATMOSPHERICS.

STATIC CHARACTERISTIC. Characteristic graph, particularly of a valve, determined under *static* conditions; that is, with all necessary steady potentials applied, but no signal voltages. Such characteristics are useful as a means of comparing valves, and in conjunction with load lines give useful information of the performance to be expected under normal operating conditions. But such conditions may be better represented by *dynamic* characteristics. See DYNAMIC CHARACTERISTIC, VALVE CHARACTERISTIC.

STATIC FREQUENCY-CHANGER. Frequency-changer using a magnetic modulator.

STATIONARY WAVE. Synonym for STANDING WAVE.

STEM. Synonym for FOOT.

STEP-DOWN TRANSFORMER. Transformer having fewer secondary- than primary-winding turns. Thus the voltage appearing across the secondary winding is less than the source voltage applied to the primary winding. In specifying the transformer ratio, the number relating to the primary should be put first. A step-down transformer might be described as having a "10-to-1" step-down turns ratio, and a step-up transformer as having a "1-to-10" step-up turns ratio. See TRANSFORMER RATIO.

STEP-UP TRANSFORMER. Transformer having more secondary-winding turns than primary-winding turns. Thus the voltage appearing across the secondary winding is greater than the source voltage applied to the primary winding. See STEP-DOWN TRANSFORMER, TRANSFORMER RATIO.

STEREOPHONIC REPRODUCTION. Reproduction of sound in such a manner as to create the illusion of true aural perspective. A typical method is illustrated in Fig. 40, from which it will be seen that two loudspeakers are placed in an auditorium at positions corresponding with the positions of two microphones in a concert hall.

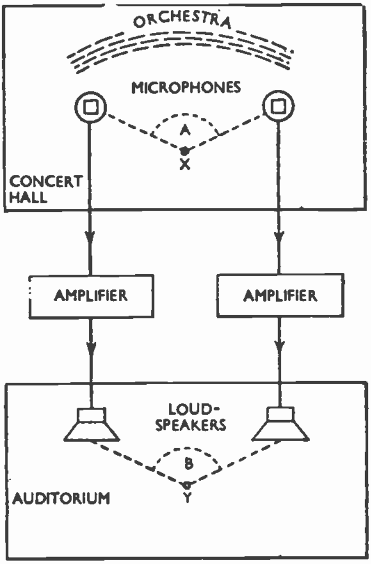


Fig. 40. Stereophonic reproduction of music by two separate sound channels. A listener at *Y* in the auditorium would have the same aural perspective as when situated at *X* in the concert hall, angles *A* and *B* being equal.

By using two separate sound channels, a listener in the auditorium placed at the point *Y* will have the same aural sensations as he would if listening in the concert hall at a point *X*. For full stereophonic effect, the angle *A* should equal angle *B*.

STEREOSCOPIC REPRODUCTION. Method of picture reproduction to give effect of solidity, i.e. vision in three dimensions. Solidity is given to any object by the use of two simultaneous viewpoints corresponding to the two viewpoints provided by the human eyes. The normal camera and normal picture is not stereoscopic; it is the reproduction of a view as seen by one eye—the single lens. Stereoscopic reproduction necessitates the projection of *two* pictures, giving the viewpoints of two lenses simultaneously. And these pictures must be viewed by the two eyes of the observer *separately*, one eye looking at one picture and the other eye at the other picture.

The stereoscopic camera for photography uses two lenses, separated by a distance equal to that between the human eyes, and registering each image on separate film. By printing on separate pieces of paper, and by then looking at the two photographs through a viewer that ensures that each eye looks only at the picture from the lens corresponding to it, a picture in three dimensions is seen.

Various systems have been tried to provide stereoscopic reproduction of cinema pictures and of television pictures. One system, the Anaglyph, provided for simultaneous projection of two pictures, taken by a two-lens camera, the pictures on the screen being of different colour. By viewing the screen through spectacles fitted with colour filters, the pictures were "sorted out" so that each eye saw only the picture that belonged to it, and stereoscopy was achieved.

Another similar system employed plane-polarized light and special de-polarizing spectacles. A third system threw the pictures on the screen alternatively, and they were viewed through a special device which synchronously permitted viewing by alternate eyes.

Similar devices can be applied to television, the pictures being reproduced on separate cathode-ray screens; but such reproduction necessitates transmission on two distinct channels, which means a great deal of equipment and a wide band of frequencies.

An advance on this was made by the Marconi Company, and this provides for alternate scanning of a picture at the sender through two storage cameras with lenses set apart by the necessary distance. The images are then scanned in alternate lines, so that first a line from No. 1 camera is sent and then a line from No. 2, then back to No. 1 for line 3, and to No. 2 for line 4, and so on. In other words, a form of interlacing was employed, but using alternate cameras for alternate lines.

At the receiver, the signals coming in are the interlaced signals from the two cameras. They are fed to one cathode-ray tube which is viewed through a special grating so arranged that it cuts off alternate lines from one eye, allowing, say, the right eye to see only the 1st, 3rd, 5th, etc., lines, and the left eye to see only the 2nd, 4th, 6th, etc., lines. Since these lines correspond to those of the two vision pick-ups, with lenses corresponding to right and left eyes, stereoscopic reproduction is achieved. Although not in use commercially, the system is an interesting attempt to solve the problem.

STILL-PICTURE TRANSMISSION. See FACSIMILE TELEGRAPHY.

STOP FILTER. See BAND-STOP FILTER, NULL NETWORK.

STOPPER. Small resistor or inductor connected in the grid or anode circuit of a valve to prevent parasitic oscillation. See PARASITIC OSCILLATION, PARASITIC STOPPER.

STORAGE BATTERY. Battery of accumulator cells.

STORAGE CAMERA. Apparatus for the conversion of a scene or picture into an electrical pattern. Two forms of storage camera are the Iconoscope, and its British development, the

Emitron camera. The device was produced originally by Zworkykin of America.

An optical lens system focuses an image on to the surface of a screen composed of a mosaic of extremely small photocells (see MOSAIC). These cells are deposited on a mica sheet backed by a metal plate, as shown in Fig. 41. The effect of imposing the image on the mosaic is to release electrons from the active surface of the cells, the emission being dependent on the intensity of the light on each cell.

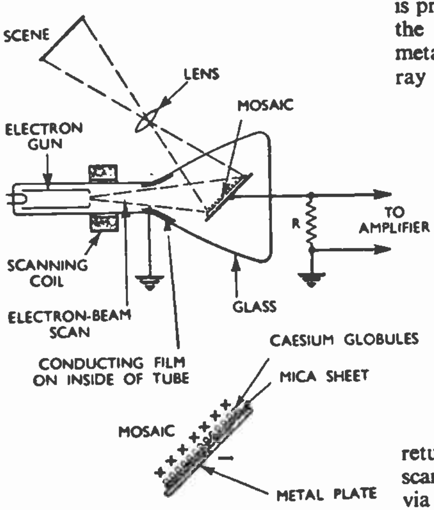


Fig. 41. The mosaic of a storage camera is scanned by an electron beam which neutralizes the positive charges of electricity formed on the cells by the action of light. As the cells are discharged by the cathode ray, the potential developed across *R* is proportional to the amount of light falling on the part of mosaic being scanned.

Since the cells are insulated from each other, their active portions, the metal backing plate and the separating mica form minute capacitors which are charged by the emission from the cells undergoing light activation. Each capacitor develops a charge proportional to the intensity of the light and the time during which the light has been directed on to the cell.

By scanning the mosaic with an electron beam, each of the small capacitors can be discharged in turn, since the emission, under the influence of light, causes them to lose electrons and become positively charged at the surface of the mosaic.

The voltage changes thus created are communicated to the external circuit. One connexion to the circuit is provided by the metal plate backing the mica sheet; the other by the metallic lining to a part of the cathode-ray tube, which acts as an electron return. The electrons comprising the scanning-beam return to the cathode via this metallic lining after they have accomplished their task of discharging the tiny capacitors.

The camera is used in a similar way to an ordinary cinematograph camera. The optical lens will have, usually, a focal length of between 2 in. and 20 in. The camera is not uniformly sensitive to all colours, being least sensitive in the middle of the spectrum and most sensitive at the red and violet ends. This limitation of the camera has to be borne in mind, not only when artificial light is used and the infra-red content may be large, but when outside broadcasts are carried out.

It is possible on a very hot day, when grass is in the picture, for the apparent sensitivity in the green part of the spectrum, usually below that of red or violet, to increase by a noticeable extent. This appears to be due, not to visual light, but to infra-red rays reflected from the ground. Thus the green grass will be emphasized while green trees will not be so well reproduced, apparently because of lack of infra-red reflection.

Care has to be taken in using the storage camera that the mosaic is not exposed to very bright light. If this occurs, the emission from the caesium (the photo-sensitive substance used) is excessive and the cells are de-sensitized. A dark patch appears on any image reproduced from such a camera over the area "burned" by the excessive light exposure.

STRAIGHT-LINE FREQUENCY CAPACITOR. Form of variable capacitor so constructed that, when used to tune an inductor in a resonant circuit, the frequency of resonance is proportional to the movement of the control. If a dial is attached to the control knob and marked with the resonant frequency, the divisions would be equally spaced. See VARIABLE CAPACITOR.

STRAIGHT-LINE FREQUENCY CONDENSER. See STRAIGHT-LINE FREQUENCY CAPACITOR.

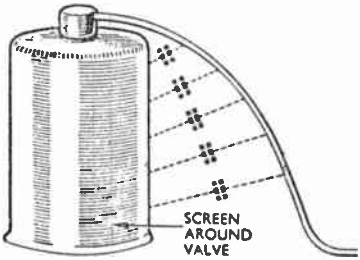


Fig. 42. An example of stray capacitance (represented by dotted capacitors) is that which may occur between a lead and an earthed valve screen.

STRAIGHT-LINE RECTIFICATION. Synonym for LINEAR RECTIFICATION. See LINEAR DETECTION.

STRAIGHT-LINE WAVELENGTH CAPACITOR. Form of variable capacitor so constructed that, when used to tune an inductor in a resonant circuit, the wavelength at resonance is proportional to the movement of the control. If a dial is attached to the control knob and marked with the wavelength at resonance, the divisions would be equally spaced. See VARIABLE CAPACITOR.

STRAIGHT-LINE WAVELENGTH CONDENSER. See STRAIGHT-LINE WAVELENGTH CAPACITOR.

STRAIGHT RECEIVER. Receiver circuit not employing the superheterodyne principle, any radio-frequency amplification being done at the actual signal frequency. See RADIO RECEIVER, RECEPTION, SUPERHETERODYNE RECEPTION.

STRAIGHT SCANNING. Synonym for SEQUENTIAL SCANNING.

STRANDED WIRE. Wire built up from a number of separate strands of small gauge in order to give increased flexibility.

STRAY CAPACITANCE. Unintentional and usually unwanted capacitance between one part of a circuit and another. Stray capacitance is of some importance in radio design, because it may be the cause of energy loss to earth, as in Fig. 42, or of unwanted energy-transfer in, for example, an amplifier. It may be mitigated by suitable spacing of parts (to reduce its magnitude) or the interposition of an earthed metallic screen. See SCREENING.

STRAY CAPACITY. Synonym for STRAY CAPACITANCE.

STRAY PICK-UP. See DIRECT PICK-UP.

STRAYS. Obsolete term for ATMOSPHERICS.

STRETCHED-DIAPHRAGM MICROPHONE. Microphone in which the diaphragm is secured around its periphery under conditions of radial stretching. By suitable adjustment to the tensioning of such a diaphragm, the frequency of its natural resonance may be increased beyond the range of normal hearing. See MICROPHONE.

STRIKING VOLTAGE. Voltage at which the gas in a glow-tube ionizes. See GLOW-TUBE, IONIZATION, IONIZATION POTENTIAL.

STRIP-FREQUENCY. Synonym for LINE-FREQUENCY.

STRIP-MOUNTED SET. Group of narrow panels fitted together to form a unit. See PANEL, PANEL-MOUNTING.

STROBOSCOPE. Speed-checking device extensively used on gramophone reproducing turntables. It may take the form of a series of black and white markings on the periphery of the rotating member, a small disc having black and white radial divisions which can be placed over the shaft, or a series of holes in the periphery of the moving part which are illuminated from an A.C. source.

In each case, when the black and white markings or holes appear to be stationary, correct speed is indicated. The number of holes or markings required can be calculated from $S = \frac{2f \times 60}{n}$, where S is the number of markings or holes, f is the frequency of the lighting supply in c/s, and n is the required speed of rotation in r.p.m.

STUDIO. See BROADCASTING STUDIO.

STUDIO BROADCASTING. Term used to differentiate between the broadcasting of programmes made in a broadcasting studio and OUTSIDE BROADCASTING (q.v.).

STUDIO-CONTROL CUBICLE. Cubicle, next to a broadcasting studio, with a glass window looking into the studio. In the cubicle various controls are located so that a producer or programme engineer can monitor programmes performed in the studio. Many methods have been tried to enable a skilled person to monitor programmes. Monitoring is the process of controlling the relative levels of the outputs from different microphones in different positions, adding reverberation, giving visual signals to studio performers, rehearsing performers, and "mixing-in" gramophone recordings to the programme. The B.B.C. has standardized the studio-control cubicle used for this purpose.

A typical cubicle (Fig. 43) has a desk facing a sound-proof window through which the whole of the studio may be seen. A panel mounts several controls for mixers, level control, reverberation control and so on, and headphones or loudspeakers are provided so that the programme may be heard as it goes on the air. As several microphones may be in use at one time, "effects" are obtained from recordings by use of a pick-up which is operated by an assistant. A microphone may be used during rehearsals to speak to performers in the studio. The output from the cubicle is taken via the control room and its line amplifiers to the sender; or it may be transmitted over trunk lines when simultaneous broadcasting is taking place.

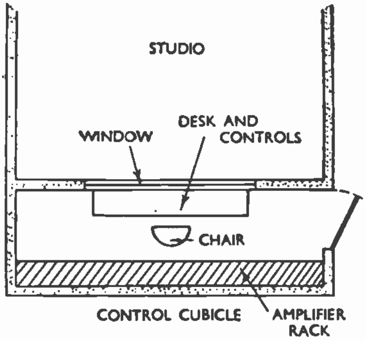


Fig. 43. Plan of a studio-control cubicle in which a producer or engineer is able to carry out the monitoring of broadcast programmes.

See BROADCASTING, CONTROL ROOM, SIMULTANEOUS BROADCASTING.

STYLUS. In gramophone recording (see ELECTRICAL RECORDING), the tool which cuts the groove. It is usually a V-shaped synthetic sapphire, slightly rounded at the tip. In gramophone reproduction (see GRAMOPHONE PICK-UP), however, it is the reproducing needle.

SUB-AUDIO FREQUENCY. Frequency below the lower limit of the range of the human ear. The lower limit varies with individuals, but is in the neighbourhood of 16 c/s.

SUB-MODULATOR. Penultimate stage in the modulating-wave amplifier of a radio sender. See MODULATOR.

SUPER-AUDIO FREQUENCY. Frequency above those employed in speech and music transmission circuits, usually within the frequency limits of 8,000–25,000 c/s.

SUPER EMITRON. Special form of vision pick-up developed by Marconi-E.M.I. to enable short-focus lenses to be used. Because of the size of the photo-sensitive mosaic in the normal storage camera employed in Britain, it is impossible to use a short-focus lens, and the shortest focus permissible is 6·5 in. This is a disadvantage as it limits the depth of focus.

The Super Emitron enables a short-focus, small-diameter lens to be used, but does not employ a mosaic as does the storage camera. Instead, the image from the lens is focused on a transparent photo-cathode, on the reverse side of which is a continuous coating of photo-sensitive material. The photo-cathode is only a few millimetres in diameter and is circular, and is so placed in the cathode-ray tube that the lens can be close to it, providing the necessary short focal length.

While light is on the photo-cathode, electrons are given off from each part of the cathode in proportion to the amount of light falling on it. These electrons are then focused on a mica plate by means of a coil carrying a direct current. The result is that the mica plate is bombarded by electrons situated in the same relative positions as when they left the cathode.

The mica plate is set at an angle so that it may be scanned by the electron beam from the cathode of the cathode-ray tube, in the same way as the mosaic is scanned in the standard type of camera tube. Adjustments on the Super Emitron tube are more critical than on the normal type, since it is important that the coils focusing the electrons from the photo-cathode on to the mica electrode are correctly placed, otherwise curvature and distortion result. See STORAGE CAMERA.

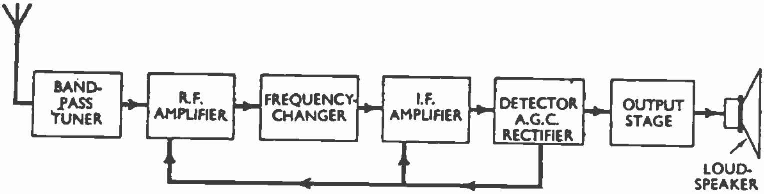


Fig. 44. Block diagram of a better-class superheterodyne receiver. The upper arrows show the path of a signal through the apparatus, while the lower arrows indicate the distribution of the automatic gain-control voltages.

SUPER-FREQUENCY WAVE. Radio-wave between the frequency limits of 3,000 to 30,000 Mc/s, that is, within a wavelength range of 1–10 cm. See CENTIMETRIC WAVE.

SUPERHETERODYNE RECEIVER. Receiver in which the carrier frequency of incoming signals is converted to the same fixed (intermediate) frequency and amplified at this frequency before detection (Fig. 44). At first regarded as a circuit for de luxe receivers only, the superheterodyne arrangement has become standard practice for all broadcast receiving sets, except the smallest, because, while being selective, it causes less attenuation distortion than the straight, or T.R.F., receiver.

Its outstanding quality is the high selectivity which it gives without involving the use of a large number of circuits all accurately tuned to the carrier frequency. If similar selectivity were attempted with a straight receiver, that is, one using radio-frequency amplification of the signals without irst converting them to a fixed frequency, it would be necessary to use some five or six tuned circuits, with resultant complexity and expense.

The simplest possible superheterodyne, on the other hand, need contain but one circuit tuned to the carrier frequency. The rest of its tuned circuits would be set to a fixed frequency when the receiver was first commissioned, and thereafter left alone. The frequency-setting device would probably take the form of small adjustable, rather than variable, capacitors, and the whole assembly would be correspondingly compact and inexpensive.

A further advantage of the principle of amplifying all signals at the same fixed frequency is that the tuned circuits wherein this is done can be arranged to give some carefully planned shape of resonance curve. In this way it is possible for the designer to ensure that his receiver shall provide uniformly good quality of audio-frequency reproduction, regardless of the carrier frequency of the sender.

The straight receiver, with numerous tuned circuits, on the contrary, tends persistently to give a varying degree of both selectivity (hence quality of reproduction) and amplification at different points on the tuning scale.

The simplest superheterodyne receiver has only one signal-frequency tuned circuit, although more ambitious receivers may use as many as three such circuits. In the simple type, therefore, there are two tuned circuits in addition to the intermediate-frequency circuits. Of these, one is a receiving circuit proper, tuned to the carrier frequency, and the other is that in which the local oscillations are generated. The latter will, of course, be tuned at all times to a frequency differing from that of the sender by the intermediate frequency.

Of methods of combining the local with the incoming oscillations there is great variety. In modern practice, however, some form of multi-electrode valve is commonly the frequency-changer. It is then a straightforward matter to apply the signal voltages to one control electrode, and the local oscillations to another, thus causing both frequencies to appear in the anode circuit. If the latter contains a circuit suitably tuned, the required intermediate frequency can then be extracted and made available for transfer to the intermediate-frequency amplifying circuits.

A valve much favoured as a frequency-changer is the triode-hexode, wherein the triode section provides the local oscillator, and the hexode portion serves to combine the two sets of oscillations (Fig. 45). Since the triode grid is connected internally to one of the control grids of the hexode, the mixing process is, so to speak, automatic.

Without a frequency-changer of the multi-electrode type, the problem is of some difficulty. It is not easy to inject the local oscillations into the receiving circuit without causing

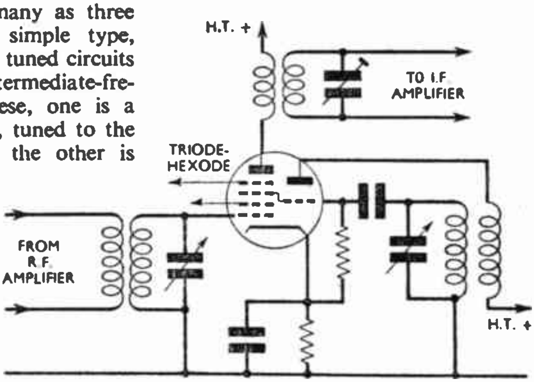


Fig. 45. Typical triode-hexode frequency-changer circuit of the kind widely used in superheterodyne broadcast receivers.

undesirable interaction between the tuning of the local oscillator and that of the signal-frequency circuits. This makes accurate ganging difficult, and there is, moreover, considerable risk of radiating the local oscillations, to the annoyance of other listeners in the neighbourhood. The popularity of the multi-electrode frequency-changer is, therefore, understandable.

The intermediate-frequency signal generated by the frequency-changer passes to one or more amplifying stages, almost always employing variable-mu valves. Here the inter-valve coupling circuits are commonly of transformer type, often with separately-tuned primary and secondary. Careful choice or adjustment of the primary-secondary coupling then enables a band-pass effect to be obtained, with consequent improvement in fidelity of audio-frequency reproduction.

In some of the more elaborate broadcast receivers, some control over this coupling is placed in the hands of the user. He is thus able to choose either a band-pass effect for high fidelity on his local stations, or a narrow-peak response curve, giving high selectivity (at some sacrifice of quality), for distant listening.

After passing through the intermediate-frequency amplifier, the signal reaches the detector, generally a diode, and often one of a pair of which the other provides the voltages for automatic gain-control purposes.

The output from the detector may or may not be of sufficient amplitude to be applied direct to the output valve, depending upon the amount of pre-detector amplification that has been used. Sometimes, therefore, a superheterodyne receiver will be found to include a stage of low-gain audio-frequency amplification between detector and output stage.

On the selection of the best intermediate frequency there has been much controversy. Originally, very low frequencies, such as 110 kc/s, were used, chiefly because of the very high gain and selectivity which can be obtained at these frequencies. Unfortunately, such low intermediate frequencies tend to give considerable trouble in the form of second-channel and image-frequency interference, particularly when short-wave reception is attempted. Hence, whereas 110 kc/s was a usual intermediate frequency when the superheterodyne was a new thing, frequencies of the order of 465 kc/s are now common.

These design improvements have eliminated most of the drawbacks which initially delayed the general adoption of the superheterodyne for broadcast reception. In the more elaborate receivers, a further step is taken to remove all traces of second-channel trouble, by adding a stage of radio-frequency amplification between the aerial and the frequency-changer. See BAND-PASS TUNING, PRE-SELECTION, SECOND-CHANNEL INTERFERENCE, SUPERHETERODYNE RECEPTION.

SUPERHETERODYNE RECEPTION. System in which all incoming signals are converted to a new, fixed frequency known as the intermediate frequency, and are amplified at that frequency before detection. The change of frequency is accomplished by causing the incoming signal to beat with a locally-generated oscillation, as in beat reception, but with this difference: instead of producing an audible beat-frequency, the local oscillation is adjusted to yield a beat which is far above audibility and can, in fact, still be regarded as a radio frequency (hence the term supersonic heterodyne reception).

The new frequency can be treated like any other radio-frequency signal and passed into a suitable amplifier permanently tuned to some predetermined frequency. This, known as the intermediate-frequency amplifier, is the special feature of the superheterodyne. It can contain many tuned circuits and, if necessary, numerous valves, giving high selectivity and amplification; and yet, since it works on a fixed frequency, it involves no complicated tuning and ganging arrangements.

The valve which generates the beating oscillations is known as the local oscillator, while that which actually combines these oscillations with the signal and passes the new frequency to the intermediate-frequency amplifier is called the mixer. Where, however, both functions are performed by the same valve, it is known as the frequency-changer. See BEAT RECEPTION, SUPERHETERODYNE RECEIVER.

SUPERPOSED CIRCUIT. Synonym for PHANTOM CIRCUIT.

SUPER-REGENERATIVE RECEPTION. System in which signals are amplified by regeneration to a greater extent than is possible with normal circuits. The regenerative valve, in fact, oscillates briskly, but it is taken in and out of oscillation, i.e. it is quenched at a high, sometimes supersonic, frequency. When the quench frequency is a high audio frequency, a continuous high-pitched whistle is heard, unless a suitable filter is provided to exclude the quench frequency from the headphones or A.F.-amplifying circuits. See FLEWELLING CIRCUIT, QUENCHING, QUENCHING OSCILLATOR.

SUPERSONIC AMPLIFIER. Synonym for INTERMEDIATE-FREQUENCY AMPLIFIER.

SUPERSONIC CELL. Device in which a beam of light can be controlled by means of the DIFFRACTION (q.v.) caused by sound waves of a supersonic frequency in a liquid.

SUPERSONIC FREQUENCY. Oscillation within the radio-frequency range generated by the action of a receiver. Such oscillations are produced in superheterodyne and super-regenerative receivers. In the former, the supersonic frequency produced is known as the intermediate frequency, and in the latter it is called the quench frequency. The term supersonic frequency is used to distinguish this frequency from that of the signal arriving at the aerial. See INTERMEDIATE FREQUENCY, QUENCHING.

SUPERSONIC HETERODYNE RECEIVER. See SUPERHETERODYNE RECEIVER.

SUPERSONIC HETERODYNE RECEPTION. See SUPERHETERODYNE RECEPTION.

SUPPLY FREQUENCY. Frequency in the range normally used for power and lighting supplies of alternating current. The range is about 25–75 cycles per second (c/s), and the standard value in Great Britain is 50 c/s and in the U.S.A. 60 c/s.

SUPPLY TERMINALS. Terminals at which connexion can be made to an electric power-supply system.

SUPPRESSED-CARRIER MODULATION. Amplitude modulation producing a modulated wave containing sideband waves but no carrier wave. If two carrier waves of the same frequency are of equal amplitude and 180 deg. out of phase, their resultant is zero. If a wave modulates both of these carrier waves, increasing the amplitude of one carrier wave as much as it reduces the amplitude of the other, the resultant wave is a suppressed-carrier amplitude-modulated wave.

Fig. 46 shows two modulated waves in which the carrier waves are 180 deg. out of phase, the same modulating wave increasing the amplitude of one of the waves as it decreases the other. The resultant wave (c) is also shown. Before modulation takes place, the resultant is zero; and at the instant when the modulating wave changes sign, the resultant is also zero. During one half-cycle period of the modulating wave, one of the carrier waves provides the output wave; and in the other half-cycle period, the other carrier wave provides the output. See AMPLITUDE MODULATION, SIDEBAND WAVE.

SUPPRESSED-CARRIER MODULATOR. Modulator arranged so that the modulated wave contains only sideband waves and no carrier waves. The RING MODULATOR (q.v.) is a suppressed-carrier modulator, as are

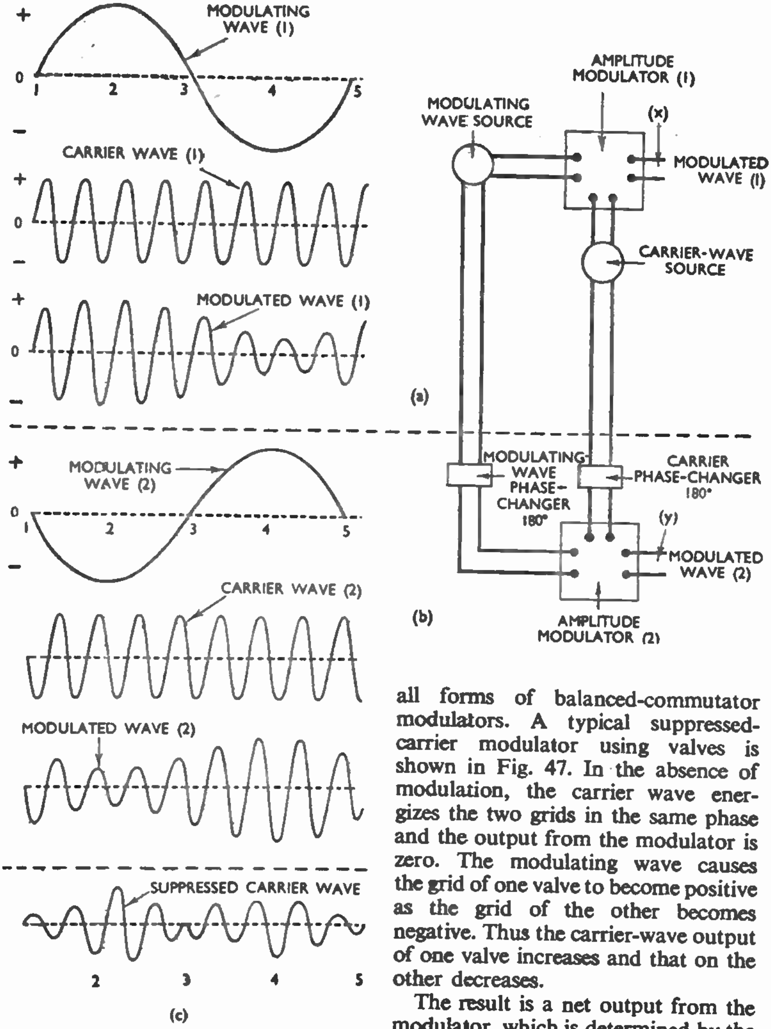


Fig. 46. Diagrams (*a*) and (*b*) show the modulating, carrier and modulated waves in regard to amplitude modulators 1 and 2 respectively. The carrier and modulating waves are 180 deg. out of phase in the two modulators, and the suppressed-carrier wave (c) results from combining the modulated wave from each; i.e., by connecting points (*x*) and (*y*) in the circuit diagram.

all forms of balanced-commutator modulators. A typical suppressed-carrier modulator using valves is shown in Fig. 47. In the absence of modulation, the carrier wave energizes the two grids in the same phase and the output from the modulator is zero. The modulating wave causes the grid of one valve to become positive as the grid of the other becomes negative. Thus the carrier-wave output of one valve increases and that on the other decreases.

The result is a net output from the modulator, which is determined by the amplitude of the modulating wave. As the modulating-wave voltage passes through zero, the phase of the carrier-wave output from the modulator reverses, showing that the output is a suppressed-carrier modulated wave. Each side of the system may be regarded as a grid modulator and the two outputs contain amplitude-modu-

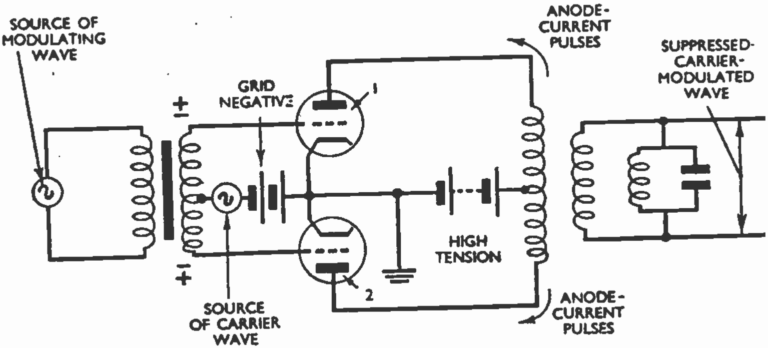


Fig. 47. Suppressed-carrier modulator, using valves. When the modulating wave increases the positive bias on the grid of valve 1 and increases the negative bias on the grid of valve 2, the anode current pulses taken by 1 are greater than those taken by 2, and a voltage at the transformer secondary results. When the modulating wave reverses, 2 has the predominant effect; thus the phase of the output wave changes over with reversals of the modulating wave.

lated waves with carrier waves 180 deg. out of phase. Thus it is a suppressed-carrier modulator. See COMMUTATION MODULATION, GRID MODULATION, RING MODULATOR, SUPPRESSED-CARRIER MODULATION.

SUPPRESSED-CARRIER SYSTEM. Transmission system in which the carrier is provided by an oscillator at the receiver and is not radiated by the sender. See SINGLE-SIDEBAND SYSTEM.

SUPPRESSOR GRID. Grid-type electrode of a pentode which collects secondary electrons emitted by the anode and prevents these reaching the screen grid (Fig. 48). It is located between anode and screen grid and is connected to cathode or control grid. It is thus at either zero or cathode potential, and produces a negative potential gradient in the space between suppressor grid and anode. The existence of this gradient prevents the secondary electrons from reaching the screen grid. See BEAM POWER VALVE, GRID, PENTODE, TETRODE, VIRTUAL CATHODE.

SUPPRESSOR-GRID MODULATION. Circuit in which amplitude modulation is obtained by applying the modulating wave to the SUPPRESSOR GRID (q.v.) of a pentode.

SURFACE-CHARGE EFFECT. Effect produced in a valve when electrons collect upon the inside surface of the bulb. Electrons may escape from the space between electrodes and, according to the residual field acting upon them, end by hitting the inside of the glass bulb. As they thus collect and do not leak away, they set up a field, which combines with the field due to the electrode potentials and so alters

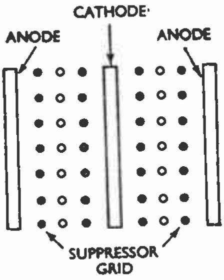


Fig. 48. Diagrammatic section through a pentode showing the relative position of the suppressor grid, which collects electrons produced by the secondary emission at the anode.

the performance of the valve, possibly unfavourably. Precautions are taken in the design of the electrode structure to prevent a serious escape of electrons and thus reduce the surface-charge effect to a minimum. See END PLATE, MAGNETRON.

SURFACE NOISE. See SCRATCH.

SURFACE RAY. Synonym for SURFACE WAVE.

SURFACE WAVE. That component of the ground wave which travels along the surface of the earth. At all except very high frequencies, the surface wave is the only component of the ground wave, but at very high frequencies, where the height of the aerial may be several wavelengths, the ground wave consists of the surface wave and an additional component known as the space wave. See GROUND WAVE, SPACE WAVE.

SUSCEPTANCE. Reciprocal of reactance; it can be defined as the ratio between the applied voltage and the alternating current which flows in a purely reactive circuit; that is, a circuit without resistance.

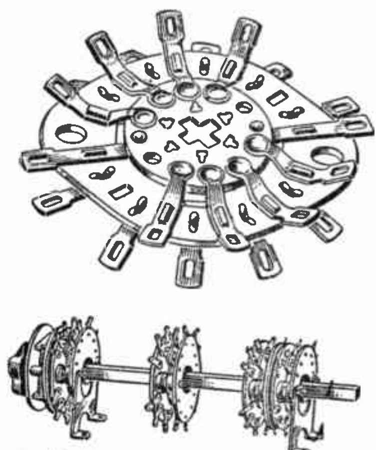


Fig. 49. Rotary wafer type of multi-way switch widely used in radio equipment. The lower drawing shows how several such units are ganged and mounted on a common control spindle.

SUSCEPTIBILITY. Property of a magnetic circuit which is proportional to the ratio of magnetic field strength to magnetization intensity.

SWEEP CIRCUIT. In a cathode-ray tube, the circuit supplying current to one pair of deflecting coils or voltage to one pair of plates while the current or voltage under test is applied to the second pair. Thus a time base is a sweep circuit.

S.W.G. Abbreviation for standard wire gauge.

SWING. Difference between the extremes of voltage or current in a wave (see DOUBLE AMPLITUDE, PEAK VALUE); or, in another sense, the angles through which the search coil of a radiogoniometer is turned when determining a bearing. Thus, in the latter sense, signals of equal strength might be heard with radiogoniometer settings of 31 and 27 deg. The average is $\frac{58}{2} = 29$ deg., and the swing is 2 deg. See DIRECTION-FINDER.

SWITCH. Mechanical device for making and breaking a circuit, or for selectively connecting one of several current paths. A switch is an essential component of every electric circuit. The types and functions of switches are perhaps more numerous and varied than any other class of component. The number of separate conducting paths or poles which the switch opens or closes simultaneously is indicated by the description "single-pole," "double-pole," "multi-pole," etc. The number of current paths or ways which may be selectively connected to a common path or to each other is indicated by the description "one-way," "two-way," "multi-way," etc.

Manual switches for controlling D.C. power supplies have a large contact movement and a snap action; that is, the contacts are opened with an action which, once it is initiated, is independent of the rate of movement of the operator. The short transit time quickly damps any tendency to arc. Similar switches are commonly used

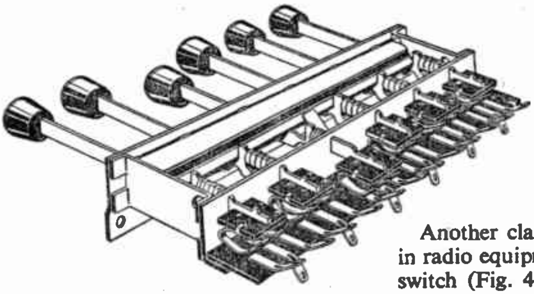


Fig. 50. Multiple push-button switch unit showing the sliding and fixed contacts. The return spring on the shaft of a depressed button is automatically released when a second button is pushed.

for A.C. supplies, but here the arc is extinguished as the current passes through zero, and types without snap action and with much smaller contact movement, called microswitches, are being increasingly used at standard voltages for controlling currents up to 10 amp.

External to telecommunications equipment, standard industrial-type switches are used. Internally, they are usually of special design to occupy the minimum of mounting space. Switches of special design for use in telephone and telegraph equipment are described under KEY (q.v.).

Another class of switch much used in radio equipment is the rotary wafer switch (Fig. 49). This is a multi-way and often multi-pole switch. It has one or more sets of wafers, each consisting of a disc in the centre of a ring, both of insulating material and both bearing contacts. The ring is attached to the framework and is stationary. The disc is attached to the common controlling spindle which is rotatable with a "click" action. The design is very flexible and allows a large variety of connexions to be made with the minimum of inter-capacitance between the different points. A multiple push-button switch unit is illustrated in Fig. 50.

SWITCHED OMNIBUS SYSTEM. See OMNIBUS TELEGRAPH SYSTEM.

SYMBOLS USED IN RADIO ENGINEERING

Term	*Symbol*	*Term*	*Symbol*
Admittance	Y	Magnetomotive force	F
Aerial current	I_{ae}	Mutual inductance	M
Aerial radiation-resistance	R_r	Mutual conductance	g_m
Amplification factor (valve)	μ	Permeability (absolute)	μ_o
Angular frequency	ω	Permeability (relative)	μ
Capacitance	C	Permittivity (absolute)	$\varkappa_o$
Conductance	G	Permittivity (relative)	$\varkappa$
Current	I	Period	T
Effective height	h_e	Phase velocity	v
Electric force	$\mathcal{E}$	Potential difference	V
Electric flux density	D	Ratio reactance to resistance	Q
Electromotive force	E	Quantity of electricity	Q
Frequency	f	Resistance	R
Fundamental frequency	f_1	Reactance	X
Natural frequency	f_o	Radiation efficiency	η_r
Impedance	Z	Reluctance	S
Magnetic flux	Φ	Self-inductance or inductance	L
Magnetic flux density	B	Slope resistance	r_a
Magnetic field strength	H	Time	t
Magnetization intensity	J	Wavelength	λ

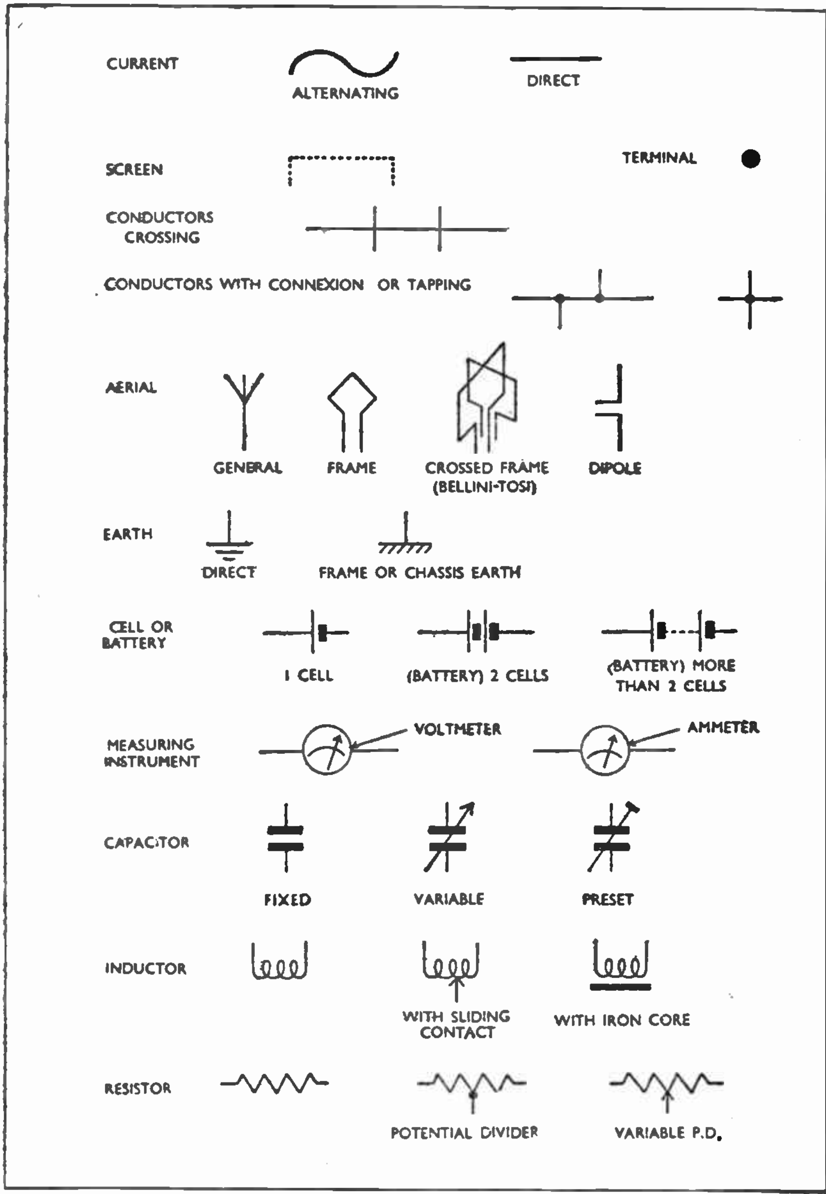
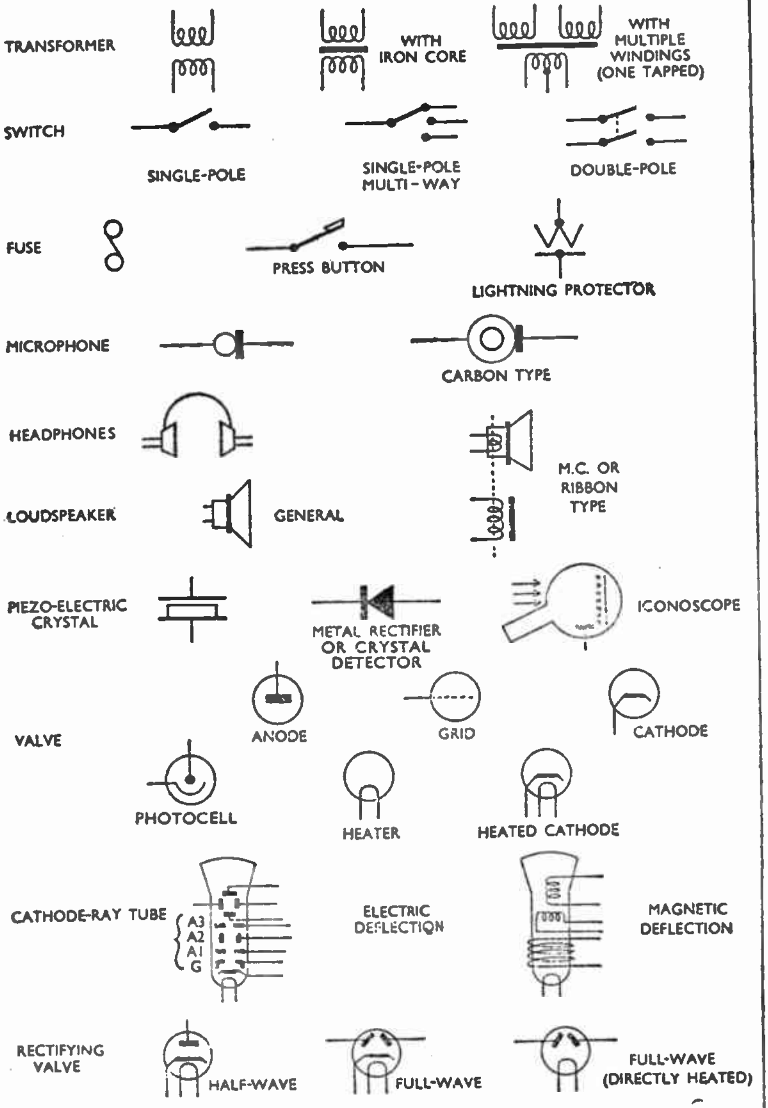


Fig. 51. Selection of the basic symbols generally used in the diagrams appearing in this encyclopaedia; the majority are based on recommendations made by the



British Standards Institution. It is sometimes convenient, however, to use more descriptive symbols in order to distinguish between specific types of component.

SWITCHING. Changing of circuit paths by means of switches. Thus telephone switching is a method of connecting different instruments and circuit points together by means of switches. "Switching-on" and "switching-off" means applying power to, or removing power from, equipments or apparatus by switches; a "switch panel" is a panel carrying switches. See SWITCH, OMNIBUS TELEGRAPH SYSTEM.

SYKES MICROPHONE. Early type of moving-coil microphone of massive construction. A freely-suspended coil forms the diaphragm which, under the pressure of the sound waves, moves in the field generated by a powerfully energized electromagnet, such movement producing e.m.f.s having the frequency of the sound.

SYMBOLS. Most of the approved and widely recognized symbols used in radio formulae are set out in the table on page 601. Standard basic symbols for the representation of components in diagrams appear in Fig. 51 on pages 602 and 603.

SYMMETRICAL DEFLECTION. In a cathode-ray tube, deflection of the electron beam by applying to a pair of deflector plates a voltage such that the p.d. between one plate and the final accelerator is always equal in magnitude but opposite in sign to that between the other plate and the final ACCELERATOR (q.v.).

SYNCHRONISM AND ISOCHRONISM. In television, the timing conditions necessary for satisfactory reception. The conditions of synchronism include that of isochronism.

The condition of isochronism occurs when the scanning of the scene and the reconstruction of the image on the receiver screen take place at the same rate. This is not, however, in itself sufficient for satisfactory reception. There must be coincidence in both time and space, the condition which is implied by the word synchronism.

If, at a particular instant, the transmitted signal corresponds to the light intensity at a point, say, at the beginning of the first line of a frame, then, at this instant, the light spot on the screen of the receiver must be at the beginning of the first line of the corresponding frame. Not only must the electron beam in the cathode-ray tube move at the same rate as the scanning beam, but it must keep in step with the scanning beam.

For synchronism, it is necessary for the time base of the receiver to maintain not only the correct line- and frame-frequencies but also the correct phases. See SYNCHRONIZATION, SYNCHRONIZING IMPULSE.

SYNCHRONIZATION. In television, the linking very closely together of the operations of sender and receiver in order to fulfil the very stringent requirements of synchronism.

The light spot on the screen of the receiver must be under the control of the sender in two different respects: The intensity of the light spot must be so controlled that the detail of the image is built up, point by point, line by line, and frame by frame, to reconstruct a picture of the televised scene. The movement of the light spot must be kept precisely in step with that of the scanning beam.

The sender must, therefore, provide two different kinds of signal; that is, vision signals and synchronizing signals. Further, the latter must be of two kinds: line-synchronizing and frame-synchronizing signals.

In the system of television used by the B.B.C., the scanning process is momentarily interrupted at the end of each line and a line-synchronizing impulse sent. At the end of each frame, the scanning process is again interrupted (for a longer period than between lines), and a frame-synchronizing signal sent. The frame-synchronizing signal is so constituted that line synchronism is maintained during the interval between successive frames.

Vision and synchronizing impulses have separate functions to perform in the receiver and must be sent as separate entities; but the B.B.C. transmission is so arranged that it is not necessary to employ two separate channels for the vision and synchronizing signals.

The variations of light intensity produced, as the televised scene is scanned, are caused to modulate the radio-frequency output of the sender. Full white in the scene is represented by 100 per cent modulation, and black by a percentage modulation of the order of 30 per cent. Any degree of modulation between these limits produces visible effects on the screen of the receiver.

Any degree of modulation between 30 per cent and zero will cause no visible effects on the screen of the receiver because the light spot will be blacked out. The synchronizing impulses use the black level as their base and act downwards; that is to say, a synchronizing impulse is represented by a fall of modulation from 30 per cent to zero. In the receiver, the synchronizing impulses trigger the time-base oscillators and cause fly-back of the electron beam in the cathode-ray tube at the end of each line and at the end of each frame.

Each line-synchronizing signal consists of a square-wave pulse of 10 microseconds duration. Each frame-synchronizing signal consists of a group of eight square-wave impulses, each impulse being of 40 microseconds duration. The frame-synchronizing signal has a frequency component equal to the line-synchronizing frequency, thus ensuring the continuity of the line synchronism.

The receiver must be designed to bring about separation of the vision and synchronizing impulses to prevent the vision signals reaching the time base and possibly upsetting the synchronism. Separation of the vision and synchronizing impulses can be effected by some form of amplitude filter. Separation of the line and frame synchronizing impulses is necessary to avoid the possibility of the frame synchronism being upset. Such separation can be effected by frequency-discriminating circuits. See SYNCHRONISM AND ISOCHRONISM.

SYNCHRONIZATION OF BROADCAST SENDERS. Method of keeping in synchronism senders situated far apart and working on shared channels. The term may be used, even though synchronism is not established, if the frequency variation from a common mean is not more than a few cycles per second (see SHARED-CHANNEL BROADCASTING). The more nearly all senders sharing the same channel keep to the same carrier-wave frequency, the larger their service area; the best results are assured if synchronism is maintained.

In Great Britain the first attempts to keep carrier frequencies close to a mean were made by generating the carrier wave from the harmonics of an electrically maintained tuning fork vibrating at about 1,000 c/s. The maximum frequency drift of several senders was of the order 30 parts in a million. A scheme was tried in which an audio-frequency wave was transmitted from one point of generation via telephone lines to several senders in different parts of the country. The carrier wave was generated from a harmonic of the audio-frequency wave. Obviously the mean carrier frequency of all the senders was the same.

Unfortunately, phase changes of the wave sent through the lines caused the instantaneous value of the carrier frequencies to vary relatively. For instance, if 1,000 c/s is frequency-multiplied to 1 Mc/s, a phase change of 3·6 deg. in the lower frequency means a phase change of 3,600 deg.—over 60 radians—in the higher frequency. Thus as the phase of the lower frequency exhibits small positive and negative changes, a considerable phase modulation of the carrier wave results. These modulations, occurring at different degrees at different senders, limit in consequence the service area of each sender to an undesirable extent.

Crystal oscillators can be designed for a long-term stability of 1 part in 10^7, and the provision of separate crystal-oscillator drives at each sender is a satisfactory, if expensive, solution. If a long-wave sender radiated a steady wave which could be picked up without fading or severe interference anywhere in the country, it would be an ideal method for synchronizing separate senders, as there would be no phase change worth mentioning, and the ratio of the frequencies of the wave and its harmonics would not be so great as when an audio frequency is used. Such a sender would also be useful as a frequency standard for timekeeping and laboratory frequency-checking. This idea was put forward 25 years ago, but has not as yet been adopted. See FREQUENCY, FREQUENCY MODULATION, PHASE.

SYNCHRONIZATION OF OSCILLATORS. Method of providing that two or more oscillators shall maintain the same frequency of output when required. It is usual to make one of the oscillators the master-control oscillator and to synchronize the others with the master.

Part of the output of the master oscillator is fed to each of the others. Provided the natural frequency of each oscillator is very close to that of the master, the injection into the oscillator of a voltage of sufficient magnitude at the frequency of the master can be made to suppress the natural oscillation and to lock the oscillator to the master frequency.

In a simple inductance-capacitance feedback oscillator with a tuned anode circuit, a convenient point at which to inject the synchronizing voltage is the low-potential end of the grid coil.

SYNCHRONIZING IMPULSE. Separate impulse sent out in television transmissions to ensure that the scanning at the receiver is in step with that of the vision pick-up. The best method consists of generating impulses at the sender which control the scanning saw-tooth voltages on the vision pick-up and, at the same time, are sent to control the scanning voltages on the cathode-ray tube of the receiver.

The usual method is to indicate the end of each scanning line by a short pulse which forces the carrier wave down from the "zero" signal value of 30 per cent (see HIGH-DEFINITION TELEVISION) and so has no visual effect on the receiving cathode-ray tube. The line-synchronizing impulse in the B.B.C. system lasts for a period of about 1/10th of a line. The frame-synchronizing impulse sent at the end of each frame lasts for about 4/10ths of a line.

At the end of each frame the vision signals are suppressed for between 6 and 12 lines, and frame-synchronizing impulses are sent out during that period.

At the receiver, the line- and frame-synchronizing impulses are separated from the vision signal by an amplitude filter, and from each other by virtue of their differing durations. The impulses are passed through a circuit which discriminates between impulses of long (4/10ths-line) and short (1/10th-line) duration, the line synchronizing impulses being passed to the line-scan time base, and the frame-synchronizing impulses to the frame-scan generator.

It is of interest to note that the duration of the line-synchronizing impulse is longer than the time taken for the fly-back to occur at the end of the line and, since the pulse drives the carrier wave below 30 per cent modulation, the effect on the cathode-ray tube is to black it out so that no trace of the fly-back is visible.

SYNCHRONIZING VALVE. Valve used in television for separating the synchronizing impulses from the picture voltages. The valve is a form of amplitude filter, being so biased that no signal above a certain level corresponding to the 30 per cent carrier level affects the anode current. As soon as the impulse falls below that level, the anode current is affected and the signal passed through. Such a valve is used to prevent vision signals from passing through into the scanning generator circuits of a television receiver.

SYNCHRONIZING WHEEL. Toothed wheel used to control the speed of rotation of a mechanical scanning device, or other rotating device. Assume 30-line television is being received on a mechanical scanner. If the frame-frequency is 12½ per second, which was a normal periodicity in the Baird system, and 30 lines are being used, there will be 375 line-synchronizing impulses per second.

These impulses are used as follows. A wheel made of iron laminations and having 30 teeth is fitted to the spindle of the scanning disc. On exactly opposite sides of the wheel are two pole-pieces of soft iron (Fig. 52). These are yoked together and they are energized by the synchronizing impulses, which have to be amplified and supplied to the pole windings as heavy current pulses.

The poles, therefore, become magnetic 375 times a second. Now, if the disc and wheel are running at exactly the right speed one of the 30 teeth will come opposite each pole-piece 375 times per second. And in such a position the synchronizing impulse will have no effect on the speed of rotation of the wheel.

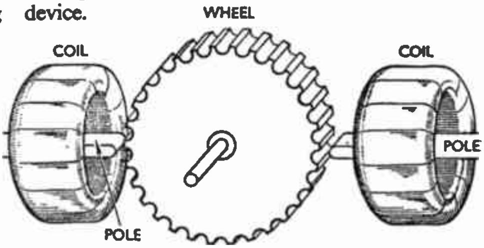


Fig. 52. Synchronizing wheel fitted to the spindle of a scanning disc; pulses fed through the coils magnetize the poles and keep the wheel rotating at a constant speed.

Suppose now that the speed is slightly slow and the teeth are in a position such as that shown in Fig. 53, when the impulse comes. The effect will be for the tooth to be attracted to the pole-piece, and over a number of such revolutions gradual speeding up of the wheel will result. If the speed is fast, an opposite effect will be obtained and the pole-piece will tend to hold the wheel back.

Naturally, the wheel must be set to run at approximately the correct speed. If it is far out, the synchronizing impulses will not be able to control it. And if it is out by a whole tooth it may well be synchronized one line out of place. Thus, in mechanical scanning, a speed control is necessary so that the disc or drum may be set to revolve at as near the right speed as possible, irrespective of the synchronizing impulses and the synchronizing wheel. See SCANNING.

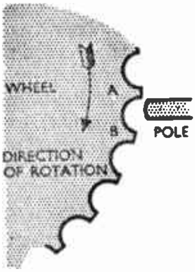


Fig. 53. With the synchronizing wheel at the position shown, a pulse passed through the coil causes the wheel to speed up because *A* is attracted by the pole. Had the pulse occurred a little earlier, the wheel would have been slowed down slightly, due to the attraction of *B*. The result in either case is synchronism, as succeeding teeth come into line with the pole-piece as each pulse occurs.

SYNCHRONOUS CARRIER SYSTEM. Simultaneous radiation by two or more radio senders at the same carrier frequency. Heterodyning between them is avoided by interlocking the drive circuits.

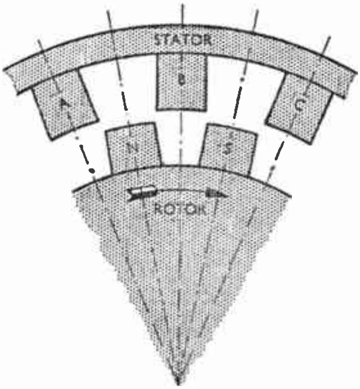


Fig. 54. Rotor magnets *N* and *S* of a synchronous motor retain a constant polarity, but the stator magnets *A*, *B* and *C* change polarity with each half-cycle of alternating current.

SYNCHRONOUS GENERATOR. Machine for generating alternating current. For normal supply frequencies, it usually consists of a rotating field system energized by direct current, and stationary armature windings arranged in one, two or three phases. The windings are contained in slots in a laminated stator core, and this is supported in a cast-iron or fabricated steel framework. Slow-speed synchronous A.C. generators have a large number of poles and these are bolted or keyed to a yoke resembling a flywheel; but turbine-driven machines, which run at 1,500 and 3,000 r.p.m. (for the usual frequency of 50 c/s), have a smooth-surfaced rotor, consisting of a solid forging, which is magnetized by windings embedded in slots machined in the surface.

Such generators are usually totally enclosed, and the circulating air is cooled by passing it over water-cooled tubes. The field current is supplied by an exciter which may be driven fr the generator shaft, or by an auxilia A.C. motor.

When a synchronous generator paralleled with other machines, runs at the common synchrono speed and supplies an amount of lo corresponding to the mechani power of its prime mover. Even the mechanical power were entir removed, it would continue to run synchronous speed but, then, as synchronous motor.

Besides the ordinary machines whi generate at supply frequencies, spec types have been developed for t generation of high-frequency curren These, however, have been large superseded by the development of t valve, which provides a more co venient means of obtaining high fr quencies. The Alexanderson alternat is a machine of the inductor ty where the flux linking the armatu windings is varied by varying the a gap. When very high frequencies a required, difficulties of constructi arise, and Latour and Bethenod ove came these by the use of three separa generators on the same shaft, althoug in later designs these were recombine into a single machine.

A novel type of synchronous generator, invented by Dr. R. Goldschmid provided high-frequency currents wit out the necessity of high-speed operation. The desired step-up of frequenc was obtained by connecting two c more parallel-tuned circuits across th rotor. The D.C. excitation was applie to the stator winding which also b came the source of the high-frequenc output.

SYNCHRONOUS MOTOR. Type c alternating-current motor which run at constant speed despite variations i its load. It is similar in construction t a synchronous A.C. generator (see SYN CHRONOUS GENERATOR). The stato windings are fed from an alternating current supply and the rotor winding are supplied with direct current whic is usually obtained from a small D.C generator known as the exciter, this being mounted on, or driven from, the motor shaft.

The rotor magnets *N* and *S* (Fig. 54) retain a constant polarity, but the stator magnets *A*, *B* and *C* change polarity with each half-cycle. Suppose that the rotor is turning in a clockwise direction, and *A* and *C* have north polarity and *B* south. Then rotor pole *N* will be repelled by *A* and attracted by *B*, while the pole *S* will be repelled by *B* and attracted by *C*. If the speed of rotation is such that the pole *N* occupies the position of *S* by the time the polarities of *B* and *C* have reversed, the motion will be maintained.

Only by running at synchronous speed is the correct relationship between the rotor and stator poles maintained; and so a definite relationship exists between the frequency of supply, the number of poles and the speed of rotation. If p is the number of poles and f the supply frequency in cycles per second, the speed N is given by the formula

$$N = 120\frac{f}{p} \text{ revolutions per minute.}$$

In practice, the salient poles *A*, *B* and *C* are replaced by distributed windings contained in slots at the inner surface of a laminated stator core, these being held in position by hardwood wedges. It is interesting to note that, unlike the usual D.C. motors, it is the field which rotates in this case, while the armature remains stationary.

Small synchronous machines are built for single-phase supply, but larger sizes are usually constructed for three-phase supply.

The motor is not self-starting: a small "pony" motor may be used to bring the rotor up to speed or, more conveniently, damping windings may be provided in the pole faces and be connected up by copper straps at the ends so as to form a squirrel cage. The motor then starts up as an induction motor, and when the action of this winding has brought the speed close to synchronous, the rotor "pulls into step" and continues to run in synchronism.

SYNCHRONOUS SPARK-GAP. Synonym for ROTARY SPARK-GAP.

SYNC-PULSE. Abbreviation for SYNCHRONIZING IMPULSE.

T

T-AERIAL. Aerial consisting of a horizontal span with a downlead or lead-in taken from the centre thereof, as shown in Fig. 1. It is commonly used on shipboard for medium and low frequencies.

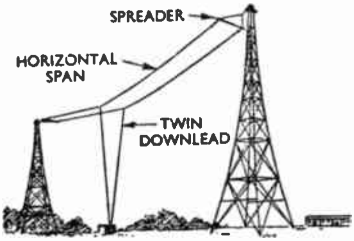


Fig. 1. Typical twin-wire T-aerial supported by a pair of lattice masts.

TANK CIRCUIT. See OSCILLATORY CIRCUIT.

TAPPER. Electromagnetic device used to shake the filings in a coherer after a passage of radio-frequency current has caused them to cohere and become conducting. See COHERER.

TARGET ELECTRODE. The electrode upon which the electron beam impinges; for example, the screen of a cathode-ray tube.

TELECINE. Composite word denoting the special type of cinematograph projector used for the televising of cinematograph films. It is incorrectly evolved, for *tele* means "at a distance" and the equipment itself has no more relationship to cinematography at a distance than has the normal projector.

One form of machine consists of a system of rotating mirrors in a complicated optical system that does away with the need for any form of gate as is used in the normal projector. The film is run constantly, all the effects of a gate and light-cutting device being obtained by changes of angle in the mirror-revolving mechanism. Light shining through the film is focused on to the mosaic of a vision pick-up which acts in the normal way.

In more modern equipments an intense unmodulated raster is built up on the screen of a cathode-ray tube, and the film to be televised is pulled past the screen at constant speed by means of an electric motor. Light from the cathode-ray tube passes through the film and a shutter and falls on a photocell, the output of which, after amplification, and insertion of synchronizing impulses to form the vision signal, provides the output of the equipment.

Telecine machines are fitted with normal sound equipment so that the sound track of any film may be utilized. The televising of film has one advantage over normal projection on a screen in that it does not matter whether the film is a negative or a positive.

In the normal cinematograph projector, the film has to be a positive print taken from the original negative, or a duplicate negative. For television purposes, all that is required is to reverse the phase of the vision-amplifier output if a negative is used instead of a positive.

TELECOMMUNICATION. Process of sending telegraphic or telephonic communication, consisting of visible or aural signals of any kind, by means of radio transmission-line or other electrical signalling system. See RADIO TELEGRAPHY, RADIO TELEPHONY, TELEGRAPH SYSTEM, TELEPHONY.

TELECONTROL. Remote control of mechanical devices by electrical transmission, radio waves, sound waves or light beams.

TELEDIFFUSION. System for relaying television broadcasts. See RADIO RELAY SYSTEM.

TELEFUNKEN SYSTEM. Particular quenched-spark radio telegraph system in which the spark-gap consists of a series of metal discs, each slightly separated from the next.

TELEGRAPH CROSSTALK. Crosstalk in telegraphic systems of signalling. See CROSSTALK.

TELEGRAPH DISTORTION. Distorted form of the received telegraphic signals in comparison with their ideal form when distortion is absent. The received signal should have a certain amplitude at a particular instant of time, but distortion delays the effect. In order to express the distortion as a numerical ratio, the delay time is divided by the time for the transmission of a code element. The delay causing the distortion is due to changes in phase velocity and attenuation distortion of the transmission line. See ATTENUATION DISTORTION, DELAY DISTORTION, TELEGRAPH SYSTEM, TRANSMISSION LINE.

TELEGRAPH REPEATER. Amplifier used in the transmission of telegraphy signals. See TELEPHONE AMPLIFIER.

TELEGRAPH SYSTEM. Any communication system in which intelligence is conveyed by means of the Morse code over an electrical circuit. In a broadcast telegraph system, a single sending station is linked to a number of receiving stations. If a switchboard is interposed between sending and receiving stations, the system is called *switched broadcast.*

If a number of stations are permanently interconnected, so that a message sent by one is received by all, the system is known as an *omnibus telegraph system.* When some of the stations have receivers only, the

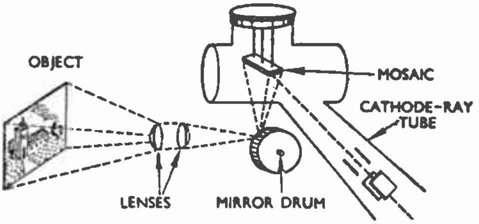


Fig. 2. Diagrammatic representation of telepantoscope operation, described in the text. A full revolution of the mirror drum constitutes a picture scan. The electron beam scans across the mosaic, retracing its path along one line each time.

system is a *partial omnibus system.* If arrangements are made to connect all the stations together by switching, the system is called a *switched omnibus system.* Where arrangements exist for the simultaneous transmission of signals in both directions over a single circuit, the service is termed a *duplex system.*

TELEGRAPH TRANSMITTER. Synonym for telegraph sender.

TELEHOR. Television system in which scanning is achieved mechanically by means of vibrating mirrors. Telehor is a trade name.

TELEPANTOSCOPE. Device in a vision pick-up which provides electronic scanning of a mosaic in the horizontal direction only, the vertical, or picture, scan being accomplished by moving the image across the mosaic. By this means the electron beam scans the same portion of the mosaic all the time, the portion being changed only when wear or damage occurs.

The device (Fig. 2) was developed by Castellain. An image of the object is focused on the photo-electric mosaic by means of a mirror drum which rotates at a frequency corresponding to the required picture-frequency, say 25 times per second. As it rotates, the image of the object moves across a small part of the mosaic in a series of steps, each reflection bringing the image farther across the mosaic until the drum has completely revolved. The image movement is then repeated.

It is obvious that the number of mirrors on the drum must equal the number of scanning lines, and that the deflection of the image on the mosaic must change by the thickness of one line at each successive mirror on the drum. Thus the electron beam scans along one line only of the mosaic, and the image is moved one line up or down on the mosaic after each line.

This system presents problems in both mechanical and electronic synchronization, and reduces the cumulative time during which the charge on the mosaic builds up while the picture is focused on it. On the other hand, it has the advantage that the mosaic need not be so large as in the case of the Iconoscope, its size in the direction covered by the rotation of the mirror drum being reduced to very small dimensions.

TELEPHONE. Equipment associated with transmission channels to enable individuals to communicate with one another by speech sounds, no limit being set to the distance separating the individuals provided each has the use of a suitable instrument. *Radio telephone* means a telephone in which a radio channel is used. Broadcast programmes are distributed by what is, basically, a radio-telephone sender. See BROADCASTING, RADIO TELEPHONY, TELEPHONY.

TELEPHONE AMPLIFIER. Audio-frequency amplifier which is used to compensate for the attenuation suffered by speech currents when travelling over long lines. Such amplifiers, sometimes called repeaters, have been a major factor in making possible the development of long-distance telephone systems.

TELEPHONE CAPACITOR. Form of fixed capacitor designed primarily for use at audio frequencies at low voltage. It has impregnated paper as the dielectric and a capacitance of the order of one microfarad. See FIXED CAPACITOR.

TELEPHONE CONDENSER. See TELEPHONE CAPACITOR.

TELEPHONE RECEIVER. Synonym for HEADPHONE.

TELEPHONE REPEATER. Synonym for TELEPHONE AMPLIFIER.

TELEPHONE TRANSMITTER. Instrument into which one speaks when using the telephone. Technically, it is described as an electromechanical device for converting sound pressure-variations into electrical signals for transmission over an electrical circuit.

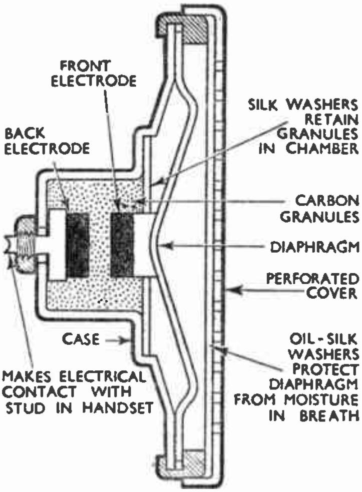


Fig. 3. Section through a telephone transmitter showing internal details.

The modern telephone transmitter depends on the fact that the resistance of carbon granules varies inversely as the pressure applied to them (see CARBON MICROPHONE). Fig. 3 shows a typical transmitter detached from the mouthpiece housing.

Sound waves impinging on the diaphragm cause the moving electrode to exert varying pressure on the carbon granules; the resulting variation in resistance causes the electric current through the circuit to vary at the frequency of the sound waves. The application of these varying currents to the receiver causes its diaphragm to vibrate at a similar frequency.

TELEPHONY. Science of speech transmission by either telephone wires or radio, or by both. A telephone transmitter and receiver at each end of the circuit permits two-way conversation between two persons in adjacent rooms or in opposite hemispheres, or at any distance between these extremities.

TELEPRINTER. Telegraph equipment in which the sending instrument takes the form of a typewriter keyboard, the receiving instrument transcribing the message into printed type. Transmission over telegraph or telephone lines is by means of electrical impulses, the duration and spacing of the impulses being different for each letter or figure.

TELESTUDIO. Term sometimes used to denote a studio for television-broadcast purposes.

TELETORIUM. Suggested term for a television studio.

TELETRON. See VISION PICK-UP.

TELETYPEWRITER. American equivalent of TELEPRINTER.

TELEVISION. Method of sending moving pictures from one point to another by means of radio or landline. See CATHODE-RAY TUBE, HIGH-DEFINITION TELEVISION, TELEVISION RECEIVER, TELEVISION SENDER, VISION PICK-UP.

TELEVISION CAMERA. Synonym for VISION PICK-UP.

TELEVISION RECEIVER. Form of radio receiver which provides, not only sound reproduction as does the normal radio receiver, but picture reproduction. The latter is usually carried out by means of a cathode-ray tube and the receiver incorporates, not only amplifiers, rectifiers and power supply to deal with sound reception, but a further set of amplifiers, rectifiers and power supply for vision reception. In addition, scanning circuits for the cathode-ray tube are incorporated.

Fig. 4 shows, schematically, the units which make up a complete television receiver. The time-base oscillators and their amplifying circuits produce voltages that move the electron beam of the cathode-ray tube (see TIME-BASE GENERATOR). Special circuits are included to filter the synchronizing impulses and apply them to the cathode-ray-tube time bases.

The aerial system consists of a half-wave dipole, with or without a reflector, coupled by means of a low-impedance (of the order of 80 ohms) line to the receiver itself.

TELEVISION SENDER. Sender of sound and vision simultaneously. The vision section must handle, without serious loss, modulation frequencies of several megacycles per second. This means that the carrier frequency must be very high. British television employs carrier frequencies of between 45 and 62 Mc/s for both vision and sound transmission.

The sender must also be able to handle all frequencies from the upper limit of about 3 Mc/s down to 0 c/s, or D.C., without serious change in gain and without serious non-linearity. Furthermore, its circuits have to be capable of carrying out amplification without phase distortion.

Vision modulation contains energy at all frequencies from several megacycles (dependent on the definition of the system) down to the line-frequency, which is about 10 kc/s in the British system. Then there is a gap until the frame-frequency is reached. The sound modulation, however, covers frequencies from the lower limit of audibility (about 16 c/s) to the upper limit of 8,000 or 10,000 c/s. These should be faithfully amplified and transmitted.

The aerials are normally vertical dipoles arranged so that there is uniform radiation in all directions from them. At Alexandra Palace, London, two sets of aerials are employed, one for sound and one for vision, but at the Sutton Coldfield sender, and in receivers, a common aerial is used to cover both frequencies.

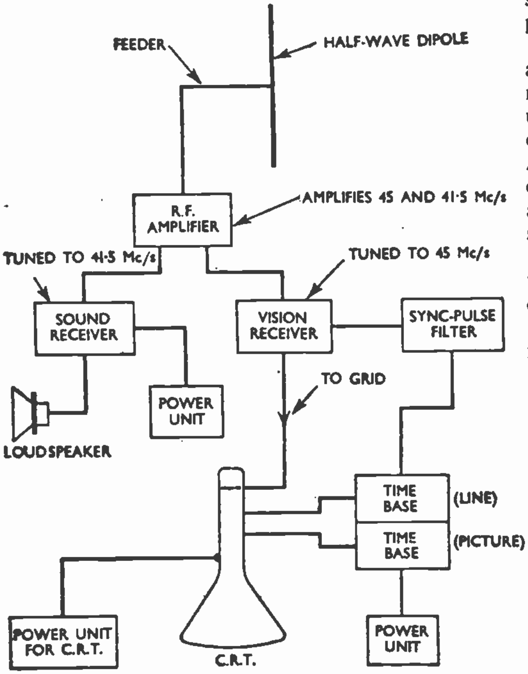


Fig. 4. Schematic diagram showing the units which comprise a complete television receiver. Sound and vision signals are both picked up by the one aerial, but pass from the R.F. amplifier into different circuits.

Modulation systems vary for sound and vision. In the sound sender there is amplitude modulation from zero to 100 per cent. The vision sender is set at 30 per cent carrier to correspond with black, and the vision modulation is made to vary the carrier above that amount, the synchronizing and black-out impulses being caused to decrease the carrier below 30 per cent. In that way, the synchronizing pulses are sent in the "blacker-than-black" modulation range.

TELEVISION TRANSMITTER. Synonym for TELEVISION SENDER.

TEMPERATURE COEFFICIENT. Measure of the relative change in any property of a material; for example, change in its resistance brought about by a unit rise in temperature.

TEMPERATURE LIMITATION. Limitation of the electrode current of a valve because the cathode is at too low a temperature for it to emit electrons in normal quantities. See EMISSION, EMISSION LIMITATION, SPACE-CHARGE LIMITATION.

TEMPERATURE RISE. Difference between the temperature of an electrical component, for example, resistor, which has been in use for a time, and that of the surrounding atmosphere: it indicates the capacity of the component to dissipate heat produced by electrical power losses.

TERMINAL. Convenient device for establishing a connexion between circuits; or, the receiving end of a transmission line. (A line terminal may be the physical means of connexion between a line and another component, or it may denote the receiving end of a line.) In a great deal of transmission equipment the connexion-type terminal is abandoned in favour of the soldered joint; but measuring apparatus and the like, which is continually being connected to different circuits, must have terminals designed for the purpose.

The term is seldom used by itself to denote the end of a transmission line; thus, for example, see TERMINAL LEVEL.

TERMINAL LEVEL. In line telephony, the test level at a point in a line which is terminated at the point by an impedance equal to the nominal impedance of the line. See IMPEDANCE, TEST LEVEL.

TERMINAL RETURN LOSS. Value of the return loss at the terminals of a trunk-telephone line, when it is terminated by circuits in the local network up to and including the subscriber's telephone. See RETURN LOSS.

TERMINATING SET. In line telephony, an equipment used for terminating the go and return channels of a four-wire circuit, and for connecting a four-wire to a two-wire circuit. See FOUR-WIRE CIRCUIT, "GO" CHANNEL, QUADRIPOLE, RETURN CHANNEL, TWO-WIRE CIRCUIT.

TESTING. Carrying out an experiment, or experiments, on a complete piece of equipment or on an individual component to determine whether it is carrying out its purpose satisfactorily. For example, if a resistor were suspected of being faulty, the first experiment likely to be carried out on it would be a continuity test (see FAULT-FINDING) designed to find out whether the component were short-circuited or open-circuited.

Since no accurate measurement is involved in such a test, and an uncalibrated instrument can be used for making it, such an experiment can be termed a *qualitative* test. If the component is found to be neither short-circuited nor open-circuited, an accurate measurement of the resistance can be made with an ohmmeter to determine if the actual value deviates appreciably from the nominal one. Such a measurement constitutes a *quantitative* test.

The following briefly describes the methods of testing radio components and complete amplifiers and receivers.

RESISTORS. The testing of resistors has been given as an example. If a resistor is suspected of being faulty, it is first subjected to a continuity test and then to a reasonably accurate

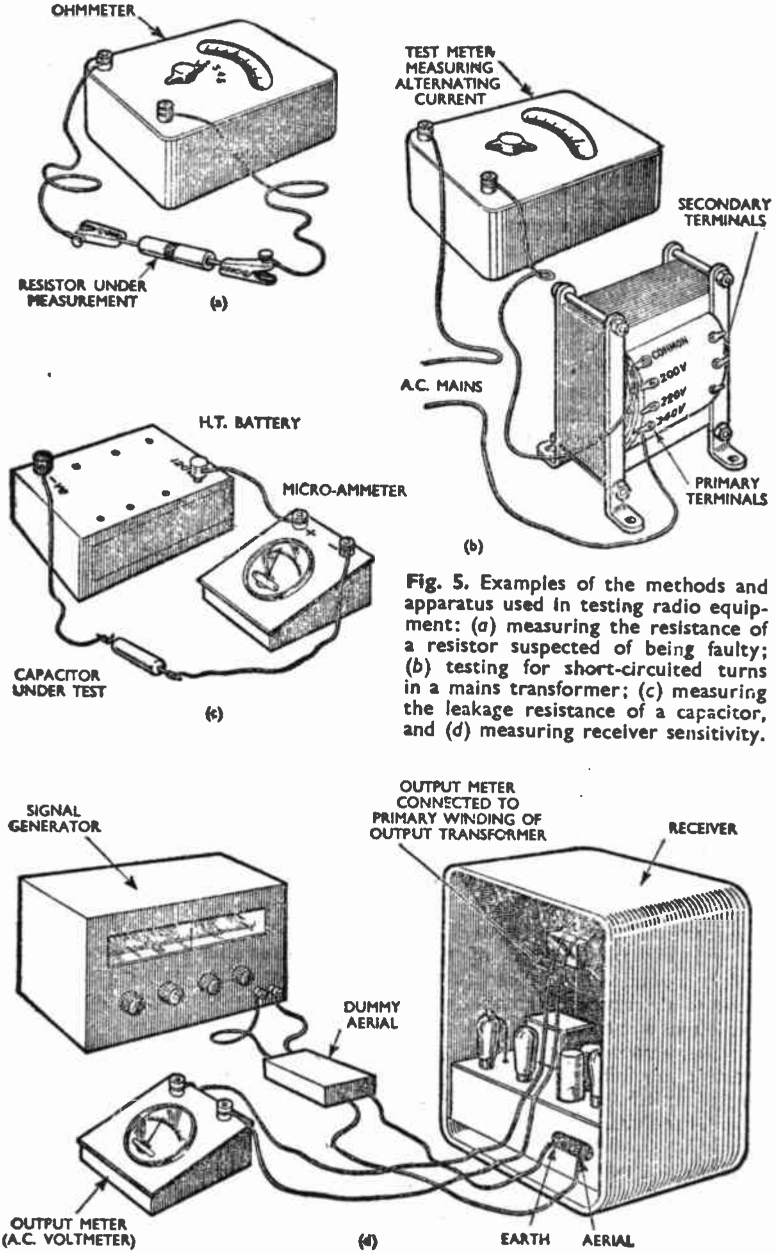


Fig. 5. Examples of the methods and apparatus used in testing radio equipment: (*a*) measuring the resistance of a resistor suspected of being faulty; (*b*) testing for short-circuited turns in a mains transformer; (*c*) measuring the leakage resistance of a capacitor, and (*d*) measuring receiver sensitivity.

measurement, as shown in Fig. 5a; a bridge instrument is probably most suitable for the second test. Sometimes resistors develop intermittent faults, and their resistance values alter from moment to moment, giving rise to noise in amplifiers and receivers. Such a state is indicated by varying readings during measurement.

If a resistor gives a correct reading under measurement, it may have a different value in operation when called upon to pass a great current causing it to get very hot. If this is suspected, its resistance should be measured indirectly by ascertaining the current passing through it and the p.d. developed across it, the determinations being made after the apparatus has been switched on for several hours. A high-grade voltmeter should be used for measuring the p.d.; the resistors used in electronic equipment have such high values (100,000 ohms is common) that low-grade voltmeters frequently take more current than the component under test, and faulty readings are then obtained.

It must be emphasized that extreme accuracy in measurement of the value of resistors is frequently unnecessary. The value of the grid-leak in an amplifier can be varied by as much as 25 per cent without appreciably altering the performance of the amplifier in any way, and this is the reason that most of the resistors used in amplifier and receiver construction have a tolerance of ± 20 per cent.

INDUCTORS AND TRANSFORMERS. If an inductor is suspected of being faulty, a continuity test can first be made to determine if the winding is continuous and then, as in the tests on resistors, an accurate resistance measurement can follow. The D.C. resistance of an R.F. inductor is usually less than 1,000 ohms, whereas the windings of an iron-cored A.F. transformer may have a resistance of several hundreds or thousands of ohms.

If the component passes this test successfully, an inductance measurement can be made; this is best carried out by means of an A.C. bridge. If a low reading is obtained, it may be due to short-circuited turns, although this condition would also give a low-resistance reading. If a mains transformer, shown at (b) of Fig. 5, has short-circuited turns, the primary current is unusually high and the component may get very hot even with the secondary loads removed.

CAPACITORS. When a capacitor is suspected of being faulty, a continuity test may be applied to it, although this can give only very limited information. The test may show the component to be faulty because of the presence of a short-circuit, but, if the test shows an open circuit, the component may still, of course, be perfect.

Almost the only method of testing a suspected capacitor is to make a determination of its capacitance by means of an A.C. bridge. If this shows little or no capacitance, the component is open-circuited.

It is very important that the capacitors used in resistance-capacitance coupled amplifiers should have a high leakage resistance, and a method of measuring this is useful. It may be measured by means of a "Megger" tester, or by the use of an H.T. battery and a milliammeter or micro-ammeter as illustrated in Fig. 5c.

This test should not, however, be applied to capacitors of the electrolytic type which, when connected to a D.C. source, take a large initial surge current which settles down to a few milliamperes after a few seconds. It is normal for electrolytic capacitors to have a poor power factor and a low leakage resistance.

VALVES. When a valve is suspected of being faulty, it is usually obvious if the heater has failed for the valve ceases to glow. If there is a doubt whether the heater or filament is open-circuited, a continuity test may be applied to the appropriate pins. If the heater is intact and the valve is still suspected of being faulty, it is best to test it on a panel specially designed for the purpose; such a panel provides facilities for the measurement of total emission from the cathode and also for the measurement of mutual conductance.

If the valve has aged, this is indicated by low readings of total emission and mutual conductance and, if the anode or cathode is open-circuited, no emission is registered. Valves may cause trouble if the insulation between cathode and heater is poor and many valve-test panels include facilities for measuring this resistance.

Complete Amplifiers and Receivers. Tests which are carried out on amplifiers usually include measurements of the following quantities: (1) voltage gain; (2) power output; (3) harmonic distortion; (4) frequency response, and (5) signal-to-noise ratio. It must be emphasized that the determinations should be made when the amplifier is working into the correct value of output load.

Similar tests are carried out on receivers, but here some further information is usually required. The following is a list of the more important of the additional measurements made, a superheterodyne receiver being assumed: (6) selectivity; (7) performance of the variable I.F. band-width control (if any); (8) the performance of the automatic gain-control circuit; (9) the performance of the image frequency and second-channel rejection circuits; (10) the tracking of the oscillator and signal-frequency circuits, and (11) the performance of the receiver with respect to cross-modulation.

The sensitivity of a receiver is usually expressed as the number of microvolts, modulated at 400 c/s and to a depth of 30 per cent, which must be applied between the aerial and earth terminals to produce an output of 50 mW from the anode of the output valve, or an agreed signal-to-noise ratio when the modulation is switched off. The measurement is made, as illustrated in Fig. 5d, with a signal generator, a dummy aerial, and an output meter; the last is usually calibrated directly in milliwatts.

TEST LEVEL. Specified value of the actual level. The origin of the circuit is energized by a generator having an internal impedance Z, equal to the nominal impedance of the circuit. The e.m.f. of the generator is $2\sqrt{\frac{Z}{1{,}000}}$ volts. Test level is measured at a frequency of 800 c/s. A means of defining the test level is provided so that comparisons of different circuits can be made. The term "level" is an abbreviation for test level. See ACTUAL LEVEL.

TETRODE. Valve with four electrodes: one anode, one cathode and two grid-type electrodes. The tetrode is essentially a triode in which a second grid, held at zero or a low alternating potential, but positively biased, is placed between the control grid and anode with the object of reducing the capacitance between control grid and anode.

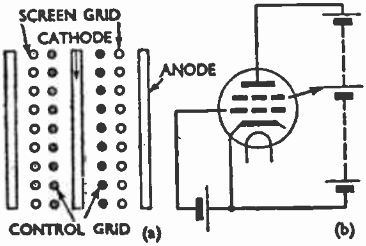


Fig. 6. At (*a*) is shown a section through a tetrode, while (*b*) indicates the conventional diagram symbol employed to represent a tetrode and also the potentials applied to its electrodes.

The effects of control-grid-to-anode capacitance in a triode limit its applications as an amplifier of radio-frequency waves (see MILLER EFFECT). To overcome this disadvantage, the screen grid of the tetrode was introduced (Fig. 6). The tetrode was introduced after the triode but before the pentode.

If the screen grid were held at earth potential, it would prevent any space current from flowing between anode and cathode. Thus, in order to accelerate electrons towards the anode, the screen grid must be biased positively; in practice, its potential is comparable with, or in excess of, the anode potential. The screen grid is always held at or near zero alternating potential.

The anode-volts/anode-current characteristic and the anode-volts/screen-current characteristic of a screened-grid tetrode (i.e. not a kinkless tetrode) are shown in Fig. 7 under four conditions: First, when anode voltage is so low that the anode does not emit secondary electrons. Anode current rises with anode voltage as in a diode or triode and the screen-grid current decreases with increasing anode current. Second, when the anode voltage is great enough to cause the electrons which bombard the anode to knock electrons off it (that is, create a secondary emission), but when the anode voltage is less than the screen-grid voltage. In this condition, the secondary emission current is subtracted from the anode current and added to the screen current. Thus an increase of anode voltage results in a decrease of anode current (see NEGATIVE SLOPE-RESISTANCE).

Thirdly, when the anode voltage is higher by a little than the screen voltage; in this condition, the secondary electrons are drawn back to the anode and the negative slope-resistance is eliminated. Changes of anode voltage, however, make considerable changes of anode current, because the potential gradient at the cathode is determined by nearly equal anode and screen voltages which are in balance, the anode voltage just predominating. The anode slope-resistance is relatively low.

Fourth, when the anode voltage is considerably greater than the screen voltage; in this condition, the anode slope-resistance is high because the screen grid shields the anode from the cathode almost completely. Thus changes in anode potential make little effect upon the potential gradient at the cathode, and so have little effect upon the anode current.

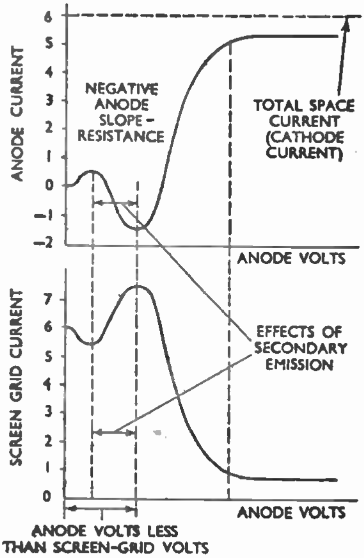


Fig. 7. Graphs which show how, in a tetrode, the sum of the screen-grid and anode currents is almost constant; also that anode current decreases with increasing anode voltage when the latter is less than the screen voltage.

The negative-resistance characteristic of a tetrode, in which nothing is done to prevent the effects of secondary emission, limits its usefulness as an amplifier. It can be used, however, to function as a negative-resistance oscillator (see DYNATRON, NEGATIVE RESISTANCE). In order to make the tetrode suitable as a linear amplifier, steps are taken to suppress the effects of secondary emission (see BEAM POWER-VALVE, PENTODE).

The tetrode is basically distinguished

from the triode by its use of a screen grid to reduce control-grid-to-anode capacitance; the pentode is a tetrode in which the suppressor overcomes the effects of secondary emission. Thus the pentode behaves, in general, as a tetrode would, but for the effects of secondary emission; and as a tetrode does when the secondary electrons are prevented from bombarding the screen grid. See AMPLIFIER, INTER-ELECTRODE CAPACITANCE, SCREENED PENTODE, SCREEN GRID, SECONDARY EMISSION, TRIODE.

THERMAL-AGITATION VOLTAGE. Potential difference produced in circuits, due to the random movements of the electrons in the conductors. It is also called "Johnson noise." Together with electronic noise in valves, it sets a natural limit to useful amplification. The voltage increases with temperature and, being uniformly distributed over the frequency spectrum, with the frequency band accepted.

If this band is sufficiently narrow for the resistance to be sensibly constant over it, the r.m.s. value of the thermal-agitation voltage is: $E = \sqrt{4KTR\delta f}$, where K = Boltzmann's constant = $1{\cdot}374 \times 10^{-23}$; T = absolute temperature (i.e. Centigrade + 273); R = resistance in ohms over δf; δf = band of frequency accepted. Being calculable, it is sometimes used as a source of voltage for measurement purposes, particularly at super-frequencies (see SUPER-FREQUENCY WAVE).

Assuming the first stage of an amplifier gives at least a several-fold gain, and the resistance of the input circuit is not unusually low, the thermal-agitation voltage of the latter is the only one that need be considered.

The noise in the input circuit of any fairly sensitive broadcast receiver can be heard by disconnecting the aerial and turning up the gain control. See NOISE FACTOR, SET NOISE, SIGNAL-TO-NOISE RATIO.

THERMAL DELAY SWITCH. Switch for opening or closing a subsidiary circuit at a predetermined time after the main circuit. The delay is determined by the length of time required to transfer a certain quantity of heat from one part (the heater) to a contact operating part, which is usually a bimetallic strip.

The switch is contained in a glass envelope with a valve-type base. The envelope is evacuated to prevent arcing at the contacts which, of necessity, open slowly and have only a small clearance. One application of such a switch is for delaying the connexion of the anode supply to an electronic circuit until the heaters of the valves or tubes have had time to warm up. See POWER SUPPLY.

THERMAL DETECTOR. Synonym for HOT-WIRE DETECTOR.

THERMIONIC AMPLIFIER. Device employing thermionic valves and used for amplifying electric voltages or currents.

THERMIONIC CURRENT. Synonym for ELECTRODE CURRENT. See also SPACE CURRENT.

THERMIONIC DETECTOR. See VALVE DETECTOR.

THERMIONIC EMISSION. See EMISSION.

THERMIONIC GENERATOR. Synonym for VALVE OSCILLATOR.

THERMIONIC MAGNIFIER. Synonym for VALVE AMPLIFIER.

THERMIONIC OSCILLATOR. See OSCILLATOR.

THERMIONIC RECTIFIER. Loose term, of very little value, which might apply to any form of rectifier in which heat and ions play some part. It is wrongly used when referring to the vacuum valve, for in this the effects due to ions are negligible.

THERMIONIC RELAY. See GAS-FILLED VALVE, RELAY, SOFT-VACUUM VALVE.

THERMIONICS. Term, suggesting the use of heat and the consequent behaviour of ions, related to the technology associated with radio valves. The use of the term is deprecated because electricity can be conducted across a vacuum by electrons emitted from cold cathodes. Moreover, the hard-vacuum valve has a far wider application than the gas-filled valve, and its action depends entirely upon electrons, not upon ions.

THERMIONIC VALVE. Valve or tube in which electrons are emitted from a heated cathode, some or all of the electrons being collected by an anode, their flow being controlled usually by additional electrodes, or grids. See GAS-FILLED VALVE, SOFT-VACUUM VALVE, THERMIONICS, VALVE.

THERMIONIC VOLTMETER. See VALVE VOLTMETER.

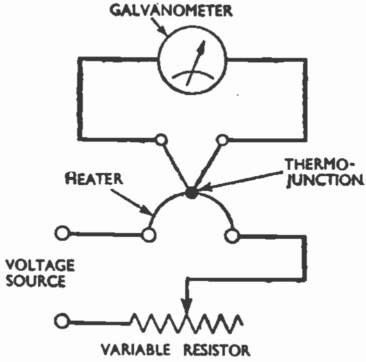


Fig. 8. Thermo-couple meter comprising a thermo-couple and galvanometer. Variation of the current varies the temperature of the heater and thus the current through the galvanometer.

THERMISTOR. Device with a large negative temperature coefficient of resistance. The resistance decreases as the current through the thermistor increases; thus its behaviour is the opposite of that of a BARRETTER (q.v.) or a metal-filament lamp. The smallest types of thermistor are heated directly by passing current through the temperature-sensitive element, but larger types have an auxiliary heater winding which is electrically insulated from the element.

Thermistors have many applications among which may be mentioned the suppression of switching surges, the measurement of temperature and the stabilization of the output of oscillators.

THERMO-COUPLE. Device in which two dissimilar metals are brought to a junction which, if heated, produces an electric current in an external circuit, the value of such current being proportional to the heat applied.

THERMO-COUPLE INSTRUMENT. Instrument employing thermo-couple principles. In Fig. 8 a thermo-couple meter is shown connected to a voltage source. Variation by the resistor of current in the heater circuit varies the temperature of the heater and hence the current through the galvanometer.

THERMO-ELECTRIC EFFECT. Production of electric current or voltage when a junction of unlike metals is heated. See PELTIER EFFECT.

THERMO-JUNCTION. Point of contact of two dissimilar metals constituting a thermo-couple and exhibiting the thermo-electric effect. See THERMO-COUPLE.

THERMOPILE. Device for converting heat into electrical energy. It consists of a number of thermo-couples connected in series or parallel (or both), electric currents being produced when heat is applied to the junctions. See THERMO-COUPLE.

THERMOSTAT. Switch that operates automatically at a predetermined temperature. It is generally used for maintaining an electrically heated device, such as an oven, at a constant temperature. Many thermostats operate by virtue of the differential thermal expansion of two dissimilar metals, either in the form of rods or tubes, or as a bimetallic strip.

THIRD-CLASS BEARING. Bearing, obtained by means of a direction-finder, and which is believed to be accurate to within ± 10 deg.

THORIATED FILAMENT. Filament coated with thoriated tungsten, to improve efficiency of the cathode. See CATHODE EFFICIENCY, EMISSION.

THREE-ELECTRODE VALVE. Synonym for TRIODE.

THREE-PHASE. Description applied to a system or apparatus in which there are three alternating voltages or currents mutually displaced in phase by 120 deg.

THRESHOLD EFFECT. Howl or noise produced by a valve when positive feedback is increased almost to the point of oscillation. See POSITIVE FEEDBACK.

THRESHOLD OF AUDIBILITY. The minimum r.m.s. value of the sound pressure of a sinusoidal sound wave which creates the impression of hearing. The value is expressed in dynes per square centimetre, or in terms of sound intensity. See AUDIBILITY, PHON, SPEECH AND HEARING.

THRESHOLD OF FEELING. The minimum r.m.s. value of the sound pressure of a sinusoidal sound wave which creates an impression of feeling in the ear. The value is expressed in dynes per square centimetre, or in terms of the sound intensity. See AUDIBILITY.

THYRATRON. Synonym for GAS-FILLED TRIODE.

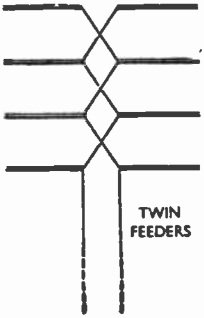


Fig. 9. Vertical tier of centre-fed half-wave dipoles.

TICKLER COIL. Inductor inserted in the anode circuit of a valve and magnetically coupled to the grid circuit to produce reaction.

TIE LINE. Line used for connecting two points in a telecommunication system.

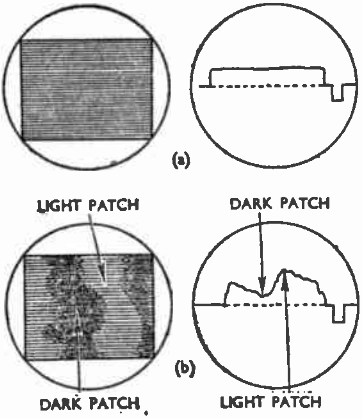


Fig. 10. Without the use of tilt and bend the vision signal from a storage camera, scanning a uniformly illuminated object, does not produce an evenly illuminated picture as at (*a*), but possibly as at (*b*), where the irregular modulation of the signal is also shown.

TIER. Array of aerial elements arranged vertically, or nearly so; a tier of half-wave dipoles is illustrated in Fig. 9.

TIGHT COUPLING. Coupling when the coupling coefficient is large; say, greater than 0·5. Two resonant circuits, if both tuned in the absence of coupling to have the same resonant frequency, produce a frequency-response characteristic which shows marked double humps when tightly coupled. See COUPLING, COUPLING COEFFICIENT, LOOSE COUPLING.

TIKKER. Synonym for CHOPPER.

TILT AND BEND. Term given to the process of adjusting the vision signal from a storage camera to compensate for irregularities in signal from the photo-sensitive mosaic (see STORAGE CAMERA, SUPER EMITRON).

It might reasonably be assumed that, if a storage camera were focused on a plain light-grey object which was uniformly illuminated, a perfectly even signal would result, with every scanning line modulated to the same degree.

In other words, that it would be somewhat as indicated in Fig. 10a.

Unfortunately, such is not the case. Because of irregularities in the action of the mosaic of the standard type of storage camera, and of the photocathode and target electrode of the Super Emitron, the line-scan wave form demonstrates wide variations in amplitude, and the receiving screen shows variations in illumination. Great patches of dark or light appear and, as the camera is panned (moved horizontally or vertically) across the object, the positions and extent of the uneven patches on the receiving tube will vary (Fig. 10b).

The cause of this phenomenon is somewhat obscure, but it seems likely that, not only is the emission from the individual granules of photosensitive material in the camera uneven, but that secondary emission takes place with the result that stray electrons from one nodule contact neighbouring nodules, upsetting the emission from them.

There is only one way to correct for the irregularities, and that is to inject a signal into the vision line in such a way as to nullify the unwanted decrease or increase of modulation from the camera. Analysis of the irregularities has shown that they consist of two wave forms, in various proportions. These are the saw tooth and the parabola. Thus, if combinations of saw tooth and parabolic wave forms (Fig. 11) are injected into the vision line in the correct proportions, the irregularities can usually be cancelled out.

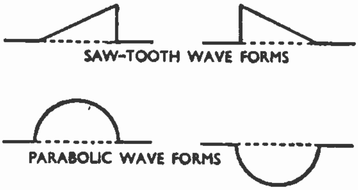


Fig. 11. Saw-tooth and parabolic wave forms which, when injected into the line signal from a storage camera, provide the necessary tilt and bend effects illustrated in Fig. 12.

Because of the shapes of the two fundamental wave forms injected into the vision line, the process is known as tilt (saw-tooth) and bend (parabolic) wave form. As will be seen in Fig. 11, these wave forms are four in number, being right- and left-hand saw tooth and the top and bottom portions of a parabola. Variations of slope of the saw tooth and of amplitude of the parabola are provided by the control potentiometers in the control racks and, provided the irregularities of the camera are not too pronounced, the vision signal can be corrected.

Adjustment is carried out by watching the monitor cathode-ray receiving tube which shows the picture obtained from the camera, light and dark patches on it being removed or reduced by injecting the requisite combination of wave forms by a process of trial and error. This is not so haphazard as it may seem, since experience tells the control engineer what is required and, by looking at the reproduced picture, he knows whether tilt or bend is required or what combination of the two is likely to be effective.

Obviously, if a picture is gradually decreasing in brightness from one side to the other, the application of a saw tooth of increasing amplitude will lift the vision signal up and increase the brightness from left to right, thereby nullifying the error. Or, if a picture is dark at the sides and bright in the middle, the application of a bottom parabola will be likely to give correction. Fig. 12 shows examples of tilt and bend applied in the line-scan direction.

If the gradation of the picture is at fault in such a way that tilt or bend applied to the frame-scan (vertical base) would be better, this can be carried out, the saw tooth being applied to the vision signal as before, but in a relation as if the base were vertical instead of horizontal. Similar-

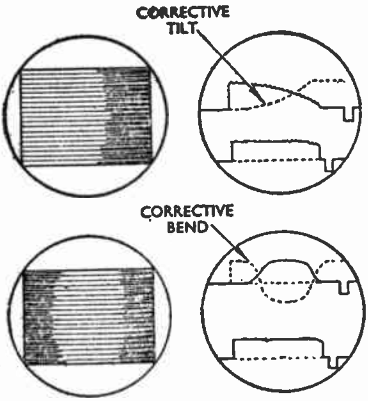


Fig. 12. Reproduced picture darkened to one side and one that is bright in the middle, together with their respective wave forms as shown on a line-scan oscilloscope. The dotted lines represent the corrective tilt and bend that must be applied in order to provide a wave of constant amplitude.

ly, the base of the parabola would be vertical instead of horizontal.

It must be realized that the illumination of the picture is not changed; that is, the light actually falling on the storage camera is unchanged. This must be adequate, and within certain limits, or tilt and bend cannot achieve its effect. You cannot produce an image if none is there because the light is too little, or the storage camera is "over-exposed" through there being too much light.

Thus, occasions arise where lighting troubles exist, and tilt and bend has no effect. The picture is then said to be "untiltable," or, where the light is such that the picture remains very white despite tilt and bend, the picture is said to refuse to "sit down."

Automatic tilt and bend has so far not been achieved, but it would not seem to be beyond the powers of circuitry to do away with the need for human adjustment of the vision signal to provide even "illumination" of the picture.

TIME BASE. Deflection of the spot of a cathode-ray tube which is defined with respect to time.

TIME-BASE GENERATOR. Apparatus for producing the voltage or current necessary to deflect the spot in a cathode-ray tube. The generator provides a voltage or current which varies in a known manner with time, usually linearly, and is applied to one pair of plates or one pair of coils to cause the spot to move horizontally, vertically or, in some cases, in a circular path.

TIME CONSTANT. Characteristic of a circuit, or part thereof, which defines its time of response to a change in the voltage applied to it. More particularly the time constant may be defined as the time taken by a capacitor to reach some specified state of charge when a voltage is first applied.

TIMED-SPARK SYSTEM. Spark system, used in radio telegraphy, in which a rotary spark-gap is employed to obtain spark discharges at regular intervals.

TIME SIGNAL. Any code signal which can be interpreted to give time to specified limits of accuracy. The B.B.C., in co-operation with the Astronomer Royal, arranges that the carrier wave of its senders shall be modulated by six successive short wave-trains, known as "pips," of 1,000 c/s frequency. The last dot coincides with a specified time. The accuracy is not high when compared with more elaborate code methods, but it is admirably convenient for setting domestic timepieces and watches.

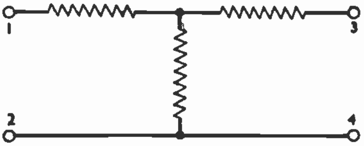


Fig. 13. Arrangement of impedances in what is known as a T-network.

T-NETWORK. Network composed of three impedances in the form of a T.

Two of the free ends are connected respectively to an input and an output terminal, and the third free end is common to the remaining input and output terminals. Fig. 13 shows a T-network. See BRIDGED T-NETWORK, C-NETWORK, H-NETWORK, LATTICE-NETWORK, L-NETWORK, O-NETWORK, PI-NETWORK.

TOLERANCE. Degree to which the frequency, sensitivity or other characteristic of an instrument or system is allowed to depart from its required value; the tolerance is usually expressed in percentage terms or in decibels. Examples: The speed of a gramophone turntable should have a tolerance not exceeding 0·5 per cent; the gain of an amplifier might be expressed as, say, 40 db. ± 2 db.

TONE CONTROL. Process of modifying the relative proportions of various audio frequencies in sound reproduction, *or* a device for achieving that end. At first glance, it might appear that to fit a tone control to a radio receiver or other sound-reproducing apparatus is a confession of failure on the part of the designer; it would seem that he should plan his circuits to yield equal amplification of *all* frequencies, and leave it at that.

Certainly, if he could do so successfully there might well be less chance of the unskilled user producing the sadly mutilated reproduction so often heard when the tone control is incorrectly adjusted.

Unfortunately, it is not feasible to endow a receiver with a balance of reproduction which will suit all occasions. Before proceeding to the *legitimate* technical reasons for this, mention must be made of a commercial reason which designers naturally regard as most illegitimate, but to the force of which they must bow. This is the highly important matter of public taste.

Before it became the general practice to fit tone controls, it was not unusual to hear a particular receiver praised for its "nice *mellow* tone," and, while technicians might dislike both the phrase and the type of reproduction it describes, they had reluctantly to admit its value as a selling point. Reluctantly because reproduction which justifies the word "mellow" is usually quite woefully deficient in those higher audio frequencies which impart proper brilliance and crispness to music and speech.

Widespread preference for such reproduction is not necessarily an indication of the depravity of public taste, as many disgruntled designers have at times thought. The matter is not quite so simple; there are certain occasions when it is far less unpleasant to listen to a receiver lacking in the higher audio frequencies than to one reproducing them in full.

Such an occasion arises, for instance, when there is much interference from stations in adjacent channels, producing a background of high-pitched whistles and spluttering noises (see SIDEBAND INTERFERENCE). Moreover, design defects in the loudspeaker are often rendered more objectionable by adequate higher-frequency response, while the more unpleasant of the effects of valve overloading are commonly heard in the upper register.

There is thus a case for a control to enable the user to reduce the upper audio-frequency response when conditions demand it. Such a control lends itself to abuse. That is unfortunate, but the remedy lies in the hands of the user, for it is not difficult to learn to use the device correctly. Having learned, he will bring the control into action only when conditions make a cut in the higher frequencies the lesser evil. At other times he will keep the control turned almost to the "bright" or "high" end of its range of adjustment.

That method is usually correct for the primitive type of tone control, which is, in fact, simply an adjustable attenuator of the higher audio frequencies. A tone control of the more

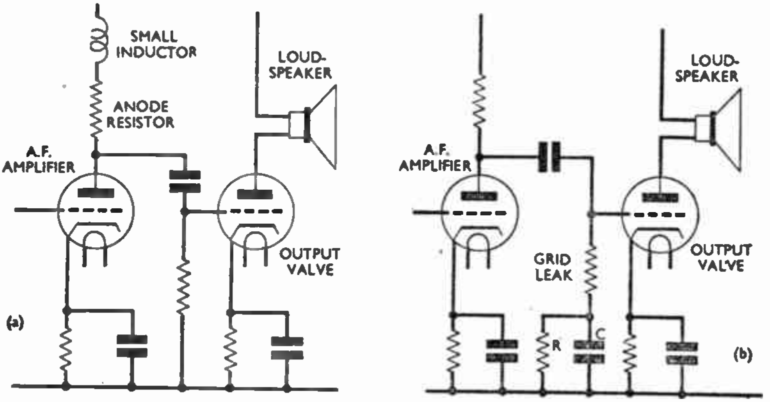
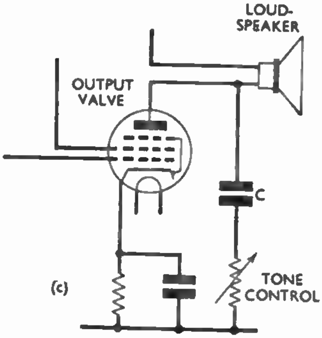
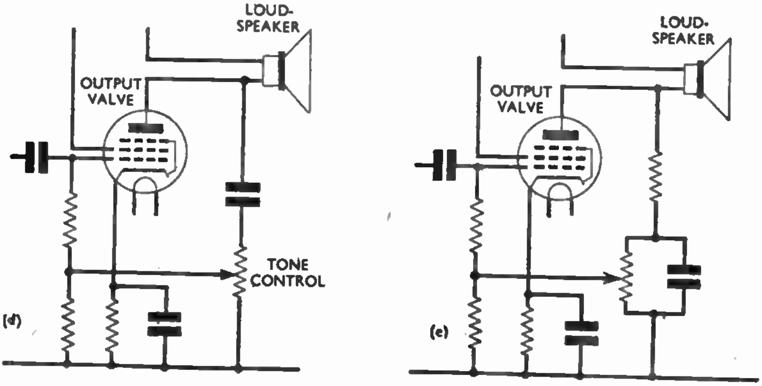


Fig. 14. Five circuits which provide tone control: (*a*) emphasis of the higher frequencies can be obtained by the inclusion of a small inductor in series with an anode resistor of reduced value, reactance of the inductor rising with frequency; (*b*) elements of a "bass-boost" circuit, in which the rising reactance of *C* at low frequencies adds to the value of the grid leak and increases the stage gain (*R* is merely to allow bias to reach the grid of the output valve); (*c*) a simple form of tone control that provides adjustable attenuation of the higher frequencies owing to the reactance of *C*; (*d*) skeleton tone-control circuit which gives control over the higher frequencies owing to feedback effects from anode to grid circuit; (*e*) by rearranging circuit (*d*), feedback voltages can be obtained for controlling low frequencies.





highly developed type, which may modify the lower frequency response at the same time as it controls the higher, is not necessarily to be treated in the same way. Depending on design factors, it may give its nearest approach to a correct balance between upper and lower register at some midway setting.

Further justification of the tone control comes from the characteristics of gramophone recording. Here, certain practical limitations make it impossible to cut the lower frequencies at their full peak-to-peak value, and some tone correction to increase the gain at these frequencies is, therefore, desirable in the reproducing circuits. It may take the form of a fixed correction brought into use by the act of switching from radio to gramophone, or an adjustable bass-emphasis circuit may be provided as part of the receiver's main tone control.

The latter method has the advantage that it can provide suitable compensation for all recordings (they differ somewhat in their bass deficiency), provided always that the user's musical ear is equal to the task. Such a control also permits the user to make some allowance for differences in broadcast transmissions and in listening conditions.

The possible methods of controlling tone are innumerable. Where the object is merely to provide means of attenuating higher frequencies to a variable degree, the control often takes the form of a by-pass capacitor arranged to shunt the unwanted frequencies past some impedance which plays a part in coupling successive valves in an audio-frequency amplifier, or past the loudspeaker itself.

In the latter case (a common one), the output valve is usually a pentode working under such conditions as tend to an over-emphasis of higher frequencies, so that there is a full range of control, running from over-much "top" through normal to subnormal. The control itself is then usually a variable resistor in series with a fixed capacitor. (Nothing definite can be said about the value of the capacitor, so much depending on other design details, but as a rough indication values from perhaps 0·005 to 0·05 μF (microfarad) or even larger may be seen in practical designs.)

Negative-feedback effects are sometimes exploited for tone-control purposes. For instance, in the type of circuit just considered, the higher frequencies will pass through the capacitor-resistor shunt to a greater degree than the medium and low ones; a suitable fraction of the voltages they set up can be fed back to the grid circuit of the valve, and there assist in reducing the gain at these frequencies. By a slight rearrangement of the circuit, feedback voltages for a reduction of bass frequencies can be obtained if desired. Fig. 14 will help to make these points clear.

By suitable juggling with resistance-capacitance networks in the output circuits, feedback voltages can be obtained for the reduction of high, low or middle frequencies, or combinations thereof. Suppose, for example, that it is arranged thus to diminish the amplification of high and middle frequencies: the effect will be as though the bass had been reinforced, and, in fact, this is sometimes used as a practical method of "bass boost."

More often, however, the same end is gained by simpler means in the inter-valve coupling circuits. Broadly, the principle of the method is to include in the inter-valve coupling a resistor of somewhat less than optimum value so that the stage gain is reduced, and to place in series therewith an impedance the value of which is negligible at middle and high frequencies but rises steeply at low ones. It thus raises the effective anode load substantially at those frequencies, and so correspondingly increases the amplification they receive.

The source of varying impedance is, of course, a capacitor, and a few practical figures will show the extent of the useful variation to be expected. Consider what happens when a capacitor of 0·01 μF is connected in series with a resistor of 200,000 ohms. In approximate figures, the reactance of the capacitor and the total impedance of the resistor and capacitor in series are related to frequency as in the table below.

The combined impedance will be seen to rise steeply below a frequency of around 200 c/s. Above that point, there is but little variation with frequency, and the table is carried only far enough to reveal the fact.

H.T. supply. It could, no doubt, be shunted with a resistor to allow the necessary voltage to reach the valve anode. But, if this resistor were of value sufficiently low to avoid a serious voltage drop, it would also be sufficiently low to make the capacitor largely ineffective as a reactance at the lower frequencies.

It is, however, possible to connect a series capacitor-resistor combination to a grid circuit without encountering so much difficulty, and this is often done. With values suitably chosen in relation to the preceding anode load resistance, the effect is closely similar to that of an anode load which rises in impedance at the lower frequencies, as, of course, the grid leak of the succeeding valve is, as far as alternating current is concerned, effectively in parallel with the anode-load resistor.

Frequency (cycles per second)	50	100	200	400	800	1,600
Reactance of Capacitor (ohms)	320,000	160,000	80,000	40,000	20,000	10,000
Impedance of Capacitor and Resistor in series (ohms)	377,000	256,000	215,000	204,000	201,000	200,000

Suppose, now, that this combination of capacitance and resistance could form the intervalve coupling in an audio-frequency amplifying stage requiring, say, 375,000 ohms for maximum practical gain. Plainly, on all except the lower frequencies, gain will be much reduced, which is another way of saying that the lower frequencies will be emphasized.

(The tabulated reactance figures were calculated mentally with the aid of a single memorized fact; namely, that the reactance of a capacitor of 1 μF at 100 c/s is roughly 1,600 ohms. It follows that the reactance of one of 0·01 μF is 160,000 ohms at 100 c/s, 320,000 ohms at 50 c/s, 80,000 at 200, and so on. The figure of 1,600 ohms for 1 μF at 100 c/s is worth remembering.)

In practice, of course, a resistor and capacitor in series cannot be used as the anode load in an audio-frequency amplifying stage, because the capacitor would isolate the valve from the

Incidentally, apart from the reasons already quoted for the use of some form of "bass boost" in an amplifier, there is a further justification to be found in the fact that a satisfactory audible balance of tones at low intensities calls for somewhat more bass than at high levels. Accordingly, in some receivers it is arranged that a bass-emphasis circuit is so associated with the gain control that, as the latter reduces the sound output, so does the corrector increase the proportion of bass frequencies.

It is occasionally desired to introduce a further type of tone control in the form of one that emphasizes the high frequencies. This is rarely seen in a general-purpose broadcast receiver, since the opposite type of control is more likely to be required when listening to distant stations.

When the transmission is so strong as to rule out all chance of interference, on the other hand, there is some justification for a device to increase the proportion of higher audio frequencies: there is a persistent tendency to attenuation of these frequencies all through a receiving system, more particularly in the tuned circuits (see RESONANCE), and wherever stray capacitances (including the inter-electrode capacitances of valves) are shunted across high impedance points in the A.F. amplifying circuits.

Some of the frequencies in the range of roughly 4,000 to 6,000 c/s are, to some extent, restored in many receivers as a result of minor resonances in the loudspeaker. But this method does not appeal to the purist, who is, in any case, inclined to regard a further range up to perhaps 10,000 or 12,000 c/s as being of considerable importance in high-fidelity reproduction.

In specialized receivers intended for use only on a few strong signals, means may be provided, therefore, for obtaining a degree of amplification which rises steadily with frequency in the upper range.

Lastly, it should be mentioned that a variation of coupling in band-pass circuits is essentially a tone control, as, when the width of the resonance-curve top is varied, so likewise is the proportion of higher frequencies in the reproduction (see BAND-PASS TUNING). In some receivers, therefore, facilities are included for using a wide-topped curve on local stations and a narrower one when necessary to isolate weaker signals from interference.

TONE WHEEL. Device formerly used in radio-telegraphy senders for producing what were then known as interrupted continuous waves (I.C.W.) and are now known as type A2 waves. It consisted of a wheel with a number of conducting segments around the periphery. The latter caused periodic interruptions of the circuit. The number of segments and the speed of the wheel were so chosen that the carrier wave was modulated by square waves with a frequency in the audio range, usually between 500 and 1,000 c/s. The method allowed the use of simple receivers, such as crystal sets, in contrast with continuous waves (type A1 waves) which required thermionic valves and a beat method of reception.

TONIC TRAIN. Term applied to those type A2 waves which have sinusoidal amplitude modulation.

TOP-CAP. Electrode connexion, usually that to the control grid, placed on the top of the bulb of a valve. The object of having an electrode connexion to a top-cap rather than a pin in the valve base is to reduce the capacitance of the electrode and to reduce inter-electrode capacitance.

TOROIDAL-WOUND INDUCTOR. Inductor having a coil wound on to a ring-shaped core or former. See FIXED INDUCTOR.

TOTAL EMISSION. Total current that can be drawn from a cathode. See EMISSION LIMITATION.

TOTAL MODULATION. Amplitude modulation in which the modulation depth is 100 per cent. See MODULATION DEPTH.

TRACE. In a cathode-ray tube, the pattern on the screen produced by the deflection of the beam.

TRACING DISTORTION. Non-linear distortion in gramophone-record reproduction, caused by the difference in shape and size of the point of the reproducing needle from that of the recording cutter. The distortion also occurs at high audio frequencies particularly at small groove diameters when the curvature of the groove is of the same order as that of the reproducing needle tip. As the groove diameter decreases, the needle has greater difficulty in tracing the wave, because of decreasing wavelengths.

Tracing distortion increases rapidly with frequency and amplitude, and occurs with both laterally and vertically cut records, but especially with the latter. It is heard as a buzz or high-pitched rattle, which is worse the wider the range of frequencies reproduced.

Even with great care in selecting needle points, it is difficult to reproduce records having heavily-cut high notes without either serious tracing distortion or limiting the frequency range by tone control. See ELECTRICAL RECORDING, NON-LINEAR DISTORTION, RADIUS COMPENSATION.

TRACKING. Maintenance of the correct frequency difference between local-oscillator and signal-frequency circuits in a superheterodyne receiver. For this purpose, padding and trimming capacitors may be added to the local oscillator circuit to produce the correct frequency difference. These capacitors are varied in some way by the wave-change switching, the requirements differing on various wave bands. See GANGING, PADDING CAPACITOR.

TRAIN OF WAVES. Unbroken group of waves. In the spark system, one train of waves is produced by each spark discharge.

TRANSCEIVER. Single unit of equipment which, by throwing a switch, may be used alternately as a sender and receiver. Parts of the circuit of both receiver and sender are generally common.

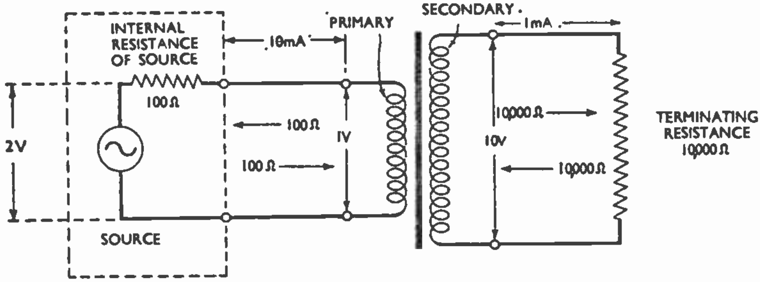


Fig. 15. Assuming the transformer shown to have no loss, the transfer impedance is 1 volt divided by 1 mA, i.e. 1,000 ohms; the ratio of transfer impedance to the impedance "seen" by the generator is 10 : 1, the transformer voltage ratio.

TRANSCONDUCTANCE. Term having the same basic meaning as mutual conductance, but applying to any electrodes and not necessarily to control grid and anode (see MUTUAL CONDUCTANCE). Mutual conductance is defined as the ratio of a small change in anode current, to the small change of grid voltage producing it; transconductance is the ratio of the small change of electrode current in one electrode, to the small change of voltage on another electrode producing it, regardless of which electrodes are in use. See VOLTAGE FACTOR.

TRANSDUCER. In general, a device for converting one form of energy into a different form. Thus a microphone might be termed an acoustical-electrical transducer. The term is sometimes used, however, to describe an electrical network used for impedance matching.

TRANSFER CONSTANT. See IMAGE-TRANSFER COEFFICIENT.

TRANSFER IMPEDANCE. Ratio of the voltage applied to any two terminals of a network to the current thereby caused to flow between another pair of terminals. The terminations across the terminals must be specified. The basic idea of transfer impedance may be understood from Fig. 15. The transformer is supposed to have no loss. The transfer impedance is 1 volt divided by 1·0 mA = 1,000

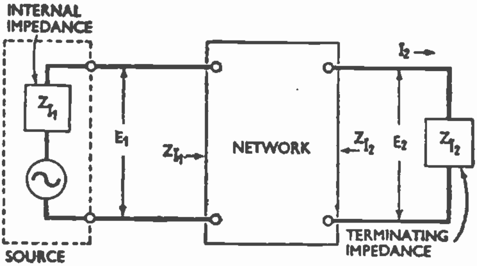


Fig. 16. This network replaces the ideal transformer of Fig. 15; it is matched on an image-impedance basis, and the transfer impedance is E_1/I_2. Comparison should be made with Fig. 17.

ohms. The impedance of the primary of the transformer is 1 volt divided by 10 mA, or 100 ohms. Thus the ratio of the transfer impedance to the impedance seen by the generator is 10 : 1, which is the voltage ratio of the transformer.

In Fig. 15 it is seen that there is perfect matching; the 10,000 ohms connected across the secondary of the transformer has the same impedance as the secondary of the transformer when the e.m.f. is considered to be short-circuited. Also, the generator terminals "look into" the reflected impedance of 10,000 divided by the impedance ratio of the transformer (the voltage ratio squared); thus the generator "sees" 100 ohms, which matches its internal impedance. Perfect matching might also be described as that condition in which the transformer is terminated on an image-impedance basis.

If the ideal transformer is replaced by any network terminated on an image-impedance basis, a transforming action takes place and the network behaves as a transformer (Fig. 16). In this case the impedances may all contain reactance and the image-transfer constant is half the natural logarithm of the ratio of the volt-amperes entering, to those leaving, the network.

The most general case is shown in Fig. 17; transfer impedance has a value, but the image-transfer coefficient can no longer be expressed, since the network is not terminated in its image impedance.

Although these considerations may seem to have little to do with the practical aspects of radio, the practical designs of radio equipment would be more difficult if the theory of networks had not been formalized. See IMAGE IMPEDANCES, IMAGE-TRANSFER COEFFICIENT, MATCHING, MATCHING TRANSFORMER, TRANSFORMER.

TRANSFORMER. Arrangement of two coils inductively coupled to one another. The transformer has a great many applications both in electrical engineering and in telecommunications. Its practical value lies in its ability to change the effective voltage of an alternating wave, a very small proportion of power being lost in the process. Thus it is used in electrical engineering to raise voltages to high values when transmitting power over

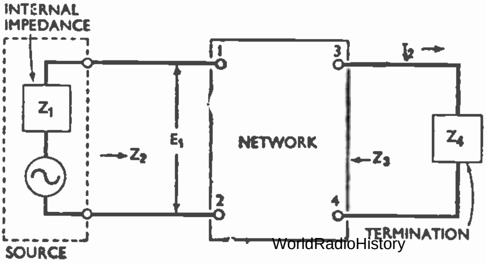


Fig. 17. Although Z_2 does not equal Z_1 and Z_3 does not equal Z_4, the transfer impedance is E_1/I_2 (as in Fig. 16). The image-transfer coefficient has no meaning, however, because the network is not matched on an image basis.

long distances to minimize the losses in conductors, while it transforms from high to low voltage so that the power for household and factory machinery can be supplied at a safe voltage.

A simple chassis-mounting audio-frequency transformer of the kind widely used in radio receivers is shown in Fig. 18.

In broadcasting apparatus, the transformer may be used to obtain a voltage gain when feeding waves into the very high-impedance grid-cathode circuit of a valve, in matching the output from a valve to a load such as that of a low-impedance loudspeaker, in matching microphones and amplifiers to lines, and in matching the output of senders to aerials. In telecommunications generally, the transformer is used chiefly for matching, conversion from balanced to unbalanced circuits and vice versa and, in some cases, to feed power from one circuit to another, there being no metallic connexion between the circuits.

Fig. 19 illustrates the basic principle of the transformer. In (a) the alternating currents in one coil create a pulsating field external to the coil. This may be resolved in (b) as two fields of constant amplitude, rotating in opposite directions and cutting the turns of the secondary coil. As the frequency of the currents decreases, so (if the primary is a pure inductance) the current and the fields increase. Thus the slower rotation of the vectors representing the pulsating field is compensated by a greater field density and a constant voltage is induced in the open-circuited secondary.

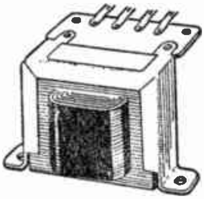


Fig. 18. Typical iron-cored A.F. transformer as used in radio receivers.

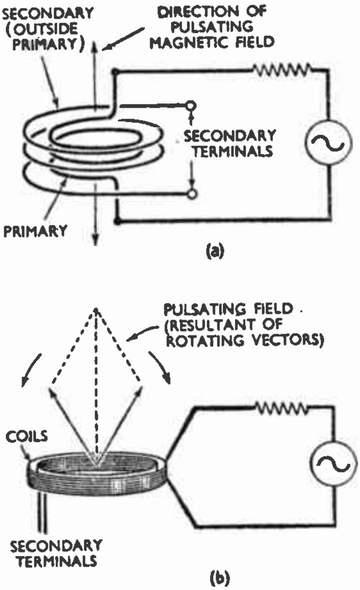


Fig. 19. Fundamentals of the transformer: (*a*) alternating current passing through one coil (the primary) causes a pulsating magnetic field to act along the axis of the two coils; (*b*) the field can be considered as the resultant of two oppositely rotating fields of constant strength.

When the secondary is loaded by a resistance, currents flow in the resistance due to the induced secondary voltage. The secondary currents are 180 deg. out of phase with the primary currents; thus the primary has less effective inductance. This is because some of the opposing voltage, always present due to self-inductance, is cancelled by the rotating fields set up by the secondary currents. The lower the resistance connected to the secondary, therefore, the greater the current taken by the primary. The transformer is thus able to supply power to a secondary load; and the lower the resistance of the load, the more power, within limits, is it able to absorb.

The voltage induced in the secondary is proportional to the ratio of the secondary to primary turns. Thus the turns ratio of a transformer is also called its voltage ratio (Fig. 20). If it is assumed that no power is lost in the transformer itself, the power delivered to the primary is equal to the power drawn from the secondary; thus it may be concluded that the ratio of secondary to primary volts is equal to the square root of primary and secondary impedances when matching exists (see MATCHING, TRANSFER IMPEDANCE). There is thus a voltage ratio and an impedance ratio of a transformer, and the latter is the square of the former.

Fig. 21 shows the meaning of leakage inductance. If a direct current is passed through the primary of a transformer, the flux lines might take up a form such as shown. It is seen that not all the flux lines cut the secondary coil; this implies that the secondary voltage is, in practice, somewhat less than the turns ratio suggests, because of the failure to get a unity coupling coefficient.

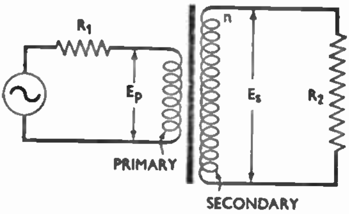


Fig. 20. In a transformer assumed to have no loss, if the ratio of secondary turns to primary turns is n : 1, the secondary voltage E_s is n times the primary voltage E_p. The power in R_2 is E_s^2/R_2, and that in the primary is E_p^2/R_1; $n = E_s/E_p = \sqrt{R_2/R_1}$.

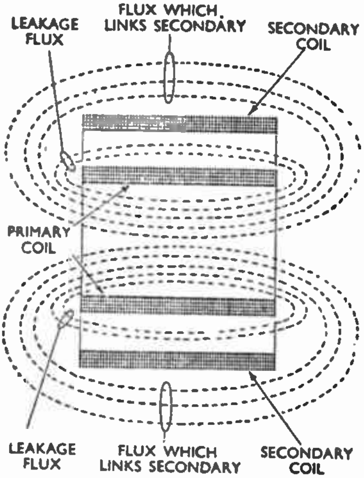


Fig. 21. Section through two coils, primary and secondary, showing lines of magnetic force produced by a direct current in the primary. That part of the flux which fails to link the secondary is called the leakage flux and causes leakage inductance.

Thus a transformer in which the coupling is not perfect may be drawn as two coils which are perfectly coupled with an inductance in series with each coil (Fig. 22a). This is the leakage inductance. As the frequency of the currents increases, so the secondary voltage of a loaded transformer must fall. Diagrams (b) and (c) of Fig. 22 show how leakage inductance can, in some circumstances, be cancelled.

In attempting to get the greatest possible coupling coefficient, leakage flux must be prevented; this is why iron cores are used (see CORE, LAMINATION, LEAKAGE INDUCTANCE). Losses are caused by eddy currents in the iron and by the friction of molecules which are turned about as the magnetizing force reverses. The latter is called hysteresis loss, the former eddy-current loss and the two together are called iron loss (see IRON LOSS).

With an open-circuited secondary, the transformer primary has the nature of an inductance; therefore a current flows in the primary, even though no current is drawn from the secondary. This current is called a magnetizing current; it becomes greater as the wave-frequency becomes lower. To minimize magnetizing current, the primary inductance must have an impedance, at the lowest wave frequency, at least twice that of the internal impedance of the generator.

Owing to leakage inductance, self-capacitance of windings, iron losses and the necessity of limiting the magnetizing current, transformers must be carefully designed if they are to give substantially equal insertion loss over a wide range of wave-frequencies. It is easier to cover a wide frequency band if the secondary is not loaded. In practice, an iron-cored transformer may be designed to have a substantially equal insertion loss from, say, 50 to 300,000 c/s if the secondary is unloaded, but considerably less if it is loaded.

When their design employs very thin laminations of high-permeability iron, iron-cored transformers may be used efficiently at low radio-frequencies (up to 1 Mc/s) provided the frequency range is not too great. At higher frequencies up to tens of megacycles per second, dust-iron cores are used. At the very highest frequencies, air cores are essential. Here, the leakage inductance may be serious but is often cancelled by a capacitive reactance in a band-pass circuit. Toroidal windings on dust-iron cores are used also, and have the least leakage inductance. See CORE, COUPLING COEFFICIENT, ELECTROMAGNETIC INDUCTION, INDUCTANCE, IRON DUST, IRON LOSS, PERMEABILITY, TRANSFORMER COUPLING, TRANSFORMER RATIO.

TRANSFORMER COUPLING. Method of transferring energy from one circuit to another by use of a transformer, the primary winding of the transformer being connected in one circuit and the secondary winding in the other.

Normally, the transference of energy can be in either direction, but, if the transformer is used to couple a valve to a load, energy can be sent only from the valve to the load. Transformers are often used to couple the anode circuit of one valve to the grid circuit of the following valve in multi-valve amplifiers. See INTER-VALVE COUPLING.

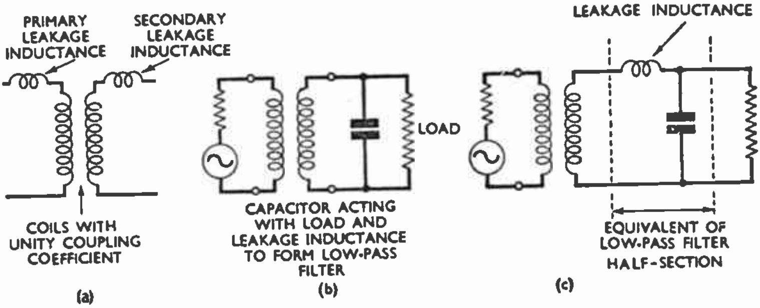


Fig. 22. Leakage inductance in a transformer may be considered as inductance in the circuit external to the windings, regarded as having unity coupling (*a*). Hence reduction in the secondary voltage of a loaded transformer with rise in frequency may sometimes be offset by the use of a capacitor, as at (*b*), to form the equivalent of a half-section low-pass filter such as that shown at (*c*).

TRANSFORMER RATIO. Ratio of the primary to secondary turns expressed as a ratio of a number to unity. A transformer ratio is either 1 to any number, or any number to 1. The primary turns are always given before the secondary. Thus a transformer with 1,000 turns on the primary and 5,000 on the secondary has a ratio expressed as 1 : 5. If the primary turns were 10,000 and the secondary 100, then the ratio would be 100 : 1. The impedance ratio is the square of the voltage (or turns) ratio. See STEP-DOWN TRANSFORMER, STEP-UP TRANSFORMER.

TRANSIENT. In an acoustic or electrical system, a disturbance resulting from a sudden change in conditions. It persists for a relatively short time after the change has taken place and has an irregular and non-repetitive wave form with a continuous spectrum. The term is particularly applied to the current wave resulting from a sudden change (i.e. a step) in voltage. See WAVE FORM.

TRANSIENT DISTORTION. Any form of signal distortion which does not occur, or is not perceptible, with steady signals. See DELAY DISTORTION, OVERSHOOT, PHASE DISTORTION.

TRANSIENT TIME. Synonym for BUILDING-UP TIME.

TRANSITRON. Circuit associated with a pentode valve and giving a negative resistance. The connexions of the transitron are shown in Fig. 23. The electrode voltages are arranged so that a virtual cathode forms between screen and suppressor grids. The capacitor is connected so that a different bias potential may be established on screen and anode, but so that each electrode potential is altered equally by an alternating potential.

In this condition, a transient increase of screen potential results in a transient decrease of screen current. Thus the screen has a negative transconductance or negative resistance characteristic, and the valve may be used to generate oscillations, as does a tetrode used as a dynatron. The valve is sometimes called a retarding-field negative-transconductance valve. See NEGATIVE SLOPE-RESISTANCE, NEGATIVE TRANSCONDUCTANCE, OSCILLATOR.

TRANSIT TIME. Time taken for an electron to travel between electrodes (see ELECTRON VELOCITY). When a valve is amplifying, generating or detecting waves of very high frequency, the transit time may be comparable with the period of alternation. This profoundly influences the performance of the valve. See CENTIMETRIC WAVE, DETECTOR, OSCILLATOR.

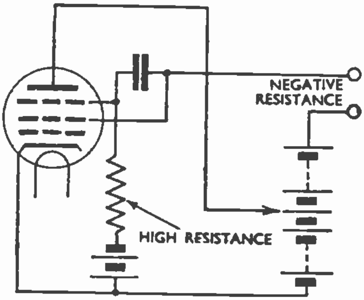


Fig. 23. Transitron circuit, showing how the capacitor is connected so that different bias potentials may be applied to the screen and suppressor grids of the pentode to form a virtual cathode between the two electrodes.

TRANSMISSION. Process whereby intelligence is communicated by electrical means; processes whereby people can talk to one another over the telephone or by means of which it is possible to send telegraphic messages over world distances. Broadcasting is a transmission process; so is radar or facsimile. Thus transmission does not mean only the sending of messages; it embraces the process of receiving as well as sending. It is therefore preferable to refer to a sender and receiver, which are both parts of a transmission system, rather than a transmitter and receiver, as "transmitter" in this instance is a misnomer.

It is unfortunate that telephone engineers talk of a "transmitter" to denote what radio engineers would call a microphone; and telephone engineers also use the term "receiver" instead of what others would call a telephone, telephone earpiece, or headphone. To a radio engineer, a receiver is the complete instrument which receives and detects modulated waves and energizes a transducer; to a telephone engineer, a receiver is the instrument which is held to the ear and converts audio-frequency currents into sound waves.

However, all agree that transmission is the process whereby messages are communicated; a transmission system embodies amplifiers, equalizers, repeaters, wave filters, detectors, modulators, demodulators and so on. A transmission network describes any network used in a transmission system, whether filter, equalizer, or similar component.

All transmission systems are based upon means of modulating carrier waves by the intelligence to be communicated, and of detecting or demodulating resultant waves at the receiver; in ordinary line telephony, in which the voice spectrum is sent without change of frequency, the carrier-wave frequency is zero and the sideband waves (which must have a positive frequency) are all in an upper sideband.

The frequency limits of the sideband are given by the voice-frequency band used. Clearly, the modulation of the direct current flowing in a carbon microphone is in effect modulation of a carrier wave of zero frequency. An electromagnetic or electrostatic microphone is the equivalent of a suppressed carrier modulator, the carrier frequency being zero. The acceptance of this generalization brings all methods of transmission into line; all are based on modulation of a carrier wave.

A common medium is used in which channels of communication are established. These channels are characterized by a carrier-wave frequency and a frequency band containing the sideband waves. Filters are used in the receiver to accept one modulated carrier wave, one sideband or one message, and reject all others flowing in other channels. The medium used for transmission may be the ether of space when radio transmission is used, or a transmission line. One transmission line may provide many channels; these are established by using carrier waves of different frequencies which are sent through the conductive line.

The theory of transmission is formalized in terms of concepts such as characteristic impedance, iterative impedance, image impedance, insertion gain and loss, return current, propagation coefficient (with its components of attenuation), phase-change coefficient, and so forth.

The engineer or technician interested in the design of broadcast receivers for domestic use may well feel that all these theoretical concepts are quite outside his experience and therefore useless to him, although realizing that those responsible for the programmes must master theory in order to consummate good practice; he might feel that the radio receiver can be designed without an acquaintance with such concepts as characteristic impedance, image-transfer coefficient and so forth.

But in dealing with television receivers, the usefulness of such abstractions is appreciated; an understanding of the concepts of transmission enables the technician to make mains units more economical, an intermediate-frequency filter more selective, and a detector more efficient. See CARRIER-WAVE TRANSMISSION, DEMODULATION, DETECTION, EQUALIZER, FILTER, FREQUENCY-CHANGING, MODULATION, NETWORK, RECEPTION, TRANSMISSION LINE.

TRANSMISSION BAND. Frequency band containing frequencies of waves which pass through a filter with zero, or relatively small, attenuation (see EFFECTIVE BAND WIDTH). A filter is a network which passes certain waves freely and attenuates others, the passing or stopping of the waves depending upon their frequencies. The term denotes the frequency band containing waves which will pass freely through a filter. For pictorial explanation of this, reference should be made to Fig. 24. See BAND-PASS FILTER, BAND-STOP FILTER, FILTER, HIGH-PASS FILTER, LOW-PASS FILTER.

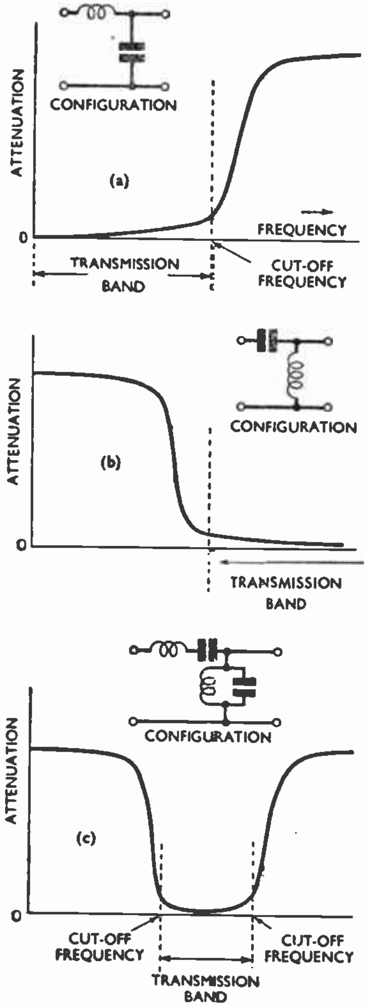


Fig. 24. Attenuation/frequency graphs, with configurations, pertaining to (*a*) low-pass, (*b*) high-pass and (c) band-pass filters; the transmission band is the frequency range in which the filter used transmits waves freely.

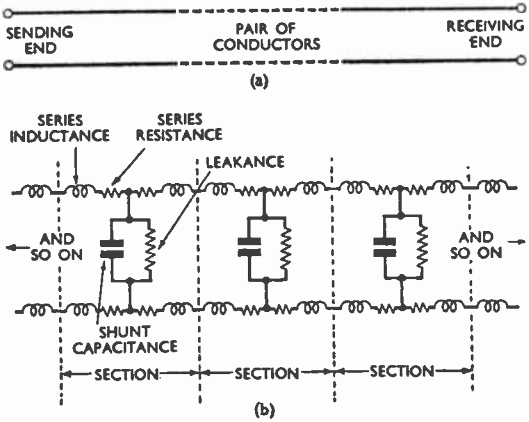
TRANSMISSION GAIN. Increase in power, expressed in decibels, in transmission from one circuit point to another. Obviously, transmission gain implies the use of an amplifier; there is no possibility of a gain of power taking place at the junctions of a passive network. On the other hand, there may be a gain in voltage (or current) by the use of a transformer, for instance, between circuit points; but this is offset by a loss of current and there cannot be a power gain. See IMAGE-TRANSFER COEFFICIENT, MATCHING.

TRANSMISSION LINE. Conductive circuit used for transmission, consisting of a pair of wires insulated from one another and lying close to one another (see CABLE, EARTH, OPEN-WIRE LINE, SCREENED PAIR). The basic characteristics of a transmission line are shown in Fig. 25. In analysing the behaviour of a line in relation to messages sent in one direction it is convenient to consider a transmission line as having a sending end and a receiving end. In two-way communication, sending end and receiving end apply in relation to transmission from one end to the other of one or other of the messages.

The electrical equivalent of a uniform transmission line, shown in Fig. 25b, is a cascade of networks having series arms containing resistance and inductance, and shunt arms containing resistance and capacitance. The shunt-arm resistance is called leakance because it represents a leakage of electricity between conductors due to imperfect insulation between conductors; leakance is relatively more important in open-wire lines. A uniform line has distributed constants (capacitance and inductance) and so it is only perfectly simulated by lumped constants when these are infinitesimally small.

The cut-off frequency of a filter section having series inductance and shunt capacitance is determined by the reciprocal of the product of the

Fig. 25. The uniform transmission line (*a*) consists of a pair of conductors insulated from one another. Such a line has the electrical equivalent of a number of H-networks (*b*), joined on an iterative-impedance basis.



inductance and capacitance values. If these are infinitely small, the cut-off frequency is infinite. Thus a uniform line, suitably terminated, would transmit a wave of any frequency without loss, always provided the resistance of the line were zero. Power is lost in a line due to the resistance of the conductors and leakance, and has nothing to do with these reactances as such.

This fact is stressed because it is sometimes assumed that a uniform line has a cut-off frequency as a filter section has. In fact, the attenuation is due to line resistance. Once resistance effects come into the picture, the relative values of resistance and reactance determine attenuation (see ATTENUATION COEFFICIENT).

When a wave is passed through a transmission line, it may be reflected at the receiving end and so return to the sending end (see REFLECTION, RETURN CURRENT). There is no reflection from the receiving end of a transmission line if this is terminated by a resistance having magnitude equal to the characteristic impedance of the line. At frequencies at which the resistive effects of the line are negligible, the characteristic impedance of a line is given by the square root of the ratio of the inductance to the capacitance of the line per unit length.

The characteristic impedance of a line can be found by measuring the sending-end impedance with the receiving end open-circuited and short-circuited. The characteristic impedance of the line is then given by the square root of the product of these two impedances. If the line is very long, the sending-end impedance of the line is the same whether the receiving end is short-circuited or open-circuited, and the sending-end impedance is the same as the CHARACTERISTIC IMPEDANCE (q.v.), which depends on dimensions and spacing of the conductors.

The attenuation coefficient of a line increases with increasing frequency because the shunt capacitance has a less impedance while the series resistance remains constant (until skin-effect becomes important). If the line were very long, the power arriving at the receiving end would be so small as to decrease the signal-to-noise ratio to unacceptable values. Thus repeaters are placed in the line at intervals to raise the level at that point so that the signal-to-noise ratio is never too small, however long the line (see EQUALIZER).

It is interesting to note that, without repeaters and with a line 4,000 miles long having an attenuation coefficient of 1 db. per mile, it would require 10^{400} mW or 10^{391} MW to produce 1 mW at the receiving end. This is a greater power by far than would be available if all the power stations in the world contributed their full output! Using repeaters each taking about 10 W from the mains, placed at 40-mile intervals, would absorb a total of about 1 kW of power and the sending power would need to be of the order of only a few milliwatts.

A loaded line is one in which inductors are placed at intervals along the line. This has the effect of diminishing the rate at which attenuation increases with frequency, but sets a limit to the highest wave frequency that may be used. Loading, in other words, makes a line behave like a low-pass filter (see LOADING, LOADING COIL).

The tendency nowadays is to bury transmission lines; thus several pairs of wires, each forming part of a transmission line, are laid together in a cable; and each pair carries one or more messages. The co-axial cable has less attenuation than a two-pair line, and is used to carry many messages simultaneously by the use of modulated carrier waves (see CARRIER, CO-AXIAL CABLE). Television transmission takes place over co-axial cables. See BALANCED TRANSMISSION LINE, PHASE-CHANGE COEFFICIENT, PROPAGATION COEFFICIENT, UNBALANCED TRANSMISSION LINE.

TRANSMISSION-LINE CONTROL. Circuit in which a short transmission line is used to control the frequency of an oscillator.

TRANSMISSION LOSS. Decrease in power, expressed in decibels, in transmission from one circuit point to another. Transmission loss is due to mismatching (see MATCHING, MISMATCHING FACTOR). It is distinguished from insertion loss by the fact that it is due to loss at a circuit junction, while insertion loss is loss in the apparatus inserted in a circuit, such as in a transformer or filter. See IMAGE-TRANSFER COEFFICIENT, INSERTION GAIN, TRANSMISSION GAIN.

TRANSMISSION MEASURING SET. Apparatus consisting of a source of known internal impedance (usually 600 ohms) which can be adjusted to generate a known power, and a receiving circuit calibrated in decibels relative to 1 mW on a specified impedance. Thus the T.M.S., as the set is sometimes called, sends a known signal into any network and measures the level at the output from the network. See ATTENUATION COEFFICIENT, FILTER, INSERTION LOSS, NETWORK, PHASE-CHANGE COEFFICIENT, PROPAGATION COEFFICIENT.

TRANSMISSION NETWORK. Network used as part of a transmission system. See TRANSMISSION.

TRANSMISSION PERFORMANCE RATING. When a line or apparatus is added to, or used to replace part of, a telephone circuit, the loss or gain which must be included in the circuit to restore the original transmission.

TRANSMISSION UNIT. Obsolete term for DECIBEL.

TRANSMITTER. Mechanical equipment for sending signals over an electrical circuit. In telephony, the term "transmitter" is sometimes employed instead of MICROPHONE (q.v.). In radio, however, use of the term has been officially discouraged in favour of SENDER (q.v.) in reference to apparatus which produces and modulates R.F. energy for communication purposes.

TRANSMITTER-RECEIVER. Assembly comprising a sender and a receiver with provision for changing from send to receive, usually by means of a switching system.

TRANSMITTING VALVE. Valve that is used exclusively in senders. (As many valves are suitable for use in senders as well as receivers, the meaning of the term is limited to valves suitable only for use in senders.) See RECEIVING VALVE.

TRANSPONDER. Form of sender-receiver equipment, used particularly in beacons and aircraft, which, on receipt of a suitable signal, automatically radiates an answering signal.

TRANSPOSED TRANSMISSION LINE. Transmission line in which the lines are interchanged in position at regular intervals of distance to minimize radiation or interaction with other lines.

TRANSVERSE ELECTRIC WAVE. Electromagnetic wave in which the electric lines of force act at right-angles to the direction of propagation. See RADIATION.

TRAP AMPLIFIER. Monitoring amplifier which forms a parallel circuit or branch to a main amplifier, branching off from the main-input circuit or from an early stage in the other amplifier. The purpose of the arrangement is to ensure that any adjustments made in the monitoring amplifier, or any faults occurring therein, shall have as little effect as possible on the main circuit. This is more particularly a consideration in broadcasting, where the main amplifier may be carrying a programme on its way to a sender.

TRAPEZIUM DISTORTION. In a cathode-ray tube with electrostatic deflection, the effect produced when the deflection sensitivity of the first pair of plates through which the beam passes is modulated by asymmetrical deflection potentials applied to the second pair of plates; this in effect introduces a subsidiary electron lens. Trapezium distortion is so named because of its effect on what would otherwise be a square or rectangular frame on the screen of the cathode-ray tube (Fig. 26).

It can be avoided by using symmetrical deflection, but, as this is not always convenient, various deflector-plate constructions have been adopted to render the tube inherently free from the defect. One of these is shown in Fig. 27. See ASYMMETRICAL DEFLECTION, DEFLECTION SENSITIVITY, SYMMETRICAL DEFLECTION.

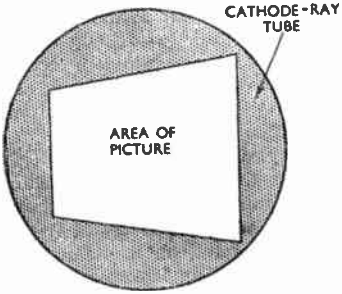


Fig. 26. Appearance that is assumed by a rectangular frame when it is subjected to trapezium distortion.

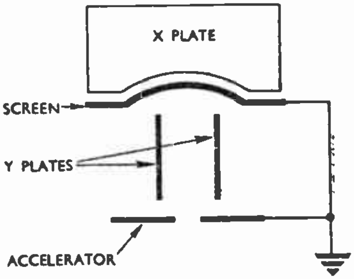


Fig. 27. Trapezium distortion can be eliminated, even with asymmetrical deflection, by shaping the X plates as shown and placing a screen (slotted to allow the beam to pass through) between them and the Y plates.

TRAPEZIUM EFFECT. See TRAPEZIUM DISTORTION.

TRAVELLING-WAVE AERIAL. Aerial in which there is no stationary pattern of voltage and current nodes and antinodes; the generator and load impedances are matched and there is, therefore, no reflection of energy to produce an interference pattern of wave impulses travelling in opposite directions. See STANDING-WAVE AERIAL.

T.R.F. Abbreviation for "tuned radio-frequency," a term applied to receiver circuits which do not incorporate the superheterodyne principle, and are sometimes called straight circuits.

TRIGGER RELAY. Thermionic relay so arranged that it undergoes changes in its electrical equilibrium when operated, and remains in its new condition after the removal of the cause of operation until such time as it is reset by a restoring operation.

TRIGGER VALVE. Valve which, on receipt of a signal of sufficient amplitude, initiates or terminates a discharge but has no subsequent control over it. This may be regarded as an example of a valve used as a TRIGGER RELAY (q.v.).

TRIMMER. Capacitor of small capacitance connected in parallel with one of large capacitance for the purpose of finely adjusting the combined capacitance. In wave filters of the type used in line communications equipment and in certain other applications, small fixed capacitors—usually of the silvered-mica type—are used as trimmers.

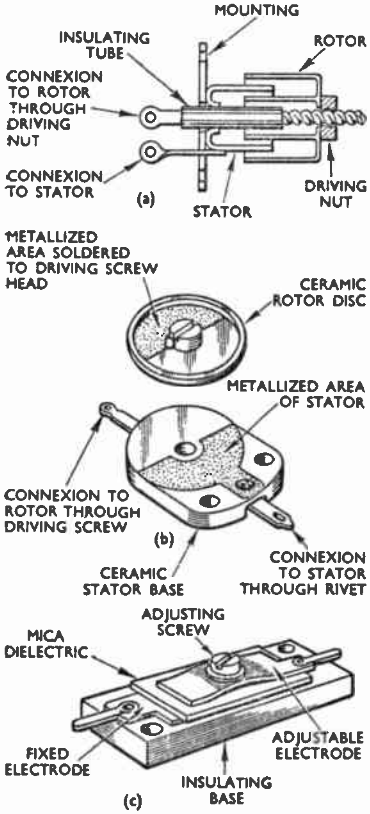


Fig. 28. Three forms of trimmer are shown: (*a*) section through a co-axial-cylinder type of trimmer; (*b*) a ceramic rotatable-disc type, and (c) a form of trimmer in which both mica and air are employed as the dielectrics.

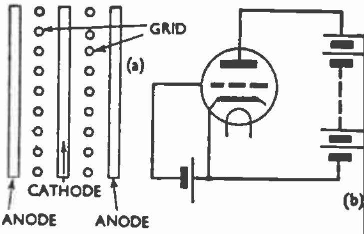


Fig. 29. Diagrams showing (*a*) a section through the electrode structure of a triode, and (*b*) the conventional symbol for the valve, with connexions for typical conditions of operation, i.e. a negative bias voltage on the grid.

In radio circuits, where trimmers are used for such purposes as compensating for a small capacitance-difference between two nominally identical capacitors or circuits, and also for tracking, trimmers are usually variable.

There are four common types of variable trimmer. The first is a miniature version of the rotary overlapping-vane type of variable air capacitor. The second uses air as the dielectric, but has electrodes consisting of two sets of co-axial cylinders axially adjustable with respect to one another by means of a screw motion, as shown in Fig. 28a.

The third (Fig. 28b) has a solid dielectric and consists of a rotatable disc of ceramic material mounted on a ceramic base. The surfaces of contact of both rotor and stator are smoothly ground. On the upper surface of each is a metallized electrode area of semicircular shape. The material of the disc forms the dielectric and its rotation changes the amount of electrode overlap in the same way as in a vane type of variable capacitor with air dielectric.

In the fourth type (Fig. 28c) the dielectric is a combination of solid (usually mica) and air, and the capacitance is varied by adjusting the electrode spacing. See FIXING CAPACITOR, GANGING, VARIABLE CAPACITOR.

TRIMMING CAPACITOR. Synonym for TRIMMER.

TRIMMING CONDENSER. Synonym for TRIMMER.

TRIODE. Valve having three electrodes, namely, anode, cathode and control grid. The triode valve (Fig. 29) laid the foundations of modern communication technology. It was invented by Lee de Forest, an American (see AUDION). The space current of a valve is determined by the potential gradient at the cathode (see VALVE). In a triode, provided that the anode potential is fixed, the potential gradient at the cathode is determined by the potential of the grid.

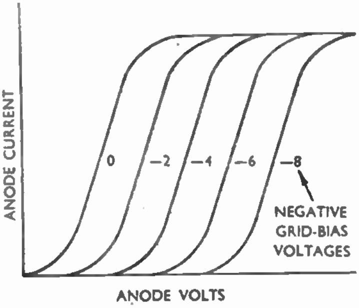


Fig. 30. Ideal anode-volts/anode-current characteristics of a triode showing that, fundamentally, when the grid-bias voltage is made more negative, the similarity in shape between this characteristic and that of a diode remains.

Consider the slightly idealized family of anode-volts/anode-current characteristics of a triode shown in Fig. 30; if each of these is compared with the anode-volts/anode-current characteristic of a DIODE (q.v.), it will be seen at once that this triode characteristic is of the same shape as the diode characteristic.

Furthermore, as the grid voltage is made more negative, the curves of similar shape are displaced to the right. The obvious interpretation is that the triode is a diode in which the potential of a grid placed between the anode and cathode determines the potential gradient at the cathode, and hence the relationship between anode current and anode volts.

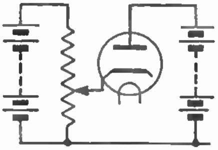


Fig. 31. Positive bias on the cathode of a diode, which may be provided as shown, is equivalent in effect to negative bias on the grid of a triode; a set of anode-volts/anode-current graphs for the diode will be similar to those for the triode in Fig. 30.

The difference between diode and triode, therefore, is that as the grid is made more and more negative, the anode current starts at a higher and higher anode voltage. Exactly the same type of characteristics could be obtained if the cathode of a diode were biased positively (Fig. 31). The next basic point about a triode (and the tetrode and pentode which were the logical developments of it) is that very

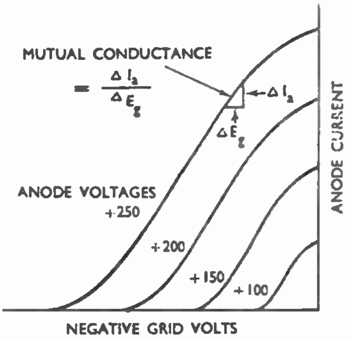


Fig. 32. Typical grid-volts/anode-current characteristics of a triode. Large changes in anode current result from small changes in grid voltage.

small changes of negative grid potential make large changes in anode current (Fig. 32). These changes are the greater for a given grid-voltage change as the mesh of the grid becomes smaller and as the grid is moved closer to the cathode, because the shielding effect of the grid on the cathode increases as the mesh is greater (see MUTUAL CONDUCTANCE). See also AMPLIFICATION FACTOR, ANODE SLOPE-RESISTANCE, GAS-FILLED TRIODE, PENTODE, TETRODE.

TRIODE-DETECTOR RECEPTION. System in which incoming signals are passed straight to the detector valve (triode type) without prior radio-frequency amplification. Increased sensitivity is usually provided by the use of regeneration.

TRIODE-HEPTODE. Valve used for frequency-changing in superheterodyne receivers and consisting of a triode and a heptode surrounding a common cathode and contained in one bulb. See FREQUENCY-CHANGER VALVE.

TRIODE-HEXODE. Valve used for frequency-changing in superheterodyne receivers and consisting of a triode and a hexode surrounding a common cathode and contained in one bulb. See FREQUENCY-CHANGER VALVE.

TRIODE-HEXODE FREQUENCY-CHANGER. Triode-hexode valve in which oscillations generated in the triode section are mixed with signals applied externally to the hexode control grid to produce new frequencies in the hexode anode circuit. See FREQUENCY-CHANGER, TRIODE-HEXODE.

TRIODE-HEXODE FREQUENCY CONVERTER. Synonym for TRIODE-HEXODE FREQUENCY-CHANGER.

TRIODE-PENTODE. Multiple valve in which the electrode assemblies of a triode and a pentode surround a common cathode in a single envelope. This type of valve was, at one time, used as a frequency-changer, the triode section acting as oscillator and the pentode section as mixer. It is now obsolescent. See FREQUENCY-CHANGER, PENTODE, TRIODE.

TRIPLE-DIODE. Three diodes contained in a single bulb and using a common cathode. See DIODE, DOUBLE DIODE.

TRUE BEARING. Bearing given in terms of true, rather than magnetic, north.

T-SECTION. Filter section in the form of a T-NETWORK (q.v.).

T.U. Abbreviation for TRANSMISSION UNIT. See DECIBEL.

TUBE. Synonym for VALVE (q.v.).

TUNE. To adjust the resonant frequency of a circuit or complete piece of apparatus to a desired figure. The word may be used also as a noun; the tune of a circuit is the frequency to which it happens to be adjusted at the time. See TUNING.

TUNED AERIAL. Aerial which resonates at only one particular frequency when connected to an associated circuit containing inductance and/or capacitance. See RESONANT AERIAL.

TUNED AMPLIFIER. Radio-frequency amplifier in which the successive valves are coupled by means of tuned circuits such as those which form a tuned transformer, rather than by aperiodic impedances as in resistance-capacitance amplifiers. See AMPLIFICATION.

TUNED-ANODE CIRCUIT. Circuit in which a capacitor and an inductor are connected in parallel, this combination being connected in the anode circuit of a valve (Fig. 33a). The tuned-anode circuit is essentially a selective circuit. The impedance of a parallel circuit rises to a maximum at the frequency of resonance (Fig. 33c). The valve can be likened to an e.m.f. in series with a resistor, this having a value equal to the internal resistance of the valve, that is, the valve slope resistance.

Thus the voltage across the tuned circuit rises as the frequency of the wave applied between the grid and cathode of the valve gets closer to the resonant frequency of the tuned circuit. The impedance of the tuned circuit at its resonant frequency is resistive, and equal to $2\pi f_o L Q_o$, where f_o is the resonant frequency, L the inductance value of the inductor and Q_o the Q-factor of the inductance at f_o (the Q-factor of the capacitor is assumed to be infinite). This formula applies when Q_o is greater than, say, 5. The circuit is widely used in radio senders and receivers to give selective response. See INTERNAL IMPEDANCE, RESONANCE, TUNED CIRCUIT.

TUNED-ANODE COUPLING. Method of coupling valves in cascade, in which each valve has a tuned-anode circuit and the output from one valve forms the input to the next. In practice, the tuning capacitors are ganged so that a frequency-selective amplifier is formed. See TUNED-ANODE CIRCUIT.

TUNED CIRCUIT. Circuit consisting of inductance and capacitance connected in series or in parallel and adjusted to resonate at the frequency of an applied alternating e.m.f. See RESONANCE.

TUNED-GRID CIRCUIT. Amplifier or oscillator-valve circuit in which a capacitor and an inductor are connected in parallel and across the grid and cathode of the valve. See OSCILLATOR, TUNED-ANODE CIRCUIT.

TUNED-SPARK SYSTEM. See SINGING SPARK SYSTEM.

TUNE-IN. To adjust apparatus to work on a particular frequency, or, more usually, for the reception of a given sender. See TUNING, TUNING-IN.

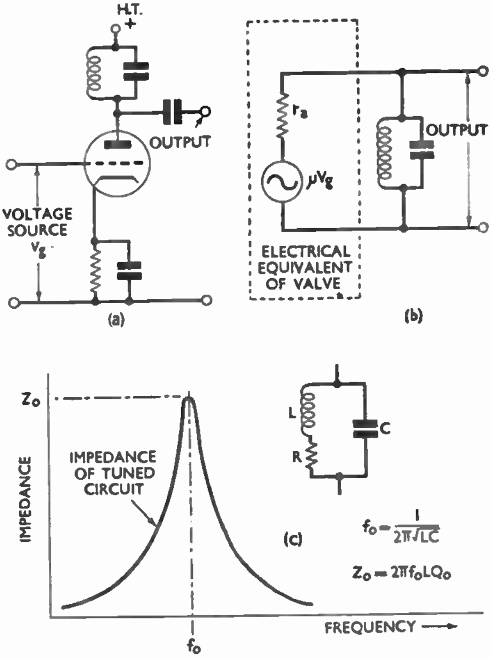


Fig. 33. The tuned-anode circuit (*a*) has the electrical equivalent (*b*), which treats the valve as a source having an e.m.f. μV_g (where μ is the amplification factor of the valve and V_g the grid–cathode r.m.s. value) and an internal resistance r_o equal to the anode slope-resistance of the valve. The impedance of the circuit has, as shown in (c), its maximum value Z_o at the resonant frequency f_o.

TUNER. That portion of a radio receiving system which contains the circuits for tuning to the desired frequencies. The tuning arrangements were, at one time, often assembled as a separate piece of apparatus, hence the name "tuner."

TUNGAR RECTIFIER. Special form of gas-filled rectifier in which the cathode is run at a temperature much greater than that normally used in vacuum-valve rectifiers, because it is found that no cathode evaporation takes place provided the gas (argon in the case of the Tungar rectifier) has the

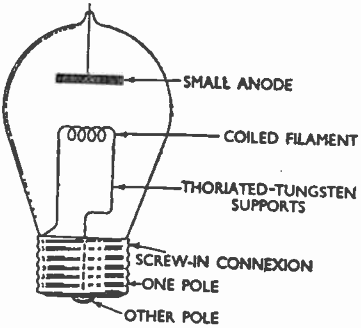


Fig. 34. Constructional details of the Tungar rectifier. The bulb contains an inert gas, normally argon.

correct pressure and temperature. A sketch of the rectifier is given in Fig. 34.

TUNING. Act or process of bringing a circuit or item of equipment into resonance with a particular frequency. Any circuit containing inductance and capacitance is potentially a tuned circuit, and will respond to an oscillatory excitation of the right frequency, provided that its resistance is not so great as to make free oscillations impossible.

The frequency to which it is tuned is fixed by the amount of inductance and capacitance it contains; more precisely, by the *product* of these two quantities. Thus, a circuit containing 100 units of inductance and 50 of capacitance will have the same natural frequency as one with 200 units of inductance and 25 of capacitance.

The process of tuning assumes, therefore, a variation in the amount of inductance or capacitance in circuit, or a variation of both. One of the earliest methods of effecting tuning, for example, used a variable inductor consisting of a single-layer winding of insulated wire whereon a sliding contact ran upon a bared track. Movement of the sliding contact varied the number of turns in the circuit and thus adjusted the inductance value.

Another form of variable inductor, still used in some types of radio receiver, consists of a winding which may be single- or multi-layered, with tappings brought out at intervals to a selector switch. This arrangement gives, of course, a variation of inductance in steps, so, for precise tuning, requires the addition of some device giving a fine adjustment (for example, a small variable capacitor) to cover the intervals between the steps.

Another type of variable inductor, popular at one time, was the variometer. This provided a truly continuous variation of inductance, but did not cover a very wide range of values and suffered from the defect that the whole winding was in circuit at all times, consequently the resistance remained high, even when the inductance was at the minimum value.

Present-day tuning methods tend to rely on variations of capacitance rather than inductance. The typical modern tuned circuit consists of a fixed-value inductor, screened as in Fig. 35, tuned by a variable capacitor of such capacitance that the desired wave band is covered. When more than one range of waves is to be covered, another inductor of different value is brought into circuit, either by switching or, less usually, by interchange of plug-in units.

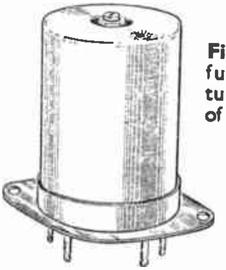


Fig. 35. Typical fully screened tuning inductor of the dust-cored type.

A variant of this general arrangement is found in some receivers intended for specialized communication purposes. In these, tapped inductors are used in combination with variable capacitors, the latter covering the intervals between the inductance steps. Some such system, in fact, becomes necessary when a great range of wavelengths is to be covered since, to provide tuning facilities from, say, 100 to 10,000 metres without gaps, by means of a switching system giving a complete change of inductors for each range, would lead to excessive complication.

The ranges in such a receiver would probably be somewhat as follows: 100 to 300 metres; 300 to 800; 800 to 2,000; 2,000 to 5,000; 5,000 to 10,000. These figures indicate merely the coverage—in practice, there would be some slight overlap provided at each end of each range.

Similarly, to cover so great a range by means of tapped inductors alone would lead to acute difficulties with dead-end effects. An effective compromise could be found in such a case by using, say, three tapped inductors, each covering a substantial wave-range, and a switching arrangement to bring them into circuit one at a time, the unused units being cut out completely.

In designing a circuit to tune over a particular wave-range, it is necessary to be able to determine the wavelength or frequency given by a specified amount of inductance and capacitance. For this the basic expression is $\lambda = 1{,}885\sqrt{LC}$, where λ (the wavelength) is in metres, L (inductance) is in microhenrys, and C (capacitance) is in microfarads.

Given a knowledge of the maximum value of the variable capacitor, and the inductance of the inductor, it is simple to calculate the upper end of the wavelength range which the combination will provide. Less simple is to decide on the lower extremity, since this is governed by the minimum capacitance of the variable capacitor, the stray capacitances in the circuit, and the self-capacitance of the inductor.

These factors are difficult to measure and impossible to calculate; but experience shows that, in an average circuit, it is a fair rule to assume that the minimum wavelength will be roughly a quarter of the maximum when the tuning capacitor is of 0·0005μF—a common size for broadcast receivers. This is sometimes called a 4-to-1 tuning ratio.

A full 4-to-1 ratio assumes favourable conditions, a variable capacitor with a low minimum value, small stray capacitances, a good inductor, and so on. In practice, therefore, it is wise to expect no more than about 3¾ to 1. Thus, if it is desired to find an inductor suitable for the usual broadcast range of about 150 to 550 metres when tuned with a variable capacitor of 0·0005μF, it is safe to choose an inductance value such that the maximum wavelength is 560 metres, with the assurance that the minimum will then be a little below the desired 150 metres, thus ensuring that neither maximum nor minimum wavelength will fall at the very end of the scale.

Any isolated conductor of finite length may be regarded as a tuned circuit, in the sense that it will resonate at a specific frequency. For example, a straight length of wire, suspended in space, will have a natural frequency determined by its physical dimensions. This frequency will correspond to a wavelength approximately twice the physical length of the wire.

The same straight wire suspended vertically and with its lower end earthed will again resonate, but in a different manner, behaving now as only *half* of an oscillatory circuit, the other half being formed by the earth beneath. The wavelength in this case will be approximately four times the physical length of the wire. See DEAD-END EFFECT, HALF-WAVE DIPOLE, INDUCTOR, MARCONI AERIAL, RESONANCE, VARIABLE CAPACITOR, VARIOMETER.

TUNING CAPACITOR. Capacitor used to bring a circuit into resonance at a desired frequency with the inductance present. Capacitors used for this purpose are, of course, normally variable. See RESONANCE, TUNING, VARIABLE CAPACITOR.

TUNING COIL. See TUNING INDUCTOR.

TUNING CONDENSER. Synonym for TUNING CAPACITOR.

TUNING CONTROL. Means of varying the frequency to which a circuit or piece of apparatus is tuned. It is usually the knob that permits adjustment of a variable capacitor (single or ganged), but it may also refer to a means of varying the amount of inductance in circuit. See TUNING, VARIABLE CAPACITOR.

TUNING CURVE. Graphic representation of the relation between dial readings and the wavelength or frequency to which a circuit or complete apparatus is tuned. It commonly relates tuning with the dial setting of a variable capacitor, and, in some cases, takes the form of a substantially straight line, as illustrated by the example in Fig. 36.

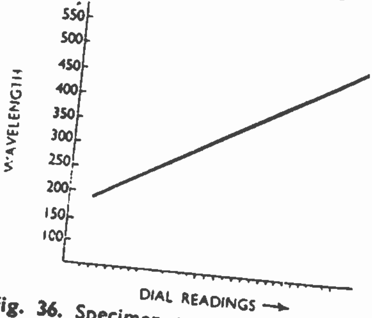


Fig. 36. Specimen tuning graph of a circuit in which the variable capacitor is of the type giving a straight-line variation of wavelength.

TUNING ERROR. See LOOP TUNING ERROR.

TUNING-FORK CONTROL. See TUNING-FORK OSCILLATOR DRIVE.

TUNING-FORK OSCILLATOR. Tuning fork which is maintained in steady oscillation by energy supplied by a valve, the frequency of oscillation being substantially that of the fork, running freely. Its use is a standard method for establishing frequencies with very great accuracy.

TUNING-FORK OSCILLATOR DRIVE. Electromechanical drive having its frequency determined by the vibration of a tuning fork.

TUNING-IN. Act of adjusting apparatus to work on a particular frequency or, more usually, for reception of a particular station. This is commonly effected by manipulation of one or more variable capacitors, but the term is often taken to include making suitable adjustments of such controls as those of gain and tone. See GAIN CONTROL, GANGED CAPACITOR, RESONANCE, TONE CONTROL.

TUNING INDUCTANCE. Amount of inductance needed to tune a circuit to the desired wavelength or frequency. See TUNING.

TUNING INDUCTOR. Inductor used to bring a circuit into resonance at the desired frequency with the capacitance present. Present-day tuning inductors take a great variety of forms; the small, concentrated winding with an iron-dust core is, however, very common. Most of the types used in broadcast receivers are enclosed in separate metal screening boxes. See RESONANCE, TUNING.

TUNING NOTE. Audio-frequency modulation of the carrier wave of a broadcasting sender which is heard as a note by anyone tuning a receiver to the sender. The idea originated in the early days of British broadcasting. The tuning note was radiated before the programmes started to enable the senders to be set up correctly and listeners to tune-in their receivers, which were then supposed to be ready to reproduce the programmes. A note of approximately 1,000 c/s is still radiated by the B.B.C. for a short period before the beginning of the day's programmes.

TUNING-OUT. Process of so manipulating the controls of a radio receiver as to exclude some unwanted signal.

TURNTABLE. In gramophone recording and reproduction, the circular plate of metal, attached to the shaft of the driving motor, on which the disc is placed or clamped. See ELECTRICAL RECORDING, GRAMOPHONE PICK-UP.

TWEETER. Small loudspeaker which is usually, but not invariably, of piezoelectric type and designed to reproduce high audio-frequencies, for example, from 1,000 c/s upwards. It is intended for use with a large-diaphragm loudspeaker (generally a moving-coil type) which reproduces low audio frequencies, the combination of the two loudspeakers giving a substantially wider audio-frequency range than is obtainable from a single loudspeaker.

TWIN CABLE. Cable containing one or more pairs of wires, each pair forming a transmission line. See CABLE, TRANSMISSION LINE.

TWIN FEEDER. Feeder with two conductors, in contrast to a single-wire feeder. See FEEDER, SINGLE-WIRE FEEDER.

TWO-CIRCUIT TUNER. Arrangement of two tuned circuits, preceding the detector or first amplifying stage of a receiver, designed to give increased selectivity as compared with a single-circuit tuner. In its classic form, it consists of a tuned primary circuit (which includes the aerial) magnetically coupled to a tuned secondary circuit across which the detector is connected.

TWO-ELECTRODE VALVE. Synonym for DIODE.

TWO-PHASE RECTIFIER. See POLYPHASE-RECTIFIER CIRCUIT.

TWO-STEP RELAY. Electromagnetic relay of which one or more contact units can be operated independently of the others by passing a small current through the winding of the electromagnet, all the contact units being operated by a larger current. See ELECTROMAGNETIC RELAY.

TWO-WAY SIMPLEX SYSTEM. See SIMPLEX SYSTEM.

TWO-WAY SWITCH. Switch for selecting one or the other of two alternative current paths. See SWITCH.

TWO-WIRE AMPLIFIER. Telephone amplifier used in a two-wire circuit; more precisely, a pair of such amplifiers, one to amplify signals passing in one direction and the other to amplify signals going in the opposite direction. To prevent "howling," as the input of one amplifier is connected to the output of the other, a hybrid coil is used. See HYBRID COIL, TELEPHONE AMPLIFIER.

TWO-WIRE CIRCUIT. Transmission line formed from two conductors. The term is used to distinguish a two-wire from a four-wire circuit. The latter term applies to a two-way signalling system (usually telephone), in which two pairs of conductors are employed. Thus, A may speak to B on one line and B to A on the other. When one pair of wires is used for simultaneous communication in a two-way system, a two-wire circuit is employed and the hybrid coil is used to connect the telephone instrument to it. See FOUR-WIRE CIRCUIT, HYBRID COIL, TRANSMISSION LINE.

TWO-WIRE REPEATER. Synonym for TWO-WIRE AMPLIFIER.

TYPE A0 WAVE. Wave generated at the radiating source by oscillations which, after a steady state is reached, are maintained continuously at constant peak value and frequency.

TYPE A1 WAVE. Continuous wave generated at the radiating source by oscillations which are key-controlled in accordance with a telegraphic code. Alternatives for the control exercised by the keying are:

(1) Starting and stopping of the radiation, so that the waves are emitted in groups of duration and spacing conforming to the code.
(2) Changes of peak value such that the marking and spacing waves are distinguished by different peak values.
(3) Changes of frequency such that the marking and spacing waves are distinguished by different oscillation frequencies.
(4) A combination of method (2) and method (3) above.

TYPE A2 WAVE. Wave generated at the radiating source by oscillations which are modulated at audio frequency, or at a number of audio frequencies, and which are also key-controlled in accordance with a telegraphic code.

The key-control may be exercised upon the modulated oscillations, or it may be exercised upon the modulation only.

TYPE A3 WAVE. Wave generated at a radiating source (for radio telephony or broadcasting) by oscillations which are modulated by speech, music or other sounds.

TYPE A4 WAVE. Wave generated at a radiating source, used for facsimile transmission, in which the oscillations are modulated by voltages produced by the process of scanning a fixed image, the permanent reproduction of which is required at the receiving point.

TYPE A5 WAVE. Wave generated at a television radiating source by oscillations which are modulated by voltages produced by the process of scanning the scene to be viewed at the receiver.

TYPE B WAVE. Wave generated at a radiating source by trains of damped oscillations, the trains being keyed in accordance with a telegraphic code.

U

ULTRA-AUDION. Term, now obsolete, for an audion with positive feedback. See AUDION.

ULTRA-HIGH FREQUENCY WAVE. Radio-wave between the frequency limits of 300 and 3,000 Mc/s, that is, within a wavelength range of 10–100 cm. See DECIMETRIC WAVE.

ULTRA-SHORT WAVE. Synonym for CENTIMETRIC WAVE, DECIMETRIC WAVE.

ULTRASONIC FREQUENCY. Synonym for SUPERSONIC FREQUENCY.

ULTRA-VIOLET RAYS. Paths followed by wave forms invisible to the human eye, their wavelength being less than 3,900 Angström units (1 Angström unit equals 10^{-8} cm).

UMBRELLA AERIAL. Aerial consisting of a single metallic mast, with numerous metallic guys radiating from the top like the ribs of an umbrella (Fig. 1). The guys slope down to near ground level and terminate at insulators, the complete assembly of mast and guys forming the aerial.

UNBALANCED CIRCUIT. Circuit of which one part is at a steady or zero potential, while the other varies in potential. See BALANCED CIRCUIT.

UNBALANCED NETWORK. Network arranged as an unbalanced circuit. Examples of unbalanced networks are L-, T- and pi-networks.

UNBALANCED TRANSMISSION LINE. Transmission line in which one conductor is purposely earthed or is the earth itself; or a transmission line in which the impedance of one conductor to earth is substantially different from that of the other to earth. See BALANCED CIRCUIT, FEEDER, TRANSMISSION LINE.

UNDAMPED OSCILLATIONS. See OSCILLATION.

UNDAMPED WAVES. See TYPE A0, A1 (etc.) WAVE.

UNDERMODULATION. Condition in which the modulation depth is small. In conditions of undermodulation at the sender, the signal-to-noise ratio at the receiver is less than it is when the modulation depth is normal.

UNIDIRECTIONAL AERIAL. Any form of aerial so designed as to radiate or receive with maximum efficiency in a particular direction.

UNIDIRECTIONAL CURRENT. Current which flows in one direction only but is not necessarily of uniform magnitude. Hence a unidirectional current is not always a steady current. A pulsating current, for instance, may be described as a unidirectional current. See PULSATING CURRENT.

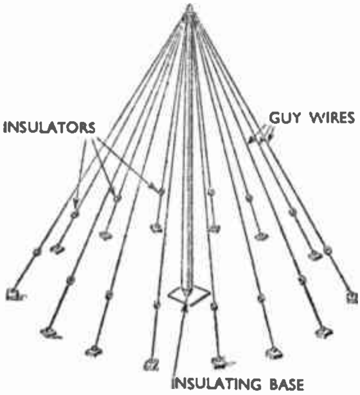


Fig. 1. Umbrella aerial, comprising a metallic mast, standing on an insulating base, and radial guys electrically connected to the mast at the top but insulated from the ground anchorages.

UNIT. Term meaning "one," and describing the unity value of a parameter. Thus 1 farad is unit capacitance; 1 henry unit inductance, and 1 ohm unit resistance in a specified system of units. See UNIT CHARGE, UNIT QUANTITY, UNITS.

UNIT CHARGE. Smallest whole-number quantity of electric charge in some specified system of units; that magnitude of charge which exerts unit force of attraction or repulsion when placed at unit distance from another of like magnitude.

UNIT QUANTITY. Smallest whole-number quantity of electricity in some specified system of units; that quantity which is delivered by unit current flowing for unit time. For example, the quantity known as the coulomb is equivalent to one ampere flowing for one second. See COULOMB.

UNITS. Arbitrary divisions or fixed quantities agreed upon as means of evaluating the properties of bodies or phenomena. Among the units frequently used in electrical and radio technology are ampere, ampere-hour, ampere-turn, British Thermal Unit, calorie, dyne, erg, farad, gauss, gilbert, henry, joule, micron, oersted, ohm, volt, and watt.

UNLOADED AERIAL. Aerial which functions in a specific way—usually by resonating at a particular frequency—without the addition of inductance or capacitance for tuning.

UNLOADED WAVELENGTH. Synonym for NATURAL FREQUENCY.

UNMODULATED WAVE. Synonym for TYPE A0 WAVE.

UNTUNED AERIAL. Synonym for APERIODIC AERIAL.

UNTUNED CIRCUIT. See APERIODIC CIRCUIT.

UPPER SIDEBAND. Sideband containing sideband waves of higher frequency than the carrier wave.

U-TYPE DIRECTION-FINDER. Form of Adcock spaced-aerial direction-finder, in which each pair of aerials bears a resemblance to the letter U, consisting of separated vertical elements joined at the base by a horizontal connexion in which the receiver-input circuit is located (Fig. 2). This arrangement illustrates the particular virtue of the Adcock system; if the

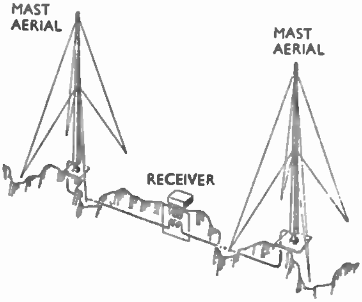


Fig. 2. Insulated-base mast aerials forming one of the pairs of spaced aerials in a U-type direction-finder with buried horizontal members.

horizontal run is suitably screened, perhaps by burying it in the ground, it has very poor pick-up efficiency. The only energy then picked up is in the vertical elements, which respond to the vertically polarized component; only this component can be relied upon to give accurate bearings.

In this, the Adcock direction-finder is superior to such types as the simple loop and the Bellini-Tosi, in which the unscreened horizontal elements of the aerial-system tend, especially after dark (see NIGHT ERROR), to be energized by horizontally polarized radiation, with consequent inaccuracies.

V

V. Abbreviation for VOLT(S).

VA. Abbreviation for VOLT-AMPERE(S).

VACUUM CAPACITOR. Form of capacitor, similar in construction to an air capacitor but housed in a strong container from which the air is evacuated. It has a voltage rating which is higher than that of an air capacitor of similar size and is sometimes used in radio senders. See FIXED CAPACITOR.

VACUUM CONDENSER. Synonym for VACUUM CAPACITOR.

VACUUM TUBE. See VALVE.

VACUUM-TUBE RECTIFIER. Synonym for VACUUM-VALVE RECTIFIER.

VACUUM VALVE. See VALVE.

VACUUM-VALVE RECTIFIER. Rectifier valve in which the gas is at such a low pressure as to have no effect upon the action of the valve. In studying and comparing rectifiers, there is an obvious distinction between tubes in which gas ionization plays a major part in determining performance and those in which conduction of current is due almost entirely to electrons.

In the latter case, that of the vacuum-valve rectifier, space-charge effects increase the internal resistance of the rectifier, and therefore represent a loss in the process of converting alternating to direct current. Nevertheless, the inherent stability and robustness of the vacuum-tube rectifier recommend it when loads are apt to be variable, and short circuits of the system probable. In such conditions, the gas-filled tubes are liable to be themselves damaged, or may have so low an internal impedance as to cause damage to external circuits.

Thus, in small power installations, and when ubiquity and robustness are desirable, the vacuum-valve rectifier finds almost universal application, because (1) the current it can deliver is limited by its higher internal impedance, and (2) the space charge protects the cathode from damage. See RECTIFIER.

V-AERIAL. Aerial consisting of two wires arranged in the horizontal plane to make a shape resembling the letter V; the wires are earthed at the separated ends through terminating resistors equal to the line impedance, and are connected to sender or receiver at the common ends.

VALVE. Assembly of electrodes in a gas-tight bulb. The gas in the bulb is at a low, or very low, pressure. One of the electrodes, the cathode, emits electrons. With the gas at a negligible pressure these electrons are the sole means of conducting current between electrodes. When the gas is at a low pressure, it becomes ionized when the potential gradient exceeds a certain value and then has a great effect upon the characteristic of the valve; the electrode currents are carried by both electrons and ions.

In that type of valve in which the space current is carried by free electrons there is, virtually, an immediate change of electrode current with change of electrode voltage. Thus a very high limit is set to the rate at which electrode current may be varied with electrode voltage (see TRANSIT TIME). The valve may, therefore, be used as a generator and amplifier of very high-frequency waves.

The term "valve," apart from its special meaning when applied to the electronic valve, implies a device in which a small force is used to control a larger one. All mechanical valves of this kind have mechanical inertia; it would, therefore, be impossible to turn a flow of steam or water on and off at a rate of, say, ten thousand times a second. The electron valve, however, can be made to change the rate of flow of electrons and the value of an electric current thousands of millions of times a second. This relative freedom from inertia effects is the unique characteristic of an electronic valve.

The principle of the hard-vacuum valve, in which the current is carried by electrons and not by electrons *and ions*, is well illustrated by tracing its historical development. The first valve was a diode: a valve with two electrodes (Fig. 1a), anode and cathode (see ANODE, CATHODE, DIODE, EDISON EFFECT). The cathode is heated to emit electrons and these conduct current between the anode and cathode electrodes (see ELECTRON EMISSION). The electron has a negative charge and is attracted by a positively charged anode. Thus the valve will not conduct unless the anode is positive with respect to the cathode (see RECTIFICATION, RECTIFIER, VALVE RECTIFIER). The relationship between anode voltage and anode current of a diode—or, indeed, of any valve—is not, however, a linear one (see EMISSION LIMITATION, SPACE CHARGE, SPACE-CHARGE LIMITATION).

The basic principle which underlies the action of a valve is that the potential gradient at the cathode is the only factor determining the current flowing from the cathode. However complicated the valve, however many electrodes it may have and whatever their potential, the number of electrons which leave the cathode, to be collected by the other electrodes, is dependent

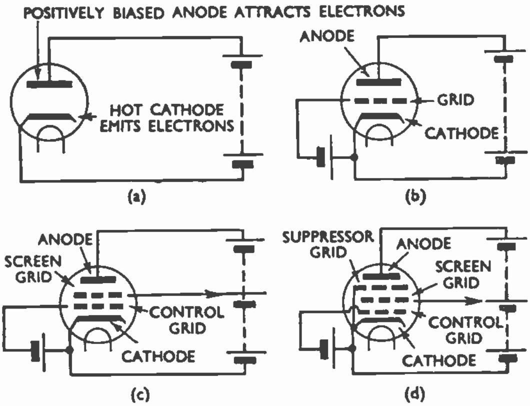


Fig. 1. Fundamentals of valve operation. In the hard-vacuum diode (*a*) current is carried from cathode to anode by electrons emitted by the former, but only when the anode is positive in respect of the cathode; the valve is therefore a rectifier. In the triode (*b*) a grid electrode, normally negatively biased, is introduced between cathode and anode to control the rate of electron flow and hence the anode current. A positively biased screen grid may be added, forming a tetrode (*c*), to reduce capacitance between the control grid and the anode. The pentode (*d*) is identical with the tetrode, except that it introduces a suppressor grid to shield the screen grid from secondary electrons emitted by the anode.

only upon the force which accelerates them from the cathode; that is, the potential gradient at the cathode (see ELECTRON VELOCITY).

The diode has a limited application as a rectifier and as a detector (see DETECTION). A whole new field of technology was opened up when a third electrode was introduced into the diode to form the triode (Fig. 1b). This third electrode is a grid-type electrode (see GRID). The grid is constructed so that electrons can flow past it to the anode, provided that the potential gradient at the cathode is in the right sense and of great enough value. The potential of the grid determines the potential gradient at the cathode, and thus the anode current.

When the valve is used as an amplifier it is usual to make the grid potential negative with respect to cathode (see BIAS), as it cannot then collect electrons. Small changes of grid potential about a negative-bias potential cause changes of anode current (see GRID-VOLTS/ANODE-CURRENT CHARACTERISTIC, MUTUAL CONDUCTANCE, TRIODE).

As the grid does not collect electrons, no current flows to and from it. Thus voltage changes can be made on it without the expenditure of power in the process. This is of great advantage in many circuit applications (see AMPLIFIER, GRID CURRENT). Since the flow of electrons is controlled by the grid potential, the flow responds immediately to change of grid potential. Thus a change of anode current follows, without sensible time-delay, a change of grid voltage (see OSCILLATOR).

The tetrode (Fig. 1c) contains an additional grid and has two grid-type electrodes, an anode and a cathode. The second grid is inserted to reduce the capacitance between the inner, or control, grid and anode (see INTER-ELECTRODE CAPACITANCE, MILLER EFFECT, TETRODE). The bias potential of this screen grid affects the potential gradient at the cathode (see SCREEN GRID). In order to cause electron flow the screen grid must be positively biased, and so that it may form a screen between anode and grid its alternating potential must be zero or nearly zero.

Secondary emission at the anode of a tetrode may give unwanted effects (see SECONDARY EMMISSION). More specifically, when electrode potentials are related in a certain way, secondary-emission current is subtracted from the anode current, and produces a negative ANODE SLOPE-RESISTANCE (q.v.). Means must therefore be provided to get rid of the secondary electrons. Thus the BEAM POWER-VALVE (q.v.) was developed to produce a virtual cathode between anode and screen, which shields the screen from secondary emission and causes the secondary electrons to be returned to the anode.

The pentode (Fig. 1d), contains a suppressor grid next to the anode, and its function is to collect secondary electrons and prevent them from reaching the screen grid (see PENTODE). The pentode is, in principle, a tetrode in which the unwanted effects of secondary emission have been eliminated by introduction of the SUPPRESSOR GRID (q.v.). Valves with more than five electrodes are used as frequency-changers (see FREQUENCY-CHANGER VALVE, FREQUENCY-CHANGING). The basic principle of the valve remains, and a hexode, heptode or octode is often seen to be a type containing one or more electrode combinations, such as triode and tetrode in one bulb.

Valves for the amplification, detection and generation of waves of very high frequency, such as centimetric waves, suffer from the inertia effects of the electrons and the reactance of the valve electrodes to such an extent that special types have had to be designed (see ELECTRODE IMPEDANCE). But even in valves which generate centimetric waves, a cathode supplying electrons and an anode attracting them remain the basic essentials of the device (see KLYSTRON, MAGNETRON).

The gas-filled valve behaves very differently from the hard-vacuum valve. The operation of a gas-filled valve can be likened to that of an electric relay, which either makes contact or does not. Thus, in a gas-filled valve, a small change of electrode potential may produce a sudden and permanent change of electrode current; in one condition the valve is virtually non-conductive, in another it draws a large electrode current. Thus, unlike the hard-vacuum valve, the gas-filled valve does not give an approximately linear relationship between electrode current and electrode voltage (see GAS-FILLED DIODE, GAS-FILLED TRIODE, IONIZATION).

One of the chief difficulties encountered in putting the principles of the hard valve into practice is that the relationship between electrode voltage and electrode current is not perfectly linear, making the valve prone to distort the wave it amplifies. The reduction of this distortion involves reducing to a very small figure the efficiency of the valve, which is measured as the ratio of power amplified to power expended in energizing the amplifier valves. Another disadvantage of the valve is that it is basically a high-impedance device; for instance, a pentode may have an internal impedance measured in megohms, but may require a comparatively small load resistance (see ANODE SLOPE-RESISTANCE, MATCHING).

If transformers cannot be used (as in very wide-band amplifiers) this bad matching of the high-impedance valve with a low impedance load involves wasting power. Finally, difficulties may be encountered because there may be differences in performance of valves of the same type and manufacture. In the last decade, these disadvantages have been largely overcome by the use of NEGATIVE FEEDBACK (q.v.), one of the most important of recent circuit developments. The use of this principle irons out discrepancies in performance of similarly constituted valves, lowers the output impedance of amplifiers, reduces distortion to negligible proportions and, generally speaking, turns what was in the past a rather vicious and troublesome device into a precision tool. Feedback does not, however, increase efficiency to any marked extent; this inefficiency remains as the chief, but seldom vital. criticism of the valve.

It would be impossible even to list the uses of the valve; enough that it ranks as one of man's most ingenious inventions. The valve has revolutionized the practice of telecommunication and is a powerful factor in solving problems of manufacture in a wide variety of applications. See AMPLIFICATION FACTOR, ELECTRON, GLOW-TUBE, MULTI-CAVITY MAGNETRON, MUTUAL CONDUCTANCE, VALVE DATA.

VALVE ADAPTER. Device for testing a valve under working conditions in its actual circuit. Alternatively, a device which enables a valve socket of one pattern to accommodate a replacement valve having a base of another pattern. The adapter is plugged into the valve socket and the valve plugged into the adapter.

In the former case, the adapter is provided with auxiliary terminals to which meters may be connected. The potentials of the various electrodes and the currents flowing to or from them may then be measured.

VALVE AMPLIFIER. Apparatus in which amplification is effected by means of valves. Although the valve is now the universal means of amplification, there have been other devices (see AMPLIFICATION).

VALVE BASE. Cap of insulating material which is affixed to the bulb of a valve and supports pins, or contacts, connected to the electrodes. It enables the valve simply to be plugged into a holder in order to put the valve in circuit. Where the valve base does not incorporate a locating key, the pins are arranged asymmetrically or are dissimilar in size (Fig. 2) in order to ensure that the valve may be plugged-

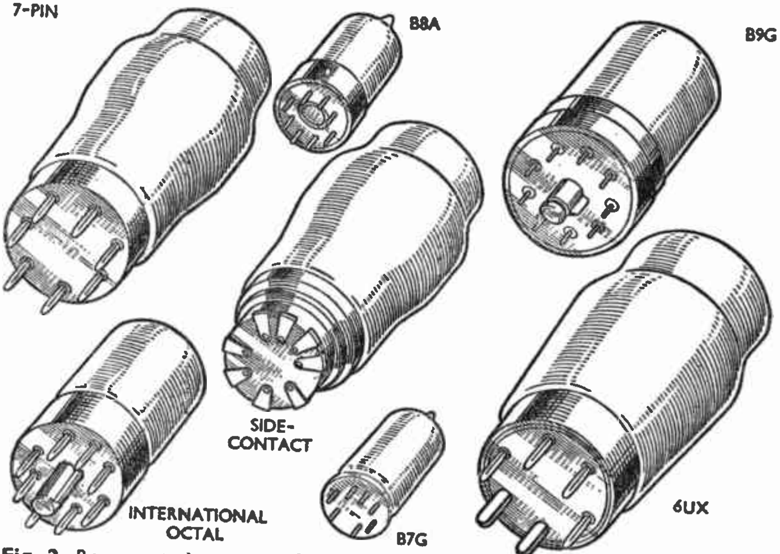


Fig. 2. Representative range of valve bases in current use, showing how they vary. Where there is no locating key, the pins are asymmetrically arranged.

in to make only the correct electrode connexions. See VALVE DATA, VALVE SOCKET.

VALVE CHARACTERISTIC. Graph, or curve, relating electrode voltage and electrode current. See ANODE-VOLTS/ANODE-CURRENT CHARACTERISTIC, GRID-VOLTS/ANODE-CURRENT CHARACTERISTIC.

VALVE COUPLING. Method of coupling in which electrical energy is conveyed from one circuit to another by the use of a valve. Amplifiers are based on valve coupling, and the output from one valve forms the input to the next. Commonly used methods are resistance-capacitance and transformer coupling (see AMPLIFIER).

A valve—notably the CATHODE FOLLOWER (q.v.)—can be usefully employed for impedance matching. Thus the output from one circuit may be of very high impedance and the input to the other of low impedance. In many cases, a transformer may be used to obtain efficient matching. In some cases, however, the insertion loss of the transformer might be so great, or the required frequency range so wide, that attenuation distortion of the transformer would be intolerable. In this case, valve coupling is useful since the input impedance of the grid-cathode circuit is very high, and the output across the cathode resistance low.

A valve coupling may be used to prevent changes in one circuit affecting another; for example, an oscillating circuit may be coupled to a modulated amplifier through a buffer valve; changes of the characteristics of the modulated amplifier will not then affect the amplitude or frequency of the waves generated by the oscillator. See AMPLITUDE MODULATOR, BALANCED CIRCUIT, MATCHING.

VALVE DATA. Electrical and physical characteristics of a valve. The valve tables appearing on pages 656–695 are for technical reference and have been made as up-to-date as possible. For each manufacturer, details are given of most of the valves made, including current types, replacement types and American types, but no details are included of obsolete types.

It should be noted that the anode and screen currents in respect of A.F.-output valves are given for maximum-signal conditions. In practice, measurements would usually be taken in conditions of zero signal, and the figures would then be somewhat lower than those shown in the tables.

The tables are subdivided into frequency-changers, R.F. pentodes, diodes, diode combinations, general-purpose triodes, output triodes, output pentodes and tetrodes, double-output valves, H.T. rectifying valves, barretters and tuning indicators; they appear in this order—approximately the order in which the valve types appear in receivers.

Base connexions are given on pages 696–704. The diagrams are drawn to show the pins as they appear when looking at the base of the valve or at the underside of the valve holder.

The base used is indicated in the data tables by a code reference contained in the "Base" column. The first numbers and letters give the base type, and indicate the group of diagrams to which reference should be made, and the final number indicates the base diagram in that group. For example, 4B3 signifies that the valve has a four-pin British base, and that the third diagram in the section shows the pin connexions. The base types of which details are given are as follows:

4B	Four-pin British;
4UX	Four-pin American (old type);
5B	Five-pin British (old type);
5UX	Five-pin American (old type);
6UX	Six-pin American (old type);
7B	Seven-pin British (old type);
7UX	Seven-pin American (old type);
7C	Seven-pin Continental;
BB	Seven-pin miniature button base, sometimes called B7G;
O	International octal;
OM	Mazda octal;
OF	Footless;
B8A	Eight-pin miniature base;
B8B	Eight-pin base, similar to international octal but with thinner pins; sometimes known as Loctal;
8S	Eight side-contact base;
9B	Nine-pin British base (old type);
B9A	Nine-pin miniature base;
B9G	Nine-pin base with thin pins (EF50 base);
—	British specials.

American valve manufacturers use a standard type-code which makes separate lists of makes unnecessary. The first figure in the code indicates the heater voltage but with the slight differences that 1 stands for 1·5 volts, 2 for 2·5 volts, and 6 or 7 for 6·3 volts. The second number denotes the number of electrodes connected to the base; the metallizing or metal shell counts as one electrode and the heater as another.

The intervening letters differentiate between different types of valve. As all the letters in the alphabet have now been used, some valve codes include two intervening letters, of which the first is A or B. Another two-letter combination begins with the letter S. Final letters are used to indicate other types of envelope and special features. For example, the 6J7G is a valve with similar characteristics to the 6J7 but has a standard glass envelope; the 6J7GT is again similar except for its small tubular glass envelope.

American-type valves are listed on pages 688–695 and are given in the order of the first number in the code. As the final letters in the valve code indicate differences only in physical make-up and not in operating characteristics, such letters are omitted from the tables.

Some British valve manufacturers make American-type valves: these are listed under the manufacturer's name and in the appropriate valve type, but, for full details of the valve characteristics, reference should be made to figures tabulated on pages 688–695.

FREQUENCY-

Make	*Type*	*Description*	*Base*	*Filament Volts*
BRIMAR Also manufacture American types 1A7, 1LA6, 6A7, 6F7, 6L7, 6SA7, 7A8, 7B8, 1R5, 6A8, 6K8, 7S7, 12K8, 14S7 (q.v.).	20A1	Triode-hexode	7B37	4·0
	15A2	Heptode	7B35	4·0
	15D1	Heptode	7B35	13·0
	15D2	Heptode	7B35	13·0
	20D2	Triode-hexode	7B37	13·0
COSSOR Also manufacture American types 1A7, 6K8, 6L7, 6SA7, 12SA7, 1R5, 7Q7, 7S7, 14S7 (q.v.).	220TH	Triode-heptode	7B11	2·0
	41MPG	Pentagrid	7B35	4·0
	41STH	Triode-hexode	7B37	4·0
	4THA	Triode-hexode	7B37	4·0
	OM10	Triode-hexode	O58	6·3
	202STH	Triode-hexode	7B37	20·0
	203THA	Triode-hexode	7B37	20·0
	302THA	Triode-hexode	7B37	30·0
EVER READY	K80A	Octode	7B7	2·0
	K80B	Octode	7B8	2·0
	A36C	Triode-heptode	7B38	4·0
	A80A	Octode	7B35	4·0
	ECH3	Triode-hexode	8S29	6·3
	ECH35	Triode-hexode	O58	6·3
	CCH35	Triode-hexode	O58	6·3
	C36A	Triode-hexode	7B37	21·0
	C36C	Triode-heptode	7B38	29·0
	C80B	Octode	7B35	13·0
	DK32	Heptode	O10	1·4
	DK91	Heptode	BB1	1·4
FERRANTI Also manufacture American types 6A8, 6K8, 6SA7, 7Q7, 12K8, 1A7, 1R5, 6K8, 7S7, 12K8. 14S7 (q.v.).	VHT4	Heptode	7B35	4·0
MARCONI AND OSRAM	X14	Heptode	O10	1·4
	X17	Heptode	BB1	1·4
	X22	Heptode	7B9	2·0
	X24	Triode-hexode	7B9	2·0
	MX40	Heptode	7B35	4·0
	X41	Triode-hexode	7B37	4·0
	X61M	Triode-hexode	O58	6·3
	X63	Heptode	O58	6·3
	X65	Triode-hexode	O58	6·3

CHANGERS

Filament Amp.	*Anode Volts*	*Screen Volts*	*Oscillator Anode Volts*	*Conversion Conduct. Mhos*	*Bias Volts*	*Type*
1·2	250	80	100	650	–1·5–30	20A1
0·65	250	100	200	550	–3–40	15A2
0·2	250	100	200	550	–3–40	15D1
0·15	250	100	200	550	–3–40	15D2
0·15	250	100	100	350	–3–30	20D2
0·2	120	45	60	200	0	220TH
1·0	250	100	100	860	–1·5	41MPG
1·15	250	100	100	600	–1·5	41STH
1·5	250	100	100	850	–2·0	4THA
0·2	250	100	70	700	–2·0	OM10
0·2	250	100	100	600	–1·5	202STH
0·3	250	100	100	850	–2·0	203THA
0·2	250	100	100	850	–2·0	302THA
0·1	135	70	70	200	0	K80A
0·13	135	45	45	270	–0·5	K80B
1·45	250	—	100	750	–2·5	A36C
0·65	250	70	90	600	–1·5	A80A
0·2	250	—	100	650	–2·0	ECH3
0·3	250	—	100	650	–2·0	ECH35
0·2	250	—	100	650	–2·0	CCH35
0·2	250	70	70	1,000	–1·5	C36A
0·2	250	70	100	750	–2·5	C36C
0·2	200	70	90	600	–1·5	C80B
0·05	90	45	90	250	0	DK32
0·05	90	67·5	67·5	300	0	DK91
1·0	250	100	100	650	–3·0	VHT4
0·05	90	45	90	250	0	X14
0·05	90	67·5	67·5	250	0	X17
0·15	150	70	150	350	0	X22
0·2	150	60	100	250	–1·5	X24
1·0	250	100	150	500	–3·0	MX40
1·2	250	80	150	640	–1·5	X41
0·3	250	100	100	620	–3·0	X61M
0·3	250	100	100	490	–3·0	X63
0·3	250	100	100	225	–3·0	X65

Continued on next page

FREQUENCY-

Make	*Type*	*Description*	*Base*	*Filament Volts*
MARCONI AND OSRAM *continued*	X76M	Triode-hexode	O58	13·0
	X81	Triode-hexode	B8B1	6·3
	X101	Triode-hexode	B8B1	19·0
MAZDA	TP22	Triode-pentode	9B2	2·0
	TP23	Triode-pentode	7B10	2·0
	TP25	Triode-pentode	OM5	2·0
	ACTP	Triode-pentode	9B5	4·0
	ACTH1	Triode-heptode	7B38	4·0
	TH41	Triode-heptode	OM26	4·0
	TH2321	Triode-hexode	7B38	23·0
	1C1	Heptode	BB1	1·4
	6C31	Triode-heptode	O58	6·3
	6C9	Triode-heptode	B8A1	6·3
	10C1	Triode-heptode	B8A1	28·0
	TH233	Triode-heptode	OM26	23·0
	TP2620	Triode-pentode	9B5	26·0
MULLARD	DK32	Heptode	O10	1·4
	DK91	Heptode	BB1	1·4
	FC2	Octode	7B8	2·0
	FC2A	Octode	7B8	2·0
	KCF30	Triode-pentode	O79	2·0
	TH4B	Triode-heptode	7B37	4·0
	FC4	Octode	7B36	4·0
	ECH3	Triode-hexode	8S29	6·3
	ECH21	Triode-heptode	B8B1	6·3
	ECH35	Triode-hexode	O58	6·3
	EK32, EK2	Octode	O56/8S28	6·3
	ECH42	Triode-hexode	B8A1	6·3
	CCH35	Triode-hexode	O58	7·0
	FC13	Octode	8S28	13·0
	FC13C	Octode	7B36	13·0
	TH21C	Triode-hexode	7B37	21·0
	TH30C	Triode-heptode	7B38	29·0
	UCH42	Triode-hexode	B8A1	14·0
	UCH21	Triode-heptode	B8B1	20·0
TUNGSRAM	TH4A/B	Triode-heptode	7B38	4·0
Also manufacture American types 1R5, 2A7, 6A7, 6A8, 6E8, 6J8, 6K8, 6L7 6SA7, 12SA7, 12A8, 12K8 (q.v.).	VO4	Octode	7B36	4·0
	ECH11	Triode-hexode	OF5	6·3
	ECH35	Triode-hexode	O58	6·3
	VO13	Octode	7B36	13·0
	TH29	Triode-heptode	7B38	29·0
	MH4105	Heptode	7B35	4·0
	CCH35	Triode-hexode	O58	7·0
	UCH41	Triode-hexode	B8A1	14·0

CHANGERS—*continued*

Filament Amp.	*Anode Volts*	*Screen Volts*	*Oscillator Anode Volts*	*Conversion Conduct. Mhos*	*Bias Volts*	*Type*
0·16	250	100	100	620	–3·0	X76M
0·3	250	100	100	650	–2·0	X81
0·1	250	100	100	650	–2·0	X101
0·25	120	60	100	500	–1·5	TP22
0·25	120	60	80	250	–1·5	TP23
0·2	120	60	80	260	–1·5	TP24
1·25	250	200	150	700	–5·0	ACTP
1·3	250	100	75	750	–3·0	ACTH1
1·3	250	100	75	750	–3·0	TH41
0·2	150	100	75	650	–3·0	TH2321
0·05	90	67·5	67·5	300	0	1C1
0·85	250	100	75	750	–3·0	6C31
0·45	250	100	85	650	–2·5	6C9
0·1	175	100	75	650	–2·5	10C1
0·2	175	100	75	640	–3·0	TH233
0·2	200	200	150	700	–5·0	TP2620
0·05	90	45	90	250	0	DK32
0·05	90	67·5	67·5	300	0	DK91
0·1	135	70	135	200	0	FC2
0·13	135	45	135	270	–0·5	FC2A
0·2	120	60	100	230	–1·5	KCF30
1·45	250	100	100	750	–2·5	TH4B
0·65	250	70	90	600	–1·5	FC4
0·2	250	100	100	650	–2·0	ECH3
0·33	250	100	100	750	–2·0	ECH21
0·3	250	100	100	650	–2·0	ECH35
0·2	250	50	200	550	–2·0	EK32,EK2
0·225	250	100	100	710	–2·5	ECH42
0·2	250	100	100	650	–2·0	CCH35
0·2	200	70	90	600	–1·5	FC13
0·2	200	70	90	600	–1·5	FC13C
0·2	250	70	100	1,000	–1·5	TH21C
0·2	250	100	100	750	–2·5	TH30C
0·1	200	84	110	690	–2·0	UCH42
0·1	200	100	120	750	–2·0	UCH21
1·5	250	100	125	750	–2·5	TH4A/B
0·65	250	70	90	600	1·5–25	VO4
0·2	250	100	150	650	–2·0	ECH11
0·3	250	100	150	650	–2·0	ECH35
0·2	250	70	90	600	1·5–25	VO13
0·2	250	100	125	750	–2·5	TH29
0·5	250	100	200	520	–3·0	MH4105
0·2	250	100	150	650	–2·0	CCH35
0·1	200	105	100	500	–2·2	UCH41

SCREEN-GRIDS

Make	Type	Description	Base	Filament Volts	Filament Amp.	Anode Volts
BRIMAR ..	8A1	P	5B19/7B23	4·0	1·0	200
Also manufacture American types 1LN5, 1N5, 6C6, 6D6, 6SG7, 6SH7, 6SJ7, 6SK7, 6U7, 7A7, 7B7, 7C7, 7H7, 12SJ7, 12SK7, 77, 78, 1L4, 1T4, 6AU6, 6BA6, 6J7, 6K7, 12AU6, 12BA6, 12J7, 12K7, 14H7 (q.v.).	9A1	VP	5B19/7B23	4·0	1·0	200
	8D2	P	7B30	13·0	0·2	250
	8D3	P	BB5	6·3	0·3	250
	8D4	P	O47	6·3	0·2	250
	9D2	VP	7B30	13·0	0·2	250
	9D6	VP	BB5	6·3	0·2	250
COSSOR ..	210VPT	VP	4B8/7B4	2·0	0·1	150
Also manufacture American types 1N5, 6AB7, 6C6, 6D6, 6J7, 6K7, 6SH7, 6SJ7, 6SK7, 6SS7, 12SG7, 12SK7, 1T4, 7B7, 7H7 (q.v.).	210VPA	VP	4B8/7B4	2·0	0·1	150
	210SPT	P	4B8/7B4	2·0	0·1	150
	2201PT	P	7B28	2·0	0·2	120
	4TSP	P	7B23	4·0	1·0	250
	MS/PEN	P	5B19/7B23	4·0	1·0	200
	MVS/PEN	VP	5B19/7B23	4·0	1·0	200
	MS/PEN B	P	7B26	4·0	1·0	200
	MVS/PEN B	VP	7B26	4·0	1·0	200
	OM6	VP	O47	6·3	0·2	250
	13VPA	VP	7B26	13·0	0·2	200
	202VP	VP	7B23	20·0	0·2	250
	202VPB	VP	7B26	20·0	0·2	250
	4TPB	P	7B26	4·0	1·0	250
	42MPT	P	7B23	4·0	2·0	200
	41MTS	Split anode P	7B44	4·0	1·0	250
	4TSA	„	7B43	4·0	1·0	250
	42SPT	P	7B23	4·0	2·0	250
	61SPT	P	O87	6·3	1·27	250
	6AM6	P	BB5	6·3	0·30	250
	63SPT	P	B9G1	6·3	0·30	250
EVER READY	K50M	VP	7B4	2·0	0·18	135
	K50N	VP	7B5	2·0	0·14	135
	K40N	VS	4B5	2·0	0·18	150
	A50M	VP	7B23	4·0	1·0	200
	A50N	VP	7B23	4·0	1·2	200
	A50P	VP	7B26	4·0	0·65	250
	A50A	P	7B23	4·0	1·0	200
	A50B	P	7B26	4·0	0·65	250
	EF9/39	VP	8S24/O47	6·3	0·2	250
	DF33	P	O7	1·4	0·05	90
	DF91	P	BB6	1·4	0·05	90
	C50N	VP	7B26	13·0	0·2	200
	C50B	P	7B26	13·0	0·2	200

AND R.F. PENTODES

Screen Volts	Bias Volts	Anode Current (mA)	Screen Current (mA)	Bias Res. Ohms	Slope mA/V	Type
80	–1·5	3·5	0·7	200	4·0	8A1
80	–1·5 –30	5·0	1·0	200	4·25	9A1
100	–3·0	2·0	0·5	1,000	1·25	8D2
250	–2·0	10·0	2·6	160	7·5	8D3
100	–2·0	3·0	0·8	500	1·8	8D4
125	–3 –40	10·5	2·6	200	1·65	9D2
200	–2·5	8·0	2·1	250	2·5	9D6
60	0–9	2·9	0·75	—	1·1	210VPT
60	–1·5 –8	2·9	1·0	—	1·1	210VPA
60	0	2·9	0·75	—	1·3	210SPT
60	–1·5	2·2	0·50	—	1·0	220IPT
150	–3·0	12·0	—	–	8·0	4TSP
100	–1·5	4·8	1·3	—	2·8	MS/PEN
100	–1·5	4·3	1·3	V	2·2	MVS/PEN
100	–1·5	4·8	1·3	250	2·8	MS/PEN B
100	–1·5	4·3	1·3	V	2·2	MVS/PEN B
100	–2·5	6·0	1·8	V	2·2	OM6
100	–3·0	7·0	1·7	V	1·8	13VPA
100	–1·5	4·3	1·3	V	2·2	202VP
100	–1·5	4·3	1·3	V	2·2	202VPB
150	–3·0	12·0	—	—	8·0	4TPB
200	–3·0	34·0	—	—	8·5	42MPT
100	0	5·0	—	—	1·6	41MTS
100	0	5·0	—	—	1·6	4TSA
250	–10·5	64·0	15·0	—	11·0	42SPT
250	–10·5	64·0	15·0	130	11·0	61SPT
250	–2·0	10·0	2·5	160	7·5	6AM6
250	–2·0	10·0	3·0	160	6·5	63SPT
135	0–7	3·0	—	-	1·5	K50M
60	–1·5	2·0	-	—	1·4	K50N
90	0–7	2·5	—	—	1·4	K40N
100	–2 –50	4·5	—	V	2·3	A50M
100	–2·0	4·25	—	V	2·5	A50N
250	–3·0	11·5	—	V	2·0	A50P
100	–2·0	3·0	—	—	2·3	A50A
250	–2·4	4·0	—	—	3·4	A50B
100	–2·5	6·0	—	—	2·2	EF9/39
90	0	1·2	0·3	—	0·75	DF33
67·5	0	3·5	1·4	—	0·90	DF91
200	–2·0	9·0	—	V	2·2	C50N
200	–2·2	2·5	—	—	2·8	C50B

Continued on next page

SCREEN-GRIDS

Make	*Type*	*Description*	*Base*	*Filament*		*Anode Volts*
				Volts	*Amp.*	
FERRANTI .. Also manufacture American types 6AB7, 6AC7, 6C6, 6D6, 6K7, 6SG7, 6SH7, 6SJ7, 6SK7, 6U7, 12SG7, 12SH7, 12SJ7, 12SK7, 1T4, 6AK5, 6J7, 6K7, 7A7, 7B7, 7H7, 12J7, 12K7, 14A7, 14H7 (q.v.).	S2	—	—	2·0	0·15	120
	VS2	VS	4B5	2·0	0·15	120
	VPT2	VP	7B4	2·0	0·1	120
	SPT4A	P	7B23	4·0	1·0	250
	VPT4	VP	5B19	4·0	1·0	250
	VPT4B	VP	7B23	4·0	1·0	250
HIVAC	XSG 1·5V	S	4D2	1·5	0·08	50
	XW 1·5V	P	5D1	1·5	0·08	50
	XSG 2·0V	S	4D2	2·0	0·08	50
	XVS 2·0V	VS	4D2	2·0	0·08	50
	XW 2·0V	P	5D1	2·0	0·08	50
MARCONI AND OSRAM	Z14	P	O7	1·4	0·05	90
	Z21	P	4B8/7B4	2·0	0·1	150
	Z22	P	7B4	2·0	0·1	150
	W17	P	BB6	1·4	0·05	90
	W21	VP	4B8/7B4	2·0	0·1	150
	MS4B	S	5B17	4·0	1·0	250
	VMS4B	VS	5B17	4·0	1·0	200
	MSP4	P	5B17/7B23	4·0	1·0	250
	VMP4G	VP	7B23	4·0	1·0	250
	KTW61	VP	O47	6·3	0·3	250
	KTW63	VT	O47	6·3	0·3	250
	KTZ63	T	O47	6·3	0·3	250
	W76	VP	O47	13·0	0·16	250
	W77	VP	BB5	6·3	0·2	200
	W81	VP	B8B2	6·3	0·3	250
	Z77	P	BB5	6·3	0·3	250
	Z90	P	B9G1	6·3	0·3	250
	W101	VP	B8B2	19·0	0·1	250
MAZDA ..	VP210	VP	7B4	2·0	0·1	120
	VP23	VP	OM3	2·0	0·05	120
	AC/SG	S	5B17	4·0	1·0	200
	AC/SGVM	VS	5B17	4·0	1·0	200
	AC/SP1	P	7B23	4·0	1·0	200
	AC/SP3	P	7B26	4·0	1·0	250
	AC/VP1	VP	7B23	4·0	0·65	250
	AC/VP2	VP	7B26	4·0	0·65	250
	VP41	VP	OM24	4·0	0·65	250
	SP41	P	OM24	4·0	0·95	200
	SP42	P	OM24	4·0	0·95	140
	SP61	P	OM24	6·3	0·6	200
	SP181	P	OM24	18·0	0·2	200

ND R.F. PENTODES—*continued*

Screen Volts	*Bias Volts*	*Anode Current (mA)*	*Screen Current (mA)*	*Bias Res. Ohms*	*Slope mA/V*	*Type*
60	-1·0	2·25	0·3	—	1·1	S2
60	-2·5	2·0	—	—	1·4	VS2
60	-1·5	—	—	—	1·1	VPT2
100	-1·5	2·0	1·2	—	2·3	SPT4A
100	-3·0	5·5	3·0	V	2·3	VPT4
100	-3·0	6·0	3·0	V	3·2	VPT4B
30	0	0·55	0·25	—	0·30	XSG 1·5V
45	0	0·75	0·2	—	0·52	XW 1·5V
30	0	0·6	0·3	—	0·4	XSG 2·0V
30	0	0·4	0·15	—	0·33	XVS 2·0V
45	0	0·95	0·3	—	0·60	XW 2·0V
90	0	1·2	0·25	—	0·75	Z14
150	0	2·5	0·8	—	1·7	Z21
120	0	2·5	0·8	—	1·7	Z22
67·5	0	3·5	1·4	—	0·9	W17
150	-1·5	3·6	1·2	—	1·4	W21
80	-1·0	3·4	1·2	150	3·2	MS4B
80	-1·0	5·2	1·1	V	2·4	VMS4B
100	-1·75	3·3	1·0	400	2·4	MSP4
100	-2·0	8·0	5·0	V	2·7	VMP4G
100	-3·0	10·0	—	V	2·9	KTW61
100	-3·0	7·6	1·5	V	1·5	KTW63
125	-2·0	1·0	0·25	—	1·225	KTZ63
100	-3·0	7·6	1·9	300	1·5	W76
200	-2·5	8·0	—	300	2·5	W77
100	-3·0	8·0	2·7	300	2·8	W81
250	-2·0	10·0	2·5	160	7·5	Z77
250	-2·0	10·0	3·0	150	6·3	Z90
100	-3·0	8·0	2·7	300	2·8	W101
60	-1·5	1·1	0·38	—	0·82	VP210
60	-1·5	1·45	0·5	—	1·08	VP23
60	-1·5	4·5	0·8	280	1·9	AC/SG
60	-2·0	5·8	0·9	300	1·8	AC/SGVM
200	-3·0	4·9	4·1	330	2·65	AC/SP1
100	-1·7	7·9	2·5	160	7·0	AC/SP3
200	-2·8	7·4	1·85	300	2·0	AC/VP1
200	-2·8	7·4	1·85	300	2·0	AC/VP2
200	-2·7	7·7	2·0	280	2·0	VP41
200	-1·5	10·9	2·7	110	8·5	SP41
140	-1·25	27·0	6·75	37	8·75	SP42
200	-1·5	10·9	2·7	110	8·5	SP61
200	-1·5	10·9	2·7	110	8·5	SP181

Continued on next page

SCREEN-GRIDS

Make	Type	Description	Base	Filament Volts	Filament Amp.	Anode Volts
MAZDA *continued*	VP1322	VP	7B26	13·0	0·2	250
	VP133	VP	OM24	13·0	0·2	150
	1F2	P	BB6	1·4	0·05	90
	1F3	VP	BB6	1·4	0·05	90
	V453	P	OM24	4·0	0·65	250
	6F11	P	B8A2	6·3	0·2	250
	6F12	P	BB5	6·3	0·3	250
	6F13	P	B8A2	6·3	0·35	200
	6F14	P	B8A2	6·3	0·35	140
	6F15	VP	B8A2	6·3	0·2	250
	6F32	P	OM24	6·3	0·63	200
	6F33	P	BB5	6·3	0·35	200
	10F9	VP	B8A2	13·0	0·1	175
	6F1	P	B8A9	6·3	0·35	200
	10F1	P	B8A9	23·0	0·1	200
	20F2	P	B8A2	11·0	0·2	140
MULLARD ..	DF33	VP	O7	1·4	0·05	90
	DF70	P	wires	0·625	0·025	30
	DF91	VP	BB6	1·4	0·05	90
	SP2	P	7B4	2·0	0·18	135
	VP2	VP	7B4	2·0	0·18	135
	VP2B	VP	7B5	2·0	0·14	135
	TSP4	P	7B26	4·0	1·3	200
	SP4	P	5B19/7B23	4·0	1·0	200
	SP4B	P	7B26	4·0	0·65	250
	VP4	VP	5B19/7B23	4·0	1·0	200
	VP4A	VP	5B19/7B23	4·0	1·2	200
	VP4B	VP	7B26	4·0	0·65	250
	KF35	VP	O6	2·0	0·05	120
	EF9/39	VP	8S24/047	6·3	0·2	250
	EF22	VP	B8B2	6·3	0·2	250
	EF37A	P	O47	6·3	0·2	250
	EF42	P	B8A2	6·3	0·33	250
	EF50	P	B9G1	6·3	0·3	250
	EF54	P	B9G2	6·3	0·3	250
	EF55	P	B9G1	6·3	1·0	250
	EF91	P	BB5	6·3	0·3	250
	EF92	VP	BB5	6·3	0·2	250
	SP13	P	8S24	13·0	0·2	200
	SP13C	P	7B26	13·0	0·2	200
	VP13A	VP	8S24	13·0	0·2	200
	VP13C	VP	7B26	13·0	0·2	200

ND R.F. PENTODES—*continued*

Screen Volts	*Bias Volts*	*Anode Current (mA)*	*Screen Current (mA)*	*Bias Res. Ohms*	*Slope mA/V*	*Type*
200	–2·8	7·4	1·85	300	2·0	VP1322
150	–2·7	8·0	2·2	270	2·1	VP133
67·5	0	2·9	1·2	—	0·92	1F2
45	0	1·8	0·65	—	0·75	1F3
100	–1·75	4·5	0·8	330	2·0	V453
100	–1·8	4·4	1·35	310	2·2	6F11
250	–2·0	10·0	2·5	160	7·5	6F12
200	–1·8	10·0	2·6	150	9·0	6F13
140	–1·25	28·0	7·0	36	10·6	6F14
100	–2·5	7·0	2·0	280	2·3	6F15
200	–4·5	5·1	3·45	526	3·0	6F32
200	–4·0	5·75	3·1	450	3·55	6F33
100	–2·5	7·0	2·0	280	2·3	10F9
200	–1·8	10·0	2·6	150	9·0	6F1
200	–1·8	10·0	2·6	150	9·0	10F1
140	–1·25	28·0	7·0	36	10·6	20F2
90	0–4	1·2	0·3	—	0·75	DF33
30	0	0·375	0·125	—	0·22	DF70
67·5	0–9	3·5	1·4	—	0·9	DF91
135	0	3·0	1·0	—	1·8	SP2
135	0–7	3·0	1·25	—	1·5	VP2
60	–1·5 –7·5	2·0	—	—	1·4	VP2B
200	–2·5	8·0	—	250	4·7	TSP4
100	–2·0	3·0	—	—	2·3	SP4
250	–2·4	4·0	1·5	470	3·4	SP4B
100	–2·0 –50	4·5	1·9	—	2·3	VP4
100	–2·0 –25	4·25	1·8	—	2·5	VP4A
250	–3·0 –45	11·5	4·25	—	2·0	VP4B
60	–1·5	1·45	0·5	—	1·08	KF35
100	–2·5 –49	6·0	1·7	325	2·2	EF9/39
100	–2·5 –46	6·0	1·7	330	2·2	EF22
100	–2·0	3·0	0·8	500	1·8	EF37A
250	–2·0	10·0	2·3	160	9·5	EF42
250	–2·0	10·0	3·0	160	6·5	EF50
250	–1·7	10·0	1·45	150	7·7	EF54
250	–4·5	40·0	5·5	100	12·0	EF55
250	–2·0	10·0	2·55	160	7·65	EF91
200	–2·5 –28	8·0	2·0	650	2·5	EF92
100	–2·0	3·3	1·2	400	2·2	SP13
200	–2·2	2·5	0·9	680	2·8	SP13C
100	–2·0 –20	4·0	1·4	360	2·2	VP13A
200	–2·0 –34	9·0	3·6	160	2·2	VP13C

Continued on next page

SCREEN-GRIDS

Make	*Type*	*Description*	*Base*	*Filament*		*Anode Volts*
				Volts	*Amp.*	
TUNGSRAM .. Also manufacture American types 1T4 6C6, 6D6, 6J7, 6K7, 6U7, 6SG7, 6SH7, 6SJ7, 6SK7, 12SG7, 12SH7, 12SJ7, 12SK7, 12J7, 12K7 (q.v.).	SE211	VS	4B5	2·0	0·12	150
	HP210	P	7B4	2·0	0·12	150
	SS210	T	4B5	2·0	0·12	150
	HP211	VP	7B4	2·0	0·12	150
	AS4125	VS	5B17	4·0	1·2	200
	AS4120	T	5B17	4·0	1·0	250
	HP4101	P	5B19/7B23	4·0	1·0	200
	SP4B	P	7B26	4·0	0·65	250
	HP4106	VP	5B19/7B23	4·0	1·0	200
	VP4B	VP	7B26	4·0	0·65	250
	EF9/39	VP	8S24/O47	6·3	0·2	250
	SP13B	P	7B26	13·0	0·2	250
	VP13B	VP	7B26	13·0	0·2	250
	VP13K	VP	7B26	13·0	0·2	200
	HP6	P	BB5	6·3	0·3	250
	UF41	VP	B8A2	12·6	0·1	200

DIODES

Make	*Type*	*Description*	*Base*	*Filament*		*Max. Diode Volts*	*Max. Diode Current*
				Volts	*Amp.*		
BRIMAR .. Also manufacture American types 6AL5, 6H6 (q.v.).	10D1	DD	5B12	13·0	0·2	50	1·0
COSSOR .. Also manufacture American types 6H6, 6AL5 (q.v.).	DDL4	DD	5B12	4·0	0·75	200	10·0
	SD6	D	BB10	6·3	0·15	150	10·0
EVER READY	A20B	DD	5B12	4·0	0·65	200	0·8
	EB34	DD	O38	6·3	0·2	200	0·8
	C20C	DD	5B12	13·0	0·2	200	0·8
FERRANTI Also manufacture American types 6H6, 6AL5 (q.v.).	DD6	DD	BB7	6·3	0·30	150	9·0
HIVAC .. Manufacture American type 1A3 (q.v.).							

Continued on opposite page

AND R.F. PENTODES—*continued*

Screen Volts	*Bias Volts*	*Anode Current (mA)*	*Screen Current (mA)*	*Bias Res. Ohms*	*Slope mA/V*	*Type*
75	–0·9	1·0	0·1	—	1·5	SE211
150	–1·5	1·9	0·7	—	1·9	HP210
75	–1·0	0·6	0·1	—	1·4	SS210
150	–1·0 –17	2·6	0·6	—	1·7	HP211
100	–1·5 –40	3·0	0·8	V	3·0	AS4125
100	–2·0	3·0	0·8	500	3·0	AS4120
100	–2·0	3·5	0·6	600	3·5	HP4101
250	–2·0	2·9	0·8	500	4·0	SP4B
100	–1·5 –35	5·0	1·3	V	3·5	HP4106
250	–1 –50	10·0	2·5	V	4·0	VP4B
250	–2·5 –55	6·0	1·7	V	2·2	EF9/39
250	–1·5	3·5	1·5	—	3·5	SP13B
200	–1 –50	10·0	3·5	V	3·5	VP13B
100	–3·0	8·0	2·6	280	2·0	VP13K
250	–2·0	10·0	2·1	160	7·5	HP6
200	–3·0	7·2	2·0	300	2·3	UF41

DIODES—*continued*

Make	*Type*	*Description*	*Base*	*Filament*		*Max. Diode Volts*	*Max. Diode Current*
				Volts	*Amp.*		
MARCONI AND OSRAM	D41	DD	5B12	4·0	0·3	—	—
	D42	D	4B18	4·0	0·6	75	15·0
	D63	DD	O38	6·3	0·3	100	2·0
	D77	DD	BB7	6·3	0·3	350	50·0
MAZDA ..	DD41	DD	OM18	4·0	0·5	175	5·0
	V914	DD	5B21	4·0	0·3	—	0·5
	D1	D	B3G	4·0	0·2	125	5·0
	6D1	D	B3G	6·3	0·15	125	5·0
	6D2	DD	BB7	6·3	0·3	175	9·0
	20D1	DD	BB7	9·5	0·2	175	9·0
	1D13	D	BB9	1·4	0·15	130	0·5
MULLARD	EB34	DD	O38	6·3	0·2	200	0·8
	EB41	DD	B8A10	6·3	0·3	150	9·0
	EA50	D	B3G	6·3	0·15	50	5·0
	EB91	DD	BB7	6·3	0·3	200	9·0
TUNGSRAM	DD4	DD	5B12	4·0	0·65	200	0·8
	DD6G	DD	BB7	6·3	0·3	165	10·0
'Also manufacture American types 6AL5, 6H6 (q.v.).	DD13	DD	5B12/8S16	13·0	0·2	200	0·8

DIODI

Make	*Type*	*Description*	*Base*	*Filament*		*Anode*
				Volts	*Amp.*	*Volts*
BRIMAR .. Also manufacture American types 1H5, 1LH4, 1S5, 6B6, 6B7, 6R7, 6SQ7, 7B6, 7C6, 12SQ7, 12SR7, 75, 6B8, 6Q7, 6T8, 7K7, 7R7, 12C8, 12Q7, 14R7, 19T8 (q.v.).	11A2	DDT	7B19	4·0	1·0	200
	11D3	DDT	7B19	13·0	0·2	250
	11D5	DDT	7B19	13·0	0·15	250
COSSOR .. Also manufacture American types 1H5, 6B8, 6Q7, 6SQ7, 12SQ7, 7C6 (q.v.).	210DDT	DDT	5B2	2·0	0·1	100
	DDT	DDT	7B19	4·0	1·0	200
	420TDD	DDP(A.F.)	7B22	4·0	2·0	250
	202DDT	DDT	7B19	20·0	0·2	200
	OM4	DDT	O41	6·3	0·2	250
EVER READY	K23B	DDT	5B2	2·0	0·12	135
	A23A	DDT	7B19	4·0	0·65	250
	A27D	DDP	7B33	4·0	2·25	250
	EBC3/EBC33	DDT	8S21/O41	6·3	0·2	275
	EBL1/31	DDP	8S27/O53	6·3	1·5	250
	C23B	DDT	7B19	13·0	0·2	200
	DAC32	SDT	O4	1·4	0·05	90
	DAF91	SDP(R.F.)	BB3	1·4	0·05	67·5
FERRANTI Also manufacture American types 6B7, 6B8, 6F8, 6R7, 6SQ7, 7R7, 12C8, 12SR7, 1H5, 6B8, 6Q7, 7B6, 7C6, 7K7, 12Q7, 12SQ7, 14B6 (q.v.).	H2D	DDT	5B2	2·0	0·1	100
	H4D	DDT	7B19	4·0	1·0	200
	PT4D	DDP	7B32	4·0	2·0	250
MARCONI AND OSRAM	HD14	DD	O4	1·4	0·05	90
	HD24	DDT	5B2	2·0	0·1	150
	ZD17	SD(PR.F.)	BB3	1·4	0·05	90
	MHD4	DDT	7B19	4·0	1·0	250
	DL63	DDT	O41	6·3	0·3	250
	DL82	DDT(V.M.)	B8B3	6·3	0·3	250
	DH63	DDT	O41	6·3	0·3	250
	DH76	DDT	O41	13·0	0·16	250
	DH81	DDT	B8B3	6·3	0·3	250
	DH101	DDT	B8B3	19·0	0·1	250

COMBINATIONS

Screen Volts	*Ampl'n Factor*	*Slope (mA/V)*	*Bias Volts*	*Bias Res. (Ohms)*	*Anode Current (mA)*	*Output (mW)*	*Type*
—	50	2·8	-2·0	700	3·0	—	11A2
—	100	1·1	-2·0	5,000	0·4	—	11D3
—	40	1·5	-3·0	750	3·8	—	11D5
—	27·5	1·1	-1·5	—	0·75	—	210DDT
—	41	2·4	-3·0	1,000	3·0	—	DDT
250	—	7·0	-5·5	—	34·0	3,100	420TDD
—	41	2·4	-3·0	1,000	3·0	—	202DDT
—	33	2·2	-5·0	1.000	5·5	—	OM4
—	30	1·2	-1·5	—	1·95	—	K23B
—	27	2·0	-7·0	1,750	4·0	—	A23A
250	—	9·5	-6·0	150	36·0	4,300	A27D
—	30	2·0	-6·25	1,250	5·0	—	EBC3/EBC33
250	—	9·5	-6·0	150	36·0	4,300	EBL1/31
—	27	2·0	-5·0	1,250	4·0	—	C23B
—	65	0·275	0	—	0·14	—	DAC32
67·5	—	0·625	0	—	1·6	—	DAF91
—	—	1·3	—	—	3·5	—	H2D
—	39	2·7	-2·5	—	5·5	—	H4D
250	—	7·5	-6·0	140	7·0	3,600	PT4D
—	65	0·275	0	—	0·14	—	HD14
—	40	1·4	-1·5	—	0·4	—	HD24
90	—	0·63	0	—	2·7	—	ZD17
—	40	2·2	—	750	4·0	—	MHD4
—	37	1·65	-3·0	—	5·0	—	DL63
—	24	1·4	-7·5	1,500	5·0	—	DL82
—	70	1·2	-3·0	2,000	1·1	—	DH63
—	70	1·2	-3·0	3,000	1·1		DH76
—	70	1·2	-3·0	3,000	1·1	—	DH81
—	70	1·2	-3·0	3,000	1·0	—	DH101

Continued on next page

DIODE

Make	*Type*	*Description*	*Base*	*Filament* *Volts*	*Filament* *Amp.*	*Anode* *Volts*
MAZDA ..	1FD9	SDP(A.F.)	BB3	1·4	0·05	67·5
	6LD20	DDT	B8A5	6·3	0·3	250
	10LD11	DDT	B8A5	15·0	0·1	250
	HL23/DD	DDT	OM2	2·0	0·05	150
	AC/HLDD	DDT	7B19	4·0	1·0	200
	AC2/PENDD	DDP	7B32	4·0	2·0	250
	AC5/PENDD	DD Tet.	7B22	4·0	2·0	250
	PEN 45/DD	DD Tet.	OM25	4·0	2·0	250
	HL41/DD	DDT	OM21	4·0	0·65	250
	HL42/DD	DDT	OM21	4·0	0·65	65
	HL133/DD	DDT	OM21	13·0	0·2	250
	PENDD4020	DDP	7B32	40·0	0·2	240
	PEN453/DD	DD Tet.	OM25	45·0	0·2	160
MULLARD	DAC32	SDT	O88	1·4	0·05	90
	DAF91	SDP	BB3	1·4	0·05	90
	EAC91	SDT	BB11	6·3	0·3	200
	EAF42	SDP (R.F.,VM)	B8A12	6·3	0·2	250
	UAF42	SDP (R.F.,VM)	B8A12	12·6	0·1	200
	TDD2A	DDT	5B2	2·0	0·12	135
	TDD4	DDT	7B19	4·0	0·65	250
	PEN4DD	DDP	7B33	4·0	2·25	250
	EBC3/33	DDT	8S21/O41	6·3	0·2	250
	EBL21	DDP(A.F.)	B8B4	6·3	0·8	250
	EBL1/31	DDP	8S27/O53	6·3	1·2	250
	KBC32	DDT	O89	2·0	0·05	100
	UBL21	DDP(A.F.)	B8B4	55·0	0·1	200
	TDD13C	DDT	7B19	13·0	0·2	200
	CBL1/31	DDP	8S27/O53	44·0	0·2	200
	EBC41	DDT	B8A5	6·3	0·22	250
	EBF80	DDP(R.F.,VM)	B9A3	6·3	0·3	250
	UBC41	DDT	B8A5	14·0	0·1	170
	UBF80	DDP(R.F.,VM)	B9A3	17·0	0·1	200
TUNGSRAM Also manufacture American types 2A6, 2B7, 6B7, 6B8, 6Q7, 6R7, 6SQ7, 12SQ7, 12SR7, 75 (q.v.).	DDT4/S	DDT	7B19/8S21	4·0	0·65	250
	DDP4B/M	DDP	7B32/7B33	4·0	2·0	250
	EBC/33	DDT	8S21/O41	6·3	0·2	250
	EBF2	DDP(R.F.)	8S27	6·3	0·2	250
	EBL31	DDP	8S27/O53	6·3	1·4	250
	DDPP39/M/S	DDP	7B32/7B33 /8S27	35·0	0·2	200
	DDPP6B	DDP	7B32	6·3	1·4	250
	UAF41	SDP(R.F.)	B8A11	12·6	0·1	200
	CBL31	DDP(A.F.)	O53	39·0	0·2	200

COMBINATIONS—*continued*

Screen Volts	*Ampl'n Factor*	*Slope (mA/V)*	*Bias Volts*	*Bias Res. (Ohms)*	*Anode Current (mA)*	*Output (mW)*	*Type*
67·5	—	0·63	0	—	1·6	—	1FD9
—	31	2·3	–5·9	1,200	5·0	—	6LD20
—	31	2·3	–5·9	1,200	5·0	—	10LD11
—	25	1·05	–2·8	—	1·5	—	HL23/DD
—	36	2·5	–3·0	700	4·3	—	AC/HLDD
250	—	8·5	–5·3	140	32·0	3,500	AC2/PENDD
250	—	9·4	–8·5	180	40·0	4,850	AC5/PENDD
250	—	8·8	–8·5	180	40·0	4,500	PEN45/DD
—	30	2·2	–5·2	850	6·0	—	HL41/DD
—	23	2·9	–1·25	450	2·8	—	HL42/DD
—	32	2·3	–5·4	900	6·0	—	HL133/DD
250	—	7·8	–7·75	150	43·0	3,900	PENDD4020
175	—	10·5	–10·0	130	64·0	3,750	PEN453/DD
—	65	0·275	0	—	0·15	—	DAC32
90	—	0·72	0	—	2·7	—	DAF91
—	35	2·8	–2·8	400	7·5	—	EAC91
100	—	1·8	–2·0	700	5·0	—	EAF42
115	—	1·9	–2·4	300	6·0	—	UAF42
—	30	1·2	–1·5	—	1·95	—	TDD2A
—	27	2·0	–7·0	1,500	4·0	—	TDD4
250	—	9·5	–6·0	150	36·0	4,500	PEN4DD
—	30	2·0	–5·5	—	5·0	—	EBC3/33
250	—	9·0	–6·0	146	36·0	4,300	EBL21
250	—	9·5	–6·0	146	36·0	4,300	EBL1/31
—	25	1·2	0	—	2·4	—	KBC32
200	—	8·0	-13·0	200	55·0	4,800	UBL21
—	27	2·0	–5·0	1,250	4·0	—	TDD13C
200	—	8·0	–8·5	150	45·0	4,000	CBL1/31
—	70	1·3	–3·0	—	1·0	—	EBC41
85	—	2·2	–2·0	300	5·0	—	EBF80
—	70	1·65	–1·6	—	1·5	—	UBC41
85	—	2·2	–2·0	300	5·0	—	UBC80
—	40	3·6	–5·0	1,250	4·0	—	DDT4/S
250	—	8·0	–5·0	150	36·0	3,600	DDP4B/M
—	37·5	2·5	–5·5	1,100	5·0	—	EBC/33
250	—	1·8	–2·0	270	5·0	—	EBF2
250	—	9·5	–6·0	150	36·0	3,600	EBL31
200	—	8·5	–8·0	170	45·0	3,200	DDPP39/M/S
250	—	9·5	–6·0	150	36·0	3,600	DDPP6B
200	—	1·9	–2·4	300	6·0	—	UAF41
200	—	8·5	–8·0	170	45·0	3,200	CBL31

GENERAL-

Make	Type	Base	Filament Volts	Filament Amp.	Anode Volts
BRIMAR ..	HLA2	5B15	4·0	1·0	200
Also manufacture American types 6A6, 6C5, 7N7, 76, 6J5, 6N7, 6SL7, 6SN7. 12AT7 (q.v.).	4D1	7B18	13·0	0·2	250
COSSOR ..	41FP	5B15	4·0	1·0	250
Also manufacture American types 6C5, 6F8, 6J5, 6SL7, 6SN7, 12J5, 12SC7, 7N7 (q.v.).	41MH	5B15	4·0	1·0	200
	41MHL	5B15	4·0	1·0	200
	41MTL	5B15	4·0	1·0	200
	41MTB	5B15	4·0	1·0	100
	41MTA	5B15	4·0	1·0	100
EVER READY	K30K	4B4	2·0	0·1	135
	A30B	5B15	4·0	0·65	200
	A30D	5B15	4·0	0·65	250
	C30B	7B18	13·0	0·2	200
FERRANTI .. Also manufacture American types 6A6, 6C5, 6SL7, 12AH7, 12J5, 12SC7, 12SN7, 6J5 (q.v.).	D4	5B15	4·0	1·0	200
HIVAC	XH1·5V	4D1	1·5	0·08	50
Also manufacture American type 6C4 (q.v.).	XD1·5V	4D1	1·5	0·08	50
	XH2·0V	4D1	2·0	0·08	50
	XD2·0V	4D1	2·0	0·08	50
	XL1·5V	4D1	1·5	0·08	50
	XLO1·5V	4D1	1·5	0·08	50
	XL2·0V	4D1	2·0	0·08	50
	XLO2·0V	4D1	2·0	0·08	50
MARCONI	HL2	4B4	2·0	0·1	150
AND OSRAM	MH41	5B15	4·0	1·0	200
	MH4	5B15	4·0	1·0	250

PURPOSE TRIODES

Amplif'n Factor	*Impedance (Ohms)*	*Slope (mA/V)*	*Bias Volts*	*Anode Current (mA)*	*Bias Res. (Ohms)*	*Type*
50	9,000	5·5	–2·5	6·0	400	HLA2
40	10,000	4·0	–3·0	10·0	300	4D1
10	3,600	2·8	–18·0	19·0	1,000	41FP
72	18,000	4·0	–1·5	3·2	500	41MH
52	11,500	4·5	–3·0	4·0	750	41MHL
44	15,000	3·0	–2·5	5·9	400	41MTL
—	—	2·6	0	3·6	—	41MTB
72	18,000	4·0	0	4·9	—	41MTA
30	21,500	1·4	–1·5	2·2	—	K30K
72	20,600	3·5	–2·0	2·2	900	A30B
40	11,500	3·5	–4·5	6·5	700	A30D
40	12,000	3·3	–3·7	5·0	750	C30B
40	12,500	3·3	–3·0	4·0	650	D4
25	50,000	0·5	0	0·45	—	XH1·5V
20	50,000	0·4	0	0·45	—	XD1·5V
28	50,000	0·56	0	0·45	—	XH2·0V
21	38,000	0·56	0	0·65	—	XD2·0V
12	20,000	0·6	–1·0	0·7	—	XL1·5V
13	20,000	0·65	–1·0	0·9	—	XLO1·5V
10	12,500	0·84	–1·0	1·0	—	XL2·0V
11	12,500	0·92	–1·0	1·1	—	XLO2·0V
27	18,000	1·5	–1·5	2·0	—	HL2
80	13,000	6·0	–1·5	5·2	300	MH41
40	11,100	3·6	–4·0	5·0	700	MH4

Continued on next page

GENERAL-PURPOSE

Make	*Type*	*Base*	*Filament*		*Anode Volts*
			Volts	*Amp.*	
MARCONI AND OSRAM	MHL4	5B15	4·0	1·0	250
	ML4	5B15	4·0	1·0	250
	H63	O39	6·3	0·3	250
	L63	O34	6·3	0·3	250
	H30	7B18	13·0	0·3	250
	L77	BB12	6·3	0·15	250
	*B65	B8B5	6·3	0·6	300
MAZDA ..	HL23	OM1	2·0	0·05	150
	AC/HL	5B15	4·0	1·0	200
	AC2/HL	5B15	4·0	1·0	200
	HL41	OM19	4·0	0·65	250
	V312	5B14	4·0	0·65	250
	P41	OM19	4·0	0·95	250
	P61	OM19	6·3	0·6	250
	AC/P4	5B13	4·0	1·0	700
	6L18	B8A3	6·3	0·3	250
	*6L19	B8A4	6·3	0·4	250
MULLARD ..	PM2HL	4B4	2·0	0·1	135
	354V	5B15	4·0	0·65	250
	EC31	O34	6·3	0·65	250
	EC52	B9G3	6·3	0·43	250
	EC91	BB13	6·3	0·3	250
	*ECC91	BB14	6·3	0·45	100
	*ECC33	O103	6·3	0·4	250
	*ECC34	O103	6·3	0·95	250
	*ECC35	O103	6·3	0·4	250
TUNGSRAM Also manufacture American types 6C5, 6J5, 6F8, 6SN7, 12J5, 12SN7 (q.v.).	HR210	4B4	2·0	0·1	200
	LD210	4B4	2·0	0·1	150
	HL4+	5B15	4·0	0·65	250
	HL4g	7B18	4·0	0·65	250
	HL13	7B18	13·0	0·2	200

**Double triode; characteristics are for each section.*

TRIODES—*continued*

Amplif'n Factor	*Impedance (Ohms)*	*Slope (mA/V)*	*Bias Volts*	*Anode Current (mA)*	*Bias Res. (Ohms)*	*Type*
20	8,000	2·5	–8·0	8·0	1,000	MHL4
12	2,860	4·2	–16·0	14·0	1,100	ML4
100	66,000	1·5	–2·0	1·0	2,000	H63
20	7,700	2·6	–8·0	9·0	800	L63
80	13,300	6·0	–1·5	7·5	200	H30
17	7,700	2·2	–8·5	10·5	800	L77
20	7,700	2·6	–8·0	9·0	800	*B65
32	27,000	1·2	–2·4	1·5	—	HL23
35	12,500	2·8	–3·5	5·0	700	AC/HL
75	15,000	5·0	–1·75	4·9	360	AC2/HL
36	11,500	3·1	–4·5	7·0	640	HL41
33	13,000	2·3	–4·8	6·0	800	V312
17	3,700	4·5	–11·8	16·0	750	P41
17	3,700	4·5	–11·8	16·0	750	P61
20	2,800	7·0	electro	static	scanning	AC/P4
16·5	3,000	5·5	–13·3	12·0	110	6L18
55	20,000	2·75	–3·1	4·0	750	*6L19
30	21,500	1·4	–1·5	2·2	—	PM2HL
40	11,500	3·5	–4·5	6·5	700	354V
5	3,300	3·2	–16·0	20·0	800	EC31
60	9,200	6·5	–2·6	10·0	260	EC52
100	12,000	8·5	–1·5	10·0	150	EC91
38	7,100	5·3	–0·85	8·5	100	*ECC91
35	9,700	3·6	–4·0	9·0	—	*ECC33
11·5	5,200	2·2	–16·0	10·0	—	*ECC34
68	34,000	2·0	–2·5	2·3	—	*ECC35
30	23,000	1·3	–3·0	1·0	—	HR210
18	14,000	1·3	–4·5	3·0	—	LD210
33	11,000	3·5	–4·5	5·0	1,000	HL4+
33	11,000	3·5	–4·5	5·0	1,000	HL4g
30	12,000	3·5	–5·5	6·0	1,000	HL13

POWER

Make	Type	Base	Filament Volts	Filament Amp.	Anode Volts	Impedance
BRIMAR Also manufacture American types 2A3, 6A3, 6B4 (q.v.).	PA1	5B15	4·0	1·1	200	2,000
COSSOR	2P	4B4	2·0	2·0	250	1,150
	2XP	4B4	2·0	2·0	300	900
	41MP	5B15	4·0	1·0	200	2,500
	41MXP	5B15	4·0	1·0	200	1,500
	4XP	4B4	4·0	1·0	250	900
EVER READY	K30G	4B4	2·0	0·2	135	6,000
	S30C	4B4	4·0	1·0	300	1,200
	S30D	4B4	2·0	2·0	300	1,200
FERRANTI	L2	4B4	2·0	0·1	120	6,800
	L4	5B15	4·0	1·0	250	3,300
	LP4	4B4	4·0	1·0	250	980
HIVAC	XP1·5V	4D1	1·5	0·08	50	7,250
	XP2·0V	4D1	2·0	0·08	50	6,000
MARCONI AND OSRAM	LP2	4B4	2·0	0·2	150	4,170
	P2	4B4	2·0	0·2	150	2,150
	PX4	4B4	4·0	1·0	300	830
	PX25	4B4	4·0	2·0	500	1,265
MAZDA	PA20	4B21	2·0	2·0	300	1,100
	PP5/400	4B21	4·0	2·0	400	1,100
	PP3/250	4B21	4·0	1·0	300	1,100
MULLARD	PM2A	4B4	2·0	0·2	135	6,000
	PM202	4B4	2·0	0·2	150	2,000
	ACO44	4B4	4·0	1·0	300	1,200
	ACO42	4B4	2·0	2·0	300	1,200
	DO30	4B4	4·0	2·0	500	580
TUNGSRAM	LP220	4B4	2·0	0·2	150	3,900
	P215	4B4	2·0	0·15	150	3,300
	SP220	4B4	2·0	0·2	150	2,200
	P12/250	4B4	4·0	1·0	250	830
	P27/500	4B4	4·0	2·0	500	1,100

OUTPUT TRIODES

Slope (mA/V)	*Bias Volts*	*Anode Current (mA)*	*Bias Res. (Ohms)*	*Output (mW)*	*Optimum Load (Ohms)*	*Type*
5·0	–10·0	40·0	250	1,800	4,000	PA1
7·0	–22·0	40·0	550	2,000	3,000	2P
7·0	–36·0	50·0	700	3,150	4,000	2XP
7·5	–7·5	24·0	320	1,000	3,000	41MP
7·5	–12·5	40·0	300	1,600	2,000	41MXP
7·0	–28·5	48·0	600	3,000	3,000	4XP
2·0	–6·0	5·0	—	150	7,000	K30G
5·0	–38·0	50·0	600	3,500	2,300	S30C
5·0	–38·0	50·0	600	3,500	2,300	S30D
1·6	—	7·5	—	—	—	L2
3·2	–16·0	20·0	800	500	10,000	L4
5·5	–35·0	48·0	730	2,800	2,500	LP4
0·72	–4·5	1·75	—	—	—	XP1·5V
1·0	–3·0	2·0	—	—	—	XP2·0V
3·6	–4·5	10·0	—	—	9,700	LP2
3·5	–10·5	19·0	—	200	6,000	P2
6·0	–50·0	50·0	1,000	4,500	3,500	PX4
7·5	–50·0	50·0	1,000	8,500	5,500	PX25
5·2	–36·0	48·0	750	5,900	2,700	PA20
8·0	–32·0	62·5	510	6,000	2,700	PP5/400
5·2	–37·0	48·0	770	4,200	3,000	PP3/250
2·0	–6·0	5·0	—	150	7,000	PM2A
3·5	–14·0	14·0	—	—	3,700	PM202
5·0	–38·0	50·0	760	3,500	2,300	ACO44
5·0	–38·0	50·0	760	3,500	2,300	ACO42
6·9	–134·0	60·0	—	11,000	6,000	DO30
3·5	–4·5	5·0	—	200	7,500	LP220
1·5	–12·0	12·0	—	260	7,000	P215
3·0	–12·0	14·0	—	360	6,700	SP220
6·0	–33·0	48·0	700	2,800	2,400	P12/250
8·5	–32·0	62·5	500	5,000	5,000	P27/500

OUTPUT PENTODES

Make	Type	Base	Filament		Anode Volts	Screen Volts
			Volts	Amp.		
BRIMAR ..	7A2	5B18/7B31	4·0	1·2	250	250
Also manufacture American types 1A5, 1C5, 1S4, 1Q5, 3Q5, 6K6, 7B5, 7C5, 12A6, 18, 35A5, 41, 42, 43, 50L6, 1S5, 3S4, 6AG6, 6F6, 6L6, 6V6, 25A6, 25L6, 35L6 (q.v.).	7A3	7B31	4·0	2·0	250	250
	PENA1	5B4	4·0	1·0	250	250
	7D5	7B31	13·0	0·315	250	250
	7D8	7B31	13·0	0·65	250	250
	7D3	7B31	40·0	0·2	135	120
	7D6	7B31	40·0	0·2	250	250
	7D9	BB15	6·3	0·2	250	250
COSSOR ..						
(*Tetrode*)	220 OT	5B3	2·0	0·2	150	150
	332Pen	O79	33·0	0·2	200	200
(„)	61BT	O81	6·3	0·7	200	200
(„)	142BT	O79	14·0	0·2	180	180
(„)	185BT	O81	18·0	0·45	180	180
Also manufacture American types 1A5, 1C5, 3Q5, 6F6, 6L6, 6Y6, 25A6, 1S5, 3A4, 3S4, 6V6, 7C5, 35A5 (q.v.).	MPPen	5B18/7B27	4·0	1·0	250	250
	402Pen/A	7B29	40·0	0·2	150	150
EVER READY	K70B	5B4	2·0	0·15	135	135
	K70D	5B4	2·0	0·3	135	135
	A70B	7B27	4·0	1·35	250	250
	A70D	7B27	4·0	1·95	250	250
	A70E	7B27	4·0	2·1	250	275
	EL32	O50	6·3	0·2	250	250
	EL3/33	8S23/O48	6·3	0·9	250	250
	C70D	7B27	35·0	0·2	200	200
	DL35	O8	1·4	0·1	90	90
	DL92	BB8	1·4	0·1	90	67·5
FERRANTI	PT2	5B4	2·0	0·2	120	120
Also manufacture American types 6K6, 6L6, 6V6, 12A6, 42, 1A5, 1C5, 1Q5, 1S4, 1S5, 3Q5, 3S4, 6F6, 6Y6, 7C5, 25L6, 35L6, 35A5, 50A5, 50L6 (q.v.).	PT4	7B27	4·0	2·0	250	250

AND TETRODES

Slope (mA/V)	*Bias Volts*	*Bias Res. (Ohms)*	*Anode and Screen Current (mA)*	*Output (mW)*	*Optimum Load (Ohms)*	*Type*
2·35	–16·5	410	40·5	3,500	7,000	7A2
10·0	–6·0	150	38·0	3,750	8,500	7A3
3·0	–16·5	450	38·5	2,700	8,000	PENA1
2·35	–16·5	410	40·5	3,500	7,000	7D5
10·0	–6·0	150	38·0	3,750	8,500	7D8
2·4	–18·0	440	39·5	2,200	5,000	7D3
10·0	–6·0	150	38·0	3,750	8,500	7D6
2·6	–13·5	750	18·4	1,400	16,000	7D9
2·5	–4·5	—	11·5	500	20,000	220 OT
8·0	–8·5	167	51·0	4,000	4,500	332Pen
4·0	–20·0	465	43·0	2,000	—	61BT
3·7	–8·5	265	32·0	2,200	5,500	142BT
9·5	–18·0	165	107·0	4,000	2,000	185BT
3·5	–16·0	450	36·0	3,500	10,000	MPPen
8·0	–9·0	130	67·0	3,000	2,500	402Pen/A
2·2	–4·5	—	—	340	19,000	K70B
3·0	–2·4	—	—	300	24,000	K70D
2·8	–22·0	—	—	3,800	6,000	A70B
9·5	–5·8	—	—	3,800	8,000	A70D
8·5	–14·0	—	—	8,800	3,500	A70E
2·8	–18·0	—	—	3,600	8,000	EL32
9·0	–6·0	—	—	4,500	7,000	EL3/33
8·0	–9·0	—	—	4,000	4,000	C70D
1·55	–7·5	—	12·3	240	8,000	DL35
1·58	–7·0	—	8·8	270	8,000	DL92
2·6	–4·5	—	6·4	350	20,000	PT2
7·0	—	—	—	—	—	PT4

Continued on next page

OUTPUT PENTODES

Make	*Type*	*Base*	*Filament*		*Anode Volts*	*Screen Volts*
			Volts	*Amp.*		
HIVAC	XY1·4A	wires	1·4	0·032	45	45
	XY1·4B	wires	1·25	0·025	45	45
	XY1·4C	wires	1·25	0·025	45	45
	XY1·5V	5D2	1·5	0·16	45	45
	XY2·0V	5D2	2·0	0·16	50	50
MARCONI AND OSRAM	N14	O8	1·4	0·1	150	90
	N16	O12	1·4	0·1	90	90
	N17	BB8	1·4	0·1	90	67·5
(*Tetrode*)	KT2	5B4	2·0	0·2	150	150
(„)	KT24	4B4	2·0	0·2	150	150
(„)	MKT4	7B27	4·0	1·0	250	225
(„)	KT41	7B27	4·0	2·0	250	250
(„)	KT61	O48	6·3	0·95	275	275
(„)	KT63	O48	6·3	0·7	250	250
(„)	KT66	O48	6·3	1·27	500	400
	N144	BB15	6·3	0·2	250	250
(„)	N145	—	40·0	0·1	180	150
(„)	KT76	O79	15·0	0·16	175	175
(„)	KT71	O79	48·0	0·16	200	200
„)	KT45	7B23	4·0	2·0	4,000	300
	N77	BB15	6·3	0·2	250	250
(„)	KT81	B8B6	6·3	0·95	250	250
(„)	KT101	B8B6	80·0	0·1	200	200
„)	KT32	O48	26·0	0·3	135	135
	KT33C	O48	26·0 13·0	0·3 0·6	200	200
MAZDA ..	PEN220	5B4	2·0	0·2	150	150
	PEN25	OM4	2·0	0·15	120	120
	AC/Pen	7B27	4·0	1·0	250	250
	AC2/Pen	7B27	4·0	1·75	250	250
	AC5/Pen	7B20	4·0	1·75	250	250
	PEN44	OM22	4·0	2·1	260	270
	PEN45	OM22	4·0	1·75	250	250
	PEN46	OM23	4·0	1·75	350	240
	PEN383	OM22	38·0	0·2	160	175
	1P10	BB8	1·4	0·1	90	67·5
	1P11	BB22	1·4	0·1	90	90
	6P25	O79	6·3	1·1	250	250
	6P28	O81	6·3	1·1	350	250

AND TETRODES—*continued*

Slope (mA/V)	*Bias Volts*	*Bias Res. (Ohms)*	*Anode and Screen Current (mA)*	*Output (mW)*	*Optimum Load (Ohms)*	*Type*
0·55	−4·5	—	2·5	10	30,000	XY1·4A
0·60	−4·5	—	1·95	27·5	30,000	XY1·4B
0·50	−1·5	—	0·60	6·5	100,000	XY1·4C
1·0	−1·5	—	2·1	—	—	XY1·5V
1·4	−2·0	—	2·15	—	—	XY2·0V
1·55	−7·0	—	9·5	250	8,000	N14
2·1	−4·5	—	10·8	270	8,000	N16
1·58	−7·0	—	8·8	270	8,000	N17
2·5	−4·5	—	9·2	500	17,000	KT2
3·2	−2·8	—	12·1	640	10,000	KT24
3·0	−13·5	360	37·0	2,500	8,000	MKT4
10·5	−4·4	90	48·5	4,300	6,000	KT41
10·5	−4·4	90	47·5	4,300	6,000	KT61
2·5	−16·5	420	39·5	3,000	7,000	KT63
6·3	−15·0	160	91·3	7,250	2,200	KT66
2·6	−12·5	680	18·4	1,400	16,000	N144
7·5	−6·3	180	35·0	2,600	5,800	N145
2·5	−13·0	300	41·0	2,000	5,000	KT76
10·0	−9·8	120	73·0	5,000	2,500	KT71
6·3	−15·0	160	91·3	7,250	2,200	KT45
2·6	−12·0	520	23·0	1,400	16,000	N77
10·8	−4·4	90	47·5	4,300	6,000	KT81
10·0	−13·2	180	73·0	5,000	3,000	KT101
9·0	−7·6	95	80·0	3,500	1,300	KT32
10·0	−13·2	190	70·0	5,000	3,000	KT33C
2·2	−4·9	—	10·6	600	14,000	PEN220
3·0	−3·6	—	6·0	400	14,000	PEN25
2·7	−15·5	410	38·0	3,300	7,500	AC/Pen
8·5	−5·3	140	38·0	3,500	6,700	AC2/Pen
9·4	−8·5	180	48·0	4,850	5,200	AC5/Pen
10·6	−11·1	135	82·0	8,000	3,000	PEN44
8·8	−8·5	180	47·5	4,500	5,000	PEN45
9·5	−7·8	100	77·0	magnetic	scanning	PEN46
10·5	−10·0	130	77·0	3,750	2,600	PEN383
1·57	−7·0	—	8·8	270	8,000	1P10
2·15	−4·5	—	11·6	270	10,000	1P11
8·8	−8·5	180	48·0	4,500	5,000	6P25
—	−8·8	100	88·0	magnetic	scanning	6P28

Continued on next page

Make	*Type*	*Base*	*Filament*		*Anode Volts*	*Screen Volts*
			Volts	*Amp.*		
MAZDA *continued*	12E1	O81	6·3	1·6	800	300
	PEN384	OM22	38·0	0·2	110	110
	10P13	B8A6	40·0	0·1	180	150
	10P14	O48	40·0	0·1	195	210
	20P1	O81	38·0	0·2	400	250
MULLARD ..	DL33	O5	1·4	0·1	90	90
	DL35	O8	1·4	0·1	90	90
	DL71	wires	1·25	0·025	45	45
	DL72	wires	1·25	0·025	45	45
	DL92	BB8	1·4	0·1	90	67·5
	DL94	BB22	1·4	0·1	90	90
	KL35	O8	2·0	0·15	135	135
	PEN4VA	5B18/7B27	4·0	1·35	250	250
	PENA4	7B27	4·0	1·95	250	250
	PENB4	7B27	4·0	2·1	250	275
	PEN428	7B27	4·0	2·1	375	275
	PM24M	5B4	4·0	1·1	250	250
	EL31	O90	6·3	1·4	275	275
	EL3/33	8S23/O48	6·3	0·9	250	250
	EL37	O79	6·3	1·4	250	250
	EL38	O90	6·3	1·4	250	250
	EL41	B8A6	6·3	0·7	250	250
	EL42	B8A6	6·3	0·2	225	225
	EL91	BB15	6·3	0·2	250	250
	PEN36C/ CL33	7B27/O48	33·0	0·2	200	200
	CL4	8S22	33·0	0·2	200	200
	PL33	O79	19·0	0·3	200	200
	PL38	O90	30·0	0·3	200	200
	UL41	B8A6	45·0	0·1	165	165
TUNGSRAM	PP225	5B4	2·0	0·26	135	135
Also manufacture American types 1S4, 1S5, 2A5, 6F6, 6L6, 6M6, 6V6, 25A6, 25L6, 35L6, 50L6, 43 (q.v.).	APP4A	7B31/8S22	4·0	1·2	250	250
	APP4B	7B27/8S23	4·0	2·0	250	250
	EL33	O48	6·3	1·2	250	250
	EL36	O48	6·3	1·4	250	250
	PP35	7B27	35·0	0·2	200	200
	PP60	O48	6·3	1·27	500	400
	CL33	O48	35·0	0·2	200	200
	UL41	B8A6	45·0	0·1	165	165

AND TETRODES—*continued*

Slope (mA/V)	*Bias Volts*	*Bias Res. (Ohms)*	*Anode and Screen Current (mA)*	*Output (mW)*	*Optimum Load (Ohms)*	*Type*
—	-100	—	stabilized power pack			12E1
7·8	-7·0	160	42·9	1,900	2,200	PEN384
7·5	-6·3	180	34·8	2,600	5,800	10P13
7·4	-11·5	180	63·8	4,500	3,700	10P14
magnetic scanning valve					—	20P1
2·2	-4·5	—	10·5	270	8,000	DL33
1·55	-7·5	—	9·1	240	8,000	DL35
0·55	-1·25	—	0·75	6	100,000	DL71
0·5	-4·5	—	1·65	20	30,000	DL72
1·58	-7·0	—	8·8	270	8,000	DL92
2·15	-4·5	—	11·6	270	10,000	DL94
2·2	-4·5	—	5·6	340	19,000	KL35
2·8	-22·0	500	39·0	3,800	6,000	PEN4VA
9·5	-5·8	145	41·0	3,800	8,000	PENA4
8·5	-14·0	175	79·0	8,800	3,500	PENB4
8·0	-20·5	165	71·0	8,000	3,200	PEN428
3·0	-17·0	500	35·6	2,800	7,000	PM24M
14·0	-9·0	—	102·0	—	—	EL31
9·0	-6·0	—	—	4,500	7,000	EL3/33
11·0	-13·5	120	113·5	10,500	2,500	EL37
14·3	-7·0	—	113·0	magnetic	scanning	EL38
10·0	-7·0	—	41·2	4,200	7,000	EL41
3·2	-11·0	360	30·0	2,500	9,000	EL42
2·6	-13·5	680	18·4	1,400	16,000	EL91
8·0	-8·5	167	51·0	4,000	4,500	PEN36C/CL33
8·0	-8·5	167	51·0	4,000	4,500	CL4
8·6	-4·65	150	31·0	2,550	7,000	PL33
13·5	-5·5	—	84·0	magnetic	scanning	PL38
9·5	-9·5	140	63·5	4,200	3,000	UL41
2·0	-12·0	—	18·0	800	6,000	PP225
3·5	-16·5	400	42·0	3,500	7,000	APP4A
10·0	-5·0	140	40·0	3,600	7,000	APP4B
9·5	-6·0	150	40·5	3,600	7,000	EL33
15·0	-7·0	85	80·5	8,200	3,500	EL36
8·5	-6·5	170	50·0	3,200	4,400	PP35
6·8	-15·0	160	91·3	—	—	PP60
8·0	-7·5	170	50·0	3,200	4,300	CL33
9·5	-9·0	140	63·5	4,200	3,000	UL41

DOUBL

Make	Type	Circuit	Base	Filament Volts	Filament Amp.	Anode Volts
EVER READY	K33A	Class B	7B2	2·0	0·2	120
FERRANTI	HP2	Class B	7B2	2·0	0·4	120
	QPT2	QPP	7B6	2·0	0·4	150
MARCONI AND OSRAM	QP21	QPP	7B6	2·0	0·4	150
MAZDA ..	QP230	QPP	7B6	2·0	0·3	120
	QP25	QPP	OM9	2·0	0·2	150
MULLARD	PM2B	Class B	7B2	2·0	0·2	120
	QP22B	QPP	7B6	2·0	0·3	120
	KLL32	QPP	O14	2·0	0·3	135

H.T. RECTIFYING VALVES

Make	Type	Base	Filament Volts	Filament Amp.	Anode Volts Max. (r.m.s.)	Output (mA)
BRIMAR Also manufacture American types 0Z4, 5R4, 5Y3, 5Y4, 5Z3, 5Z4, 7Y4, 7Z4, 35Z3, 84, 5U4, 5V4, 6X5, 25Z4, 35Z4, 83 (q.v.).	R1	4B17	4·0	1·0	250+250	60
	R2	4B17	4·0	2·5	350+350	120
	R3	4B17	4·0	2·5	500+500	120
	R10	BB16	4·0	0·5	3,500	5
	R11	4B2	4·0	1·1	5,000	50
	1D5	5B10	40·0	0·2	250	100
	1D6	6UX16	25·0	0·3	250	100
COSSOR Also manufacture American types 5U4, 5Y3, 5Z4, 25Z4, 6X5, 7Y4, 35Z3 (q.v.).	431U	4B17	4·0	2·5	500+500	150
	451U	4B17	4·0	3·5	500+500	250
	SU2150A	4B16	2·0	1·5	5,000	10
	SU2150	4B16	2·0	1·15	8,000	2
	SU25	O85	2·0	0·5	7,000	1
	SU45	BB16	4·0	0·5	2,500	30
	52KU	O91	5·0	2·0	500+500	150
	53KU	O91	5·0	2·8	500+500	250
	54KU	O91	5·0	2·0	350+350	250
	40SUA	5B10	40·0	0·2	250	75
	225DU	7B1	2+2	·5+·5	750+750	25
	27SU	O92	26·5	0·45	250	250
	OM1	O35	30·0	0·20	250	120

Continued on opposite page

OUTPUT VALVES

Screen Volts	*Quiescent Current (mA)*	*Peak Current (mA)*	*Bias Volts*	*Output (mW)*	*Optimum Load (Ohms)*	*Type*
—	3·0	—	0	1,250	14,000	K33A
—	3·0	—	—	—	—	HP2
150	—	—	-9·0	1,200	25,000	QPT2
150	3·5	12·5	-9·0	1,000	25,000	QP21
120	5·8	20·0	-9·6	850	17,000	QP230
120	5·5	21·1	-9·75	1,200	15,000	QP25
—	3·0	20·0	0	1,250	14,000	PM2B
120	—	—	-10·3	1,000	16,000	QP22B
135	—	—	-11·3	1,200	16,000	KLL32

H.T. RECTIFYING VALVES—*continued*

Make	*Type*	*Base*	*Filament*		*Anode Volts Max. (r.m.s.)*	*Output (mA)*
			Volts	*Amp.*		
EVER READY	S11A	4B3	4·0	1·0	250+250	60
	S11D	4B3	4·0	2·0	350+350	120
	A11D	4B17	4·0	2·0	350+350	120
	A11C	4B17	4·0	2·4	500+500	120
	AZ1/31	8S1	4·0	1·1	300+300	100
	CY31	O35	20·0	0·2	250	75
	C10B	5B10	20·0	0·2	250	75
FERRANTI Also manufacture American types 0Z4, 5Y3, 5V4, 6X5, 80, 5U4, 5Z4, 7Y4, 7Z4, 35Z4, 35Y4, 35Z3 (q.v.).	R4	4B3	4·0	2·5	350+350	120
	R4A	4B3	4·0	2·5	500+500	120
	HR1	BB17	0·65	0·055	5,000	0·05
	HR2	BB16	4·0	0·5	5,500	5
	HR6	O93	4·0	1·25	5,000	60
	HR7	O93	4·0	1·25	7,000	40
	R42	4B17	4·0	2·50	350+350	125
	R52	—	5·0	2·50	350+350	125
MARCONI AND OSRAM	MU14	4B17	4·0	2·5	500+500	120
	U10	4B3	4·0	1·0	250+250	60
	U14	4B3	4·0	2·5	500+500	120

Continued on next page

H.T. RECTIFYING VALVES—*continued*

Make	*Type*	*Base*	*Filament*		*Anode Volts*	*Output*
			Volts	*Amp.*	*Max. (r.m.s.)*	*(mA)*
MARCONI AND OSRAM *continued*	U16	4B2	2·0	1·0	5,000	5
	U17	4B2	4·0	1·0	2,500	30
	U18	4B3	4·0	3·0	500+500	250
	U19/23	4B2	4·0	3·3	2,500	250
	U20	4B3	4·0	3·0	850+850	125
	U31	O35	26·0	0·3	250	120
	U33	4B2	2·0	1·0	6,300	3
	U50	O2	5·0	2·0	350+350	125
	U52	O2	5·0	3·0	500+500	250
	U76	—	30·0	0·16	250	100
	U81	B8B8	6·3	1·6	500+500	150
	U82	B8B7	6·3	0·6	325+325	75
	U84	B8B8	4·0	1·0	250+250	75
	U101	B8B9	50·0	0·1	250	100
	U143	O2	4·0	1·1	500+500	60
	U145	B8B7	40·0	0·1	250	90
	U149	B8B7	6·3	0·5	350+350	60
(*Mercury*)	GU50	4B2	4·0	3·0	1,850	250
MAZDA ..	UU5	4B17	4·0	2·3	500+500	120
	UU6	OM17	4·0	1·4	350+350	120
	UU7	OM17	4·0	2·3	350+350	180
	UU8	OM17	4·0	2·8	350+350	250
	UU9	B8A8	6·3	0·63	350+350	90
	U201	O35	20·0	0·2	250	90
	U404	B8A7	40·0	0·1	250	90
	U801	O84	80·0	0·2	250	350
	U4020	5B10	40·0	0·2	250	120
	U403	OM15	40·0	0·2	250	120
	U22	OM16	2·0	2·0	5,200	1
	U24	O82	2·0	0·15	7,800	0·5
(*Mercury*)	MU2	4B2	2·0	3·1	4,500	5
MULLARD	DW2	4B3	4·0	1·0	250+250	60
	DW4/350	4B3	4·0	2·0	350+350	120
	DW4/500	4B3	4·0	2·0	500+500	120
	IW4/350	4B17	4·0	2·0	350+350	120
	IW4/500	4B17	4·0	2·5	500+500	120
	FW4/500	4B3	4·0	3·0	500+500	250
	FW4-800	4B22	4·0	3·0	850+850	125
	CY31	O35	20·0	0·2	250	120
	UR1C	5B10	20·0	0·2	250	120
	CY32	O38	30·0	0·2	250+250	120
	HVR2	4B2	4·0	0·65	6,000	3

Continued on opposite page

H.T. RECTIFYING VALVES—*continued*

Make	*Type*	*Base*	*Filament*		*Anode Volts Max. (r.m.s.)*	*Output (mA)*
			Volts	*Amp.*		
MULLARD *continued*	HVR2A	4B2	2·0	1·5	6,000	3
	AZ1	SC1	4·0	1·1	500+500	60
	AZ31	O2	4·0	1·1	500+500	60
	GZ32	O91	5·0	2·0	350+350	250
	EZ35	O94	6·3	0·6	325+325	70
	EZ40	B8A8	6·3	0·6	350+350	90
	EZ41	B8A8	6·3	0·4	250+250	60
	EY51	wires	6·3	0·08	5,000	0·5
	EY91	BB18	6·3	0·42	250	75
	PY31	O95	17·0	0·3	250	125
	UR3C	7B15	30·0	0·2	250+250	120
	UY41	B8A7	31·0	0·1	250	90
	UY21	B8B9	50·0	0·1	250	140
	PZ30	O96	52·0	0·3	240	200
TUNGSRAM Also manufacture American types 5T4, 5X4, 5U4, 5Y3, 5Z3, 5Z4, 6X5, 25Y5/25Z5, 25Z6, 35Z4, 84/6Z4, 80, 80A, 81 (q.v.).	APV4	4B17	4·0	2·0	400+400	120
	RV120/500	4B22	4·0	2·0	500+500	120
	RV200/600	4B3	4·0	2·8	600+600	200
	PV25	7B15	25·0	0·3	250+250	120
	V30	5B10	30·0	0·2	275	120
	RG250/3000	4UX2	4·0	3·0	3,000	250
	AZ31	O2	4·0	1·1	300+300	100
	AZ32	O2	4·0	2·4	300+300	150
	RG250/1000	4B2	4·0	3·0	1,000	250
	EZ35	O94	6·3	0·6	325+325	70
	UY41	B8A7	31·0	0·1	220	90
	V20	5B10	20·0	0·2	250	120
	CY1	8S15	20·0	0·2	250	120
	CY31	O35	20·0	0·2	250	120

BARRETTERS

Make	*Type*	*Base*	*Current (amp.)*	*Voltage range*
BRIMAR	D15	O97	0·15	90—140
MARCONI AND OSRAM	161	ES cap	0·16	100—200
	301	ES cap	0·3	138—221
	302	ES cap	0·3	112—195
	303	ES cap	0·3	86—129
	304	ES cap	0·3	95—165
MULLARD	C1	8S33	0·2	80—200
	C1C	4B20	0·2	80—200

TUNING INDICATORS

Make	*Name*	*Base*	*Type*	*Operation Characteristics*
BRIMAR .. Manufacture American type 6U5 (q.v.).	—	—	—	—
COSSOR ..	63ME	O59	Cathode ray	Fil. 6·3 volts, 0·3 amp.; max. anode 250 volts
	64ME	O98	Cathode ray	Fil. 6·3 volts, 0·2 amp.; max. anode 250 volts
MARCONI AND OSRAM	Y61/62 Y63	O59	Cathode ray	Fil. 6·3 volts, 0·3 amp.; max. anode 250 volts
	Y65	O59	Cathode ray	Fil. 6·3 volts, 0·3 amp.; max. anode 250 volts
MAZDA ..	ME41	OM27	Cathode ray	Fil. 4·0 volts, 0·5 amp.; max. anode 250 volts

Continued on facing page

AMERICAN

Type	*Description*	*Base*	*Filament or Heater*		*Anode Volts (*= r.m.s.)*	*Screen Volts*	*Bias Volts*
			Volts	*Current (Amp.)*			
0Z4	Rectifier (gas) ..	O78	—	—	*300	—	—
1A3	Diode	BB9	1·4	0·15	117	—	—
1A5	A.F. Pentode ..	O8	1·4	0·05	90	90	–4·5
1A7	Pentagrid	O10	1·4	0·05	90	45	0–3
1C5	A.F. Pentode ..	O8	1·4	0·1	90	90	–7·5
1H5	Diode-triode ..	O4	1·4	0·05	90	—	0
1L4	R.F. Pentode ..	BB4	1·4	0·05	90	90	0
1LA4	A.F. Pentode ..	B8B17	1·4	0·05	90	90	–4·5
1LA6	Frequency-changer	B8B18	1·4	0·05	90	45	0–3·0
1LD5	Diode R.F. Pen. ..	B8B10	1·4	0·05	90	45	0
1LH4	Diode-triode ..	B8B16	1·4	0·05	90	—	0
1LN5	R.F. Pentode ..	B8B19	1·4	0·05	90	90	0
1N5	R.F. Pentode ..	O6	1·4	0·05	90	90	0–4·0
1N5V	R.F. Pentode ..	O6	1·4	0·05	90	90	0
1Q5	A.F. Pentode ..	O60	1·4	0·1	90	90	–4·5
1R5	Pentagrid	BB1	1·4	0·05	90	45	—
1S4	A.F. Pentode ..	BB2	1·4	0·1	90	67·5	–7·0
1S5	R.F. Pentode + diode	BB3	1·4	0·05	67·5	67·5	0
1T4	R.F. Pentode ..	BB4	1·4	0·05	90	67·5	0
2A3	Power Triode ..	4UX3	2·5	2·5	250	—	–45·0
2A5	A.F. Pentode ..	6UX10	2·5	1·75	250	250	–16·5
2A6	DD Triode ..	6UX6	2·5	0·8	250	—	–2·0
2A7	Pentagrid	7UX6	2·5	0·8	250	100	–3–40
2B7	DD R.F. Pentode	7UX5	2·5	0·8	250	125	–3·0
3A4	A.F. Pentode ..	BB19	1·4	0·20	150	90	–8·4
3D6	A.F. Pentode ..	B8B11	1·4	0·22	135	90	–4·5
3Q5	A.F. Pentode ..	O11	2·8	0·05	90	90	–4·5
3S4	A.F. Beam Tetrode	BB8	1·4	0·10	90	67·5	–7·0
5R4	Rectifier	O2	5·0	2·0	*750	—	—

TUNING INDICATORS—*continued*

Make	*Name*	*Base*	*Type*	*Operation Characteristics*
MAZDA *continued*	ME91	OM27	Cathode ray	Fil. 9·0 volts, 0·2 amp.; max. anode 175 watts
	6M1	O59	Cathode ray	Fil. 6·3 volts, 0·3 amp.; max. anode 250 volts
MULLARD	EM1	8S31	Cathode ray	Fil. 6·3 volts, 0·2 amp.; max. anode 250 volts
	EM4	8S32	Cathode ray	Fil. 6·3 volts, 0·2 amp.; max. anode 250 volts
	EM34	O98	Cathode ray	Fil. 6·3 volts, 0·2 amp.; max. anode 250 volts
TUNGSRAM Manufacture American type 6U5 (q.v.).	—	—	—	—

TYPES

Bias Res. (Ohms)	*Anode Current (mA)*	*Screen Current (mA)*	*Slope mA/V (*=Conv. Condt. μA/V)*	*Impedance (Ohms)*	*Ampl'n Factor*	*Output (Watts)*	*Optimum Load (Ohms)*	*Type*
—	—	—	—	—	—	75 mA	—	0Z4
—	0·5	—	—	—	—	—	—	1A3
—	4·0	1·1	0·85	300,000	255	0·117	25,000	1A5
—	1·2	0·6	*250	600,000	—	—	—	1A7
—	7·8	3·5	1·55	115,000	180	0·24	8,000	1C5
—	0·14	—	0·275	240,000	65	—	—	1H5
—	4·5	2·0	1·03	0·35 meg.	—	—	—	1L4
—	4·0	1·1	0·85	300,000	255	0·115	25,000	1LA4
—	1·2	0·6	*250	600,000	—	—	—	1LA6
—	0·6	0·1	0·6	0·95 meg.	—	—	—	1LD5
—	0·14	—	0·275	240,000	65	—	—	1LH4
—	1·6	0·35	0·8	1·1 meg.	880	—	—	1LN5
—	1·2	0·3	0·75	1·5 meg.	1160	—	—	1N5
—	1·6	—	0·65	1 meg.	—	—	—	1N5V
—	9·5	1·3	2·2	—	—	0·27	8,000	1Q5
—	0·8	1·9	*250	0·8 meg.	—	—	—	1R5
—	7·4	1·4	1·58	—	—	0·27	8,000	1S4
—	1·6	0·4	0·63	0·6 meg.	—	—	—	1S5
—	3·5	1·5	0·9	0·5 meg.	—	—	—	1T4
750	60·0	—	5·25	800	4·2	3·5	2,500	2A3
410	34·0	6·5	2·65	30,000	190	3·0	7,000	2A5
2,500	0·8	—	1·1	90,000	100	—	—	2A6
300	3·5	2·7	*550	360,000	—	—	—	2A7
—	10·0	2·3	1·2	600,000	—	—	—	2B7
—	13·3	2·2	1·9	0·1 meg.	—	0·7	8,000	3A4
—	9·8	1·2	2·4	150,000	—	0·5	12,000	3D6
—	9·5	2·1	2·15	—	—	0·27	10,000	3Q5
—	7·4	1·4	1·58	0·1 meg.	—	0·27	8,000	3S4
—	—	—	—	—	—	250 mA	—	5R4

Continued on next page

AMERICAN

Type	Description	Base	Filament or Heater		Anode Volts (*= r.m.s.)	Screen Volts	Bias Volts
			Volts	Current (Amp.)			
5T4	Rectifier	O2	5·0	3·0	*450	—	—
5U4	Rectifier	O2	5·0	3·0	*450	—	—
5V4	Rectifier	O36	5·0	2·0	*375	—	—
5X4	Rectifier	O1	5·0	3·0	*500	—	—
5Y3	Rectifier	O2	5·0	2·0	*350	—	—
5Y4	Rectifier	O1	5·0	2·0	*350	—	—
5Z3	Rectifier	4UX11	5·0	3·0	*450	—	—
5Z4	Rectifier	O36	5·0	2·0	*350	—	—
6A3	Power Triode	4UX3	6·3	1·0	250	—	–4·5
6A6	Double Triode	O42	6·3	0·8	250	—	–5·0
6AG6	A.F. Pentode	O49	6·3	1·2	250	250	–6·0
6A7	Frequency-changer	7UX6	6·3	0·3	250	100	–3–40
6A8	Frequency-changer	O54	6·3	0·3	250	100	–3–40
6AB7	R.F. Pentode	O99	6·3	0·45	300	200	–3·0
6AC7	R.F. Pentode	O99	6·3	0·45	300	150	–2·0
6AK5	R.F. Pentode	BB20	6·3	0·175	180	120	–2·0
6AL5	Double Diode	BB7	6·3	0·3	150	—	—
6AU6	R.F. Pentode	BB21	6·3	0·3	250	150	–1·0
6B4	Power Triode	O3	6·3	1·0	250	—	–45·0
6B5	Double Triode	6UX8	6·3	0·8	300	—	0
6B6	DD Triode	O41	6·3	0·3	250	—	–2·0
6B7	DD R.F. Pentode	7UX5	6·3	0·3	250	125	–3·0
6B8	DD R.F. Pentode	O53	6·3	0·3	250	125	–3·0
6BA6	VM R.F. Pentode	BB21	6·3	0·3	250	100	–1·0
6C4	R.F. Power Triode	BB12	6·3	0·15	250	—	–8·5
6C5	Triode	O34	6·3	0·3	250	—	–8·0
6C6	R.F. Pentode	6UX11	6·3	0·3	250	100	–3·0
6C7	DD Triode	—	6·3	0·3	250	—	–9·0
6D6	R.F. Pentode	6UX11	6·3	0·3	250	100	–3–40
6E8	Triode-hexode	O58	6·3	0·3	250	100	2·0
6F6	A.F. Pentode	O49	6·3	0·7	285	285	–22·0
6F7	Triode-pentode	7UX8	6·3	0·3	250	100	–3–35
6F8	Double Triode	O100	6·3	0·6	250	—	–8·0
6G5	Tuning Indicator	6UX12	6·3	0·3	250	—	0–22
6H6	Double Diode	O38	6·3	0·3	150	—	—
6J5	Triode	O34	6·3	0·3	250	—	–8·0
6J7	R.F. Pentode	O47	6·3	0·3	250	100	–3·0
6J8	Triode-hexode	O58	6·3	0·3	250	100	–3·0
6K6	A.F. Pentode	O48	6·3	0·4	315	250	–21·0
6K7	R.F. Pentode	O47	6·3	0·3	250	125	–3·0
6K8	Triode-hexode	O57	6·3	0·3	250	100	–3–30
6L6	A.F. Pentode	O60	6·3	0·9	300	200	–13·0
6L7	Frequency-changer	O55	6·3	0·3	250	150	–6·0
6M6	A.F. Pentode	O48	6·3	1·2	250	250	–6·0
6N6	Double Triode	O44	6·3	0·8	300	—	0

YPES—*continued*

Bias Res.)hms)	*Anode Current (mA)*	*Screen Current (mA)*	*Slope mA/V (*=Conv. Condt. µA/V)*	*Impedance (Ohms)*	*Ampl'n Factor*	*Output (Watts)*	*Optimum Load (Ohms)*	*Type*
—	—	—	—	—	—	225 mA	—	5T4
—	—	—	—	—	—	225 mA	—	5U4
—	—	—	—	—	—	175 mA	—	5V4
—	—	—	—	—	—	250 mA	—	5X4
—	—	—	—	—	—	125 mA	—	5Y3
—	—	—	—	—	—	125 mA	—	5Y4
—	—	—	—	—	—	225 mA	—	5Z3
—	—	—	—	—	—	125 mA	—	5Z4
—	60·0	—	5·25	800	4·2	3·2	2,500	6A3
—	3·0	—	1·55	22,600	35	—	—	6A6
150	32·0	6·0	10·0	60,000	600	3·75	9,000	6AG6
300	3·5	2·7	*550	360,000	—	—	—	6A7
300	3·5	2·2	*550	360,000	—	—	—	6A8
200	12·5	3·2	5·0	0·7 meg.	—	—	—	6AB7
160	10·0	2·5	9·0	1 meg.	—	—	—	6AC7
200	7·7	2·4	5·1	0·7 meg.	—	—	—	6AK5
—	9·0	—	—	—	—	—	—	6AL5
68	10·8	4·3	5·2	1 meg.	—	—	—	6AU6
—	60·0	—	5·25	750	4·2	3·2	2,500	6B4
—	43·0	—	2·4	24,000	54	4·0	7,000	6B5
—	0·9	—	1·1	90,000	100	—	—	6B6
250	10·0	2·3	1·33	600,000	800	—	—	6B7
250	10·0	2·3	1·33	600,000	800	—	—	6B8
68	11·0	4·2	4·4	1 meg.	—	—	—	6BA6
—	10·5	—	2·2	7,700	17	—	—	6C4
1,000	8·0	—	2·0	10,000	20	—	—	6C5
600	2·0	0·5	1·25	1 meg.	1,250	—	—	6C6
2,000	4·5	—	1·25	16,000	20	—	—	6C7
300	8·2	2·0	1·6	800,000	1,280	—	—	6D6
—	3·3	—	*650	—	—	—	—	6E8
440	38·0	12	2·55	78,000	200	4·5	7,000	6F6
—	2·8	0·6	*300	2 meg.	—	—	—	6F7
—	9·0	—	2·6	7,700	—	—	—	6F8
—	—	—	—	—	—	—	—	6G5
—	8·0	—	—	—	—	—	—	6H6
900	9·0	—	2·6	7,700	20	—	—	6J5
1,300	2·0	0·5	1·25	1·5 meg.	1,250	—	—	6J7
—	1·3	1·9	*290	4 meg.	—	—	—	6J8
570	28·0	9·0	2·1	75,000	—	4·5	9,000	6K6
200	10·5	2·6	1·65	600,000	1,000	—	—	6K7
300	2·5	6·0	*350	0·6 meg.	—	—	—	6K8
220	54·5	4·6	5·2	33,000	170	6·5	4,500	6L6
260	3·3	9·2	*350	1 meg.	—	—	—	6L7
150	36·0	4·0	9·5	—	—	4·4	7,000	6M6
—	43·0	8·0	2·4	24,000	54	4·0	7,000	6N6

Continued on next page

AMERICA

Type	Description	Base	Filament or Heater		Anode Volts (*= r.m.s.)	Screen Volts	Bias Volts
			Volts	Current (Amp.)			
6N7	Double Triode ..	O42	6·3	0·8	300	—	0
6Q6	Diode-triode ..	O65	6·3	0·15	250	—	–3·0
6Q7	DD Triode ..	O41	6·3	0·3	250	—	–3·0
6R7	DD Triode ..	O41	6·3	0·3	250	—	–9·0
6SA7	Heptode	O101	6·3	0·3	250	100	–2·0
6SG7	R.F. Pentode ..	O102	6·3	0·3	250	150	–2·5
6SH7	R.F. Pentode ..	O102	6·3	0·3	250	150	–1·5
6SJ7	R.F. Pentode ..	O99	6·3	0·3	250	100	–3·0
6SK7	VM R.F. Pentode	O99	6·3	0·3	250	100	–3·0
6SL7	Double Triode ..	O103	6·3	0·3	250	—	–2·0
6SN7	Double Triode ..	O103	6·3	0·6	250	—	–8·0
6SQ7	DD Triode ..	O104	6·3	0·3	250	—	–2·0
6SS7	VM R.F. Pentode	O99	6·3	0·15	250	100	–3·0
6T8	Triple D Triode ..	B9A1	6·3	0·45	250	—	–3·0
6U5	Tuning Indicator ..	6UX12	6·3	0·3	250	—	0–22
6U7	R.F. Pentode ..	O47	6·3	0·3	250	100	–3–40
6V6	A.F. Pentode ..	O60	6·3	0·45	315	225	–13·0
6X5	Rectifier	O37	6·3	0·6	*325	—	—
6Y6	A.F. Beam Tetrode	—	6·3	1·25	200	135	–14·0
6Z4	Rectifier	—	6·3	0·5	*350	—	—
6ZY5	Rectifier	O37	6·3	0·3	*325	—	—
7A7	R.F. Pentode ..	B8B2	6·3	0·3	250	100	–3–35
7A8	Frequency-changer	B8B1	6·3	0·15	250	100	–3–35
7B5	A.F. Pentode ..	B8B2	6·3	0·4	315	250	–21·0
7B6	DD Triode ..	B8B3	6·3	0·3	250	—	–2·0
7B7	R.F. Pentode ..	B8B2	6·3	0·15	250	100	–3·0
7B8	Frequency-changer	B8B14	6·3	0·3	250	100	–3·0
7C5	A.F. Pentode ..	B8B6	6·3	0·45	315	225	–13·0
7C6	DD Triode ..	B8B3	6·3	0·15	250	—	–1·0
7C7	R.F. Pentode ..	B8B1	6·3	0·15	250	100	–3·0
7H7	VM R.F. Pentode ..	B8B2	6·3	0·3	250	150	–2·5
7K7	DD Triode ..	B8B12	6·3	0·3	250	—	–2·0
7N7	Double Triode ..	B8B13	6·3	0·6	250	—	–8·0
7Q7	Heptode	B8B14	6·3	0·3	250	100	–2·0
7R7	DD R.F. Pentode ..	B8B15	6·3	0·3	250	100	–1·0
7S7	Triode-hexode ..	B8B1	6·3	0·3	250	100	–2·0
7Y4	Rectifier	B8B7	6·3	0·5	*350	—	—
7Z4	Rectifier	B8B7	6·3	0·9	*325	—	—
12A6	Beam Power Output	O48	12·6	0·15	250	250	–12·5
12AH7	Double Triode ..	—	12·6	0·15	180	—	–6·5
12AT7	Double Triode ..	B9A2	6·3	0·3	250	—	–2·0
12AU6	R.F. Pentode ..	BB21	12·6	0·15	250	150	–1·0
12BA6	R.F. Pentode ..	BB21	12·6	0·15	250	100	–1·0
12C8	DD R.F. Pentode	O53	12·6	0·15	250	125	–3·0
12J5	Triode	O34	12·6	0·15	250	—	–8·0

TYPES—*continued*

Bias Res. (Ohms)	*Anode Current (mA)*	*Screen Current (mA)*	*Slope mA/V (*=Conv. Condt. µA/V)*	*Impedance (Ohms)*	*Ampl'n Factor*	*Output (Watts)*	*Optimum Load (Ohms)*	*Type*
—	70·0	—	—	—	35	10·0	8,000	6N7
—	1·2	—	1·05	—	—	—	—	6Q6
3,000	1·0	—	1·2	58,000	70	—	—	6Q7
1,000	9·5	—	1·9	8,500	16	—	—	6R7
—	3·5	8·5	0·45	1 meg.	—	—	—	6SA7
200	9·2	3·4	4·0	1 meg.	—	—	—	6SG7
100	10·8	4·1	4·9	0·9 meg.	—	—	—	6SH7
750	3·0	0·8	1·65	1 meg.	—	—	—	6SJ7
250	9·2	2·6	2·0	0·8 meg.	—	—	—	6SK7
—	2·3	—	1·6	44,000	70	—	—	6SL7
—	9·0	—	2·6	7,700	20	—	—	6SN7
—	0·9	—	1·1	91,000	100	—	—	6SQ7
300	9·0	2·0	1·85	1 meg.	—	—	—	6SS7
—	1·0	—	1·2	58,000	70	—	—	6T8
—	—	—	—	—	—	—	—	6U5
300	8·2	2·0	1·6	800,000	1,280	—	—	6U7
315	35·0	6·0	3·75	77,000	218	5·5	8,500	6V6
—	—	—	—	—	—	70 mA	—	6X5
186	66·0	9·0	7·1	18,300	—	6·0	2,600	6Y6
—	—	—	—	—	—	60 mA	—	6Z4
—	—	—	—	—	—	40 mA	—	6ZY5
300	8·6	2·0	2·0	800,000	1,600	—	—	7A7
300	3·0	3·2	*550	700,000	—	—	—	7A8
570	28·0	9·0	2·1	75,000	150	4·5	9,000	7B5
2,000	1·0	—	1·1	91,000	100	—	—	7B6
300	8·5	2·0	1·7	700,000	1,200	—	—	7B7
300	3·5	2·7	*550	360,000	—	—	—	7B8
315	35·0	6·0	3·75	77,000	218	5·5	8,500	7C5
—	1·3	—	1·0	100,000	100	—	—	7C6
1,200	2·0	0·5	1·3	2 meg.	2,600	—	—	7C7
200	9·5	3·5	3·8	0·8 meg.	—	—	—	7H7
—	2·3	—	1·6	44,000	70	—	—	7K7
—	9·0	—	2·6	7,700	20	—	—	7N7
—	3·5	8·5	*550	1 meg.	—	—	—	7Q7
150	6·2	1·6	3·4	1 meg.	—	—	—	7R7
—	1·8	3·0	*525	1·25 meg.	—	—	—	7S7
—	—	—	—	—	—	70 mA	—	7Y4
—	—	—	—	—	—	100 mA	—	7Z4
375	30·0	3·5	3·0	70,000	210	2·8	7,500	12A6
—	7·6	—	1·9	8,400	16	—	—	12AH7
—	10·0	—	5·5	10,000	55	—	—	12AT7
70	10·8	4·3	5·2	1 meg.	—	—	—	12AU6
70	11·0	4·2	4·4	1 meg.	—	—	—	12BA6
—	10·0	2·3	1·325	600,000	—	—	—	12C8
900	9·0	—	2·6	7,700	—	—	—	12J5

Continued on next page

AMERICAN

Type	*Description*	*Base*	*Filament or Heater*		*Anode Volts (*= r.m.s.)*	*Screen Volts*	*Bias Volts*
			Volts	*Current (Amp.)*			
12J7	R.F. Pentode ..	O47	12·6	0·15	250	100	–3·0
12K7	R.F. Pentode ..	O47	12·6	0·15	250	125	–3·0
12K8	Triode-hexode ..	O57	12·6	0·15	250	100	–3·0
12Q7	DD Triode ..	O41	12·6	0·15	250	—	–3·0
12SA7	Pentagrid	O66	12·6	0·15	250	100	–2·0
12SC7	Double Triode ..	O67	12·6	0·15	250	—	–2·0
12SG7	R.F. Pentode ..	O69	12·6	0·15	250	150	–2·5
12SH7	R.F. Pentode ..	O102	12·6	0·15	250	150	–1·5
12SJ7	R.F. Pentode ..	O70	12·6	0·15	250	100	–3·0
12SK7	R.F. Pentode ..	O70	12·6	0·15	250	100	–3·0
12SN7	Double Triode ..	O103	12·6	0·3	250	—	–8·0
12SQ7	DD Triode ..	O71	12·6	0·15	250	—	–2·0
12SR7	DD Triode ..	O71	12·6	0·15	250	—	–9·0
14A7/ 12B7	R.F. Pentode ..	B8B2	12·6	0·15	250	100	–3·0
14B6	DD Triode ..	B8B3	12·6	0·15	250	—	–2·0
14H7	VM R.F. Pentode ..	B8B2	12·6	0·15	250	150	–2·5
14R7	DD R.F. Pentode ..	B8B15	12·6	0·15	250	100	–1·0
14S7	Triode-hexode ..	B8B1	12·6	0·15	250	100	–2·0
19T8	Triple D Triode ..	B9A1	19·0	0·15	250	—	–3·0
25A6	A.F. Pentode ..	O49	25·0	0·3	160	120	–18·0
25L6	A.F. Pentode ..	O48	25·0	0·3	200	110	–8·0
25Y5/ 25Z5	Rectifier	6UX5	25·0	0·3	*235	—	—
25Z4	Rectifier	O35	25·0	0·3	*250	—	—
25Z6	Rectifier	O37	25·0	0·3	*235	—	—
35A5	Beam Power Output	B8B6	35·0	0·15	200	110	–8·0
35L6	Beam Power Output	O48	35·0	0·15	200	110	–8·0
35Y4	Rectifier	—	35·0	0·15	*235	—	—
35Z3	Rectifier	B8B9	35·0	0·15	*250	—	—
35Z4	Rectifier	O35	35·0	0·15	*235	—	—
41	A.F. Pentode ..	6UX10	6·3	0·4	315	250	–21·0
42	A.F. Pentode ..	6UX10	6·3	0·7	285	285	–22·0
43	A.F. Pentode ..	6UX10	25·0	0·3	160	120	–18·0
50A5	A.F. Beam Tetrode	B8B6	50·0	0·15	200	110	–8·0
50L6	Beam Power Output	O48	50·0	0·15	200	110	–8·0
75	DD Triode ..	6UX6	6·3	0·3	250	—	–2·0
76	Triode	5UX6	6·3	0·3	250	—	–13·5
77	R.F. Pentode ..	6UX11	6·3	0·3	250	100	–3·0
78	R.F. Pentode ..	6UX11	6·3	0·3	250	125	–3–40
80	Rectifier	4UX11	5·0	2·0	*350	—	—
83	Rectifier (mercury)	4UX7	5·0	3·0	*450	—	—
84	Rectifier	5UX5	6·3	0·5	*350	—	—

TYPES—*continued*

Bias Res. (Ohms)	*Anode Current (mA)*	*Screen Current (mA)*	*Slope mA/V (*=Conv. Condt. µA/V)*	*Impedance (Ohms)*	*Ampl'n Factor*	*Output (Watts)*	*Optimum Load (Ohms)*	*Type*
1,200	2·0	0·5	1·225	1 meg.	—	—	—	12J7
—	10·5	2·6	1·65	600,000	—	—	—	12K7
—	2·5	6·0	*350	600,000	—	—	—	12K8
—	1·0	—	1·2	58,000	—	—	—	12Q7
—	3·5	8·5	*450	1 meg.	—	—	—	12SA7
—	2·0	—	1·325	53,000	—	—	—	12SC7
—	9·2	3·4	4·0	1 meg.	—	—	—	12SG7
300	10·8	4·1	4·9	0·9 meg.	—	—	—	12SH7
—	3·0	0·8	1·65	1·0 meg.	—	—	—	12SJ7
—	9·2	2·6	2·0	0·8 meg.	—	—	—	12SK7
—	9·0	—	2·6	7,700	20	—	—	12SN7
—	0·9	—	1·1	91,000	—	—	—	12SQ7
—	9·5	—	1·9	8,500	—	—	—	12SR7
—	9·2	2·6	2·0	800,000	—	—	—	14A7/ 12B7
—	0·9	—	1·1	91,000	100	—	—	14B6
200	9·5	3·5	4·2	0·8 meg.	—	—	—	14H7
130	5·7	1·7	3·2	1 meg.	—	—	—	14R7
—	1·8	3·0	*525	1·25 meg.	—	—	—	14S7
—	1·0	—	1·2	58,000	70	—	—	19T8
440	36·0	12·0	2·4	42,000	100	2·2	5,000	25A6
160	55·0	7·0	9·5	30,000	300	4·3	3,000	25L6
—	—	—	—	—	—	75 mA	—	25Y5/ 25Z5
—	—	—	—	—	—	100 mA	—	25Z4
—	—	—	—	—	—	75 mA	—	25Z6
157	44·0	7·0	5·9	40,000	236	3·3	4,500	35A5
185	44·0	7·0	5·9	40,000	236	3·3	4,500	35L6
—	—	—	—	—	—	100 mA	—	35Y4
—	—	—	—	—	—	100 mA	—	35Z3
—	—	—	—	—	—	100 mA	—	35Z4
570	28·0	9·0	2·1	75,000	150	4·5	9,000	41
440	38·0	12·0	2·55	78,000	190	4·5	7,000	42
450	36·0	12·0	2·4	42,000	100	2·2	5,000	43
140	50·0	4·5	8·5	35,000	—	3·0	3,000	50A5
160	55·0	7·0	9·5	30,000	300	4·3	3,000	50L6
2,000	0·9	—	1·1	90,000	100	—	—	75
2,500	5·0	—	1·45	9,500	13·8	—	—	76
1,000	2·3	0·5	1·25	1·0 meg.	1,250	—	—	77
200	10·5	2·6	1·65	600,000	1,000	—	—	78
—	—	—	—	—	—	125 mA	—	80
—	—	—	—	—	—	225 mA	—	83
—	—	—	—	—	—	60 mA	—	84

BRITISH FOUR-PIN

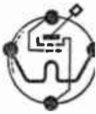
4B


4B1


4B2


4B3


4B4


4B5


4B6


4B7


4B8


4B9


4B10


4B11


4B15


4B16


4B17


4B18


4B19


4B20

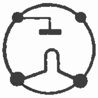

4B21


4B22

BLANKS HAVE BEEN LEFT AT THE END OF SOME GROUPS SO THAT THE READER MAY INSERT DETAILS OF FUTURE TYPES

AMERICAN UX FOUR-PIN

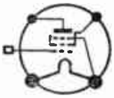
4UX

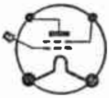

4UX1


4UX2


4UX3


4UX4


4UX5


4UX6


4UX7


4UX8

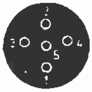

4UX9


4UX10


4UX11

BRITISH FIVE-PIN

5B




5B1


5B2


5B3


5B4


5B5


5B6


5B10


5B11


5B12


5B13


5B14

BRITISH FIVE-PIN (contd.)


5B15


5B16


5B17


5B18


5B19


5B20


5B21


5B22

5UX

AMERICAN UX FIVE-PIN


5UX1

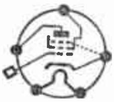

5UX2


5UX4

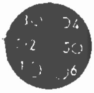

5UX5


5UX6

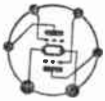

5UX7


5UX8

6UX



AMERICAN UX SIX-PIN


6UX1


6UX2

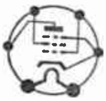

6UX3

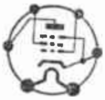

6UX5


6UX6

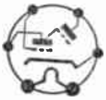

6UX7

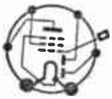

6UX8


6UX9


6UX10


6UX11


6UX12


6UX13


6UX14


6UX15

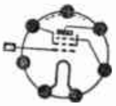

6UX16

7B

BRITISH SEVEN-PIN


7B1

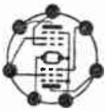

7B2

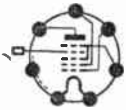

7B3

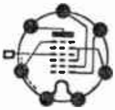

7B4

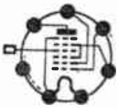

7B5

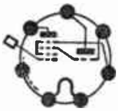
BRITISH SEVEN-PIN (contd.)


7B6

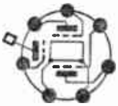

7B7


7B8


7B9


7B10

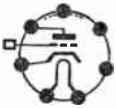

7B11


7B12

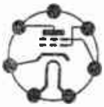

7B15

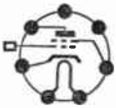

7B16

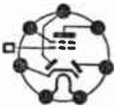

7B17

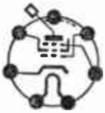

7B18

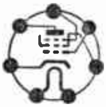

7B19

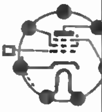

7B20

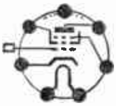

7B21


7B22


7B23

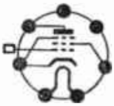

7B24

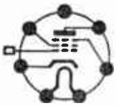

7B25


7B26

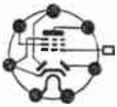

7B27

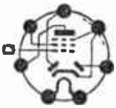

7B28


7B29

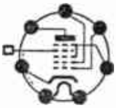

7B30

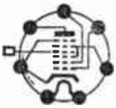

7B31

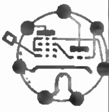

7B32

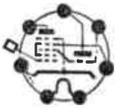

7B33

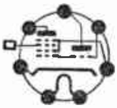

7B34


7B35

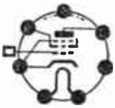

7B36


7B37


7B38


7B39


7B40

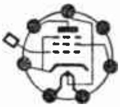

7B41


7B42


7B43


7B44

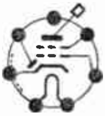

7B45


7B46


7B47


7B48

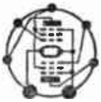

7B49


7B50


7B51

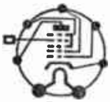
AMERICAN UX SEVEN-PIN

7UX


7UX1

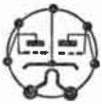

7UX4


7UX5

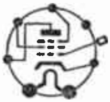

7UX6


7UX7


7UX8

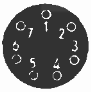

7UX9


7UX10


7UX11

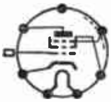
CONTINENTAL SEVEN-PIN

7C




7C1

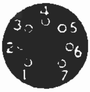

7C2

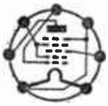

7C3


7C4

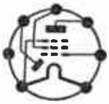
MINIATURE BUTTON OR B7G

BB

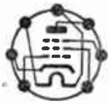



BB1


BB2


BB3

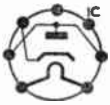

BB4


BB5


BB6


BB7

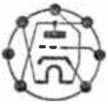

BB8



BB9


BB10


BB11


BB12


BB13


BB14


BB15

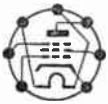

BB16


BB17


BB18


BB19


BB20


BB21


BB22

IC: SEE NOTE
AT FOOT OF
PAGE 704

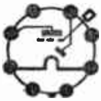
INTERNATIONAL OCTAL

O


O1

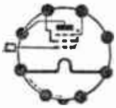

O2

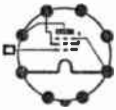

O3

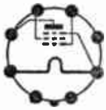

O4

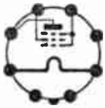

O5

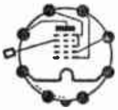
INTERNATIONAL OCTAL (contd.)


O6

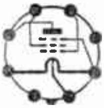

O7

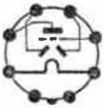

O8

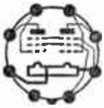

O9

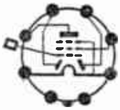

O10


O11

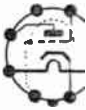

O12


O13


O14


O15


O16

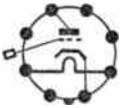

O34


O35


O36


O37

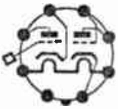

O38


O39


O40

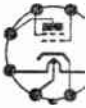

O41

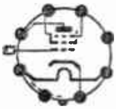

O42

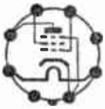

O43


O44

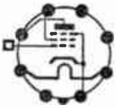

O45

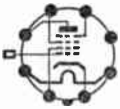

O46

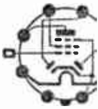

O47

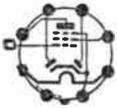

O48

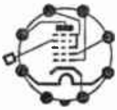

O49

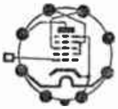

O50

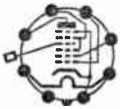

O51

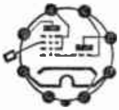

O52

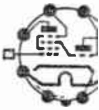

O53


O54

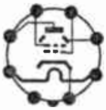

O55


O56

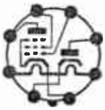

O57


O58

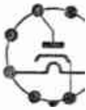

O59

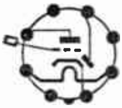

O60

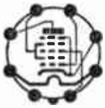

O61


O62


O63

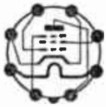

O64

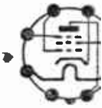

O65


O66


O67

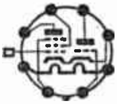

O68

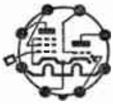

O69


O70

INTERNATIONAL OCTAL (contd.)


O71


O72


O73

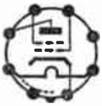

O74

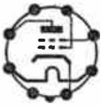

O75

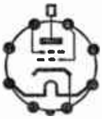

O76

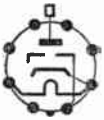

O77

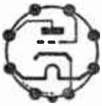

O78


O79

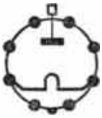

O80

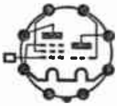

O81

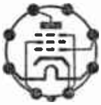

O82

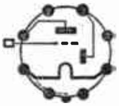

O83

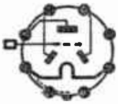

O84

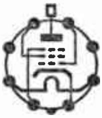

O85


O86


O87


O88


O89


O90


O91

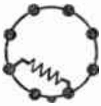

O92

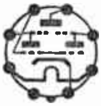

O93

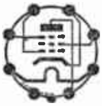

O94

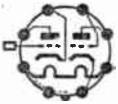

O95


O96


O97

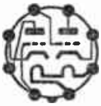

O98

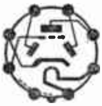

O99


O100


O101

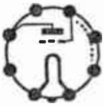

O102

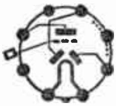

O103

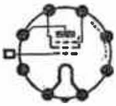

O104

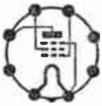
MAZDA OCTAL

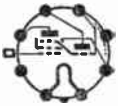
OM

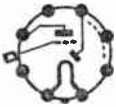

OM1

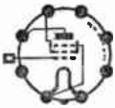

OM2

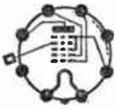

OM3


OM4


OM5


OM6


OM7

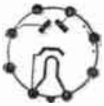

OM 8


OM9


OM15


OM16

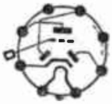
MAZDA OCTAL (contd.)

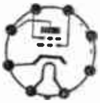

OM17


OM18

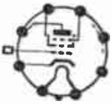

OM19

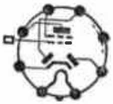

OM20

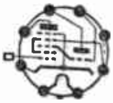

OM21

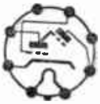

OM22

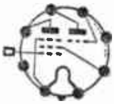

OM23


OM24


OM25


OM26


OM27


OM28

OF

FOOTLESS


OF1


OF2


OF3

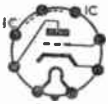

OF4

B8A

MINIATURE BASE EIGHT-PIN


B8A1

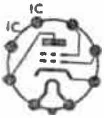

B8A2



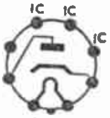
B8A3


B8A4

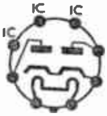

B8A5



B8A6

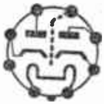


B8A7



B8A8


B8A9


B8A10


B8A11


B8A12

IC: SEE NOTE AT FOOT OF PAGE 704

B8B

B8B OR LOCTAL


B8B1


B8B2


B8B3


B8B4

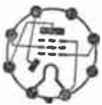

B8B5

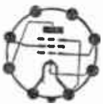

B8B6


B8B7


B8B8


B8B9

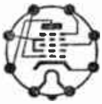

B8B10


B8B11

B8B OR LOCTAL (contd.)

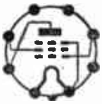

B8B12

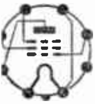

B8B13


B8B14


B8B15


B8B16


B8B17


B8B18

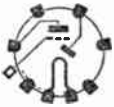

B8B19

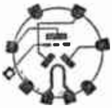
SIDE CONTACT

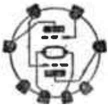
BS


8S1

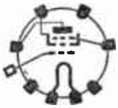

8S2


8S3

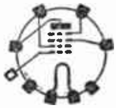

8S4

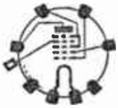

8S5


8S6


8S7


8S8


8S9


8S10

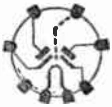

8S11


8S12

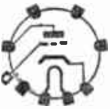

8S15


8S16


8S17

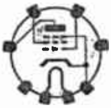

8S18


8S19

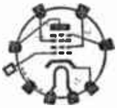

8S20


8S21

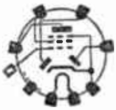

8S22

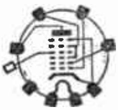

8S23


8S24


8S25


8S26


8S27

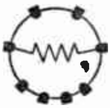

8S28

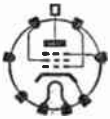

8S29


8S30


8S31

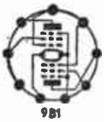

8S32


8S33


8S34

BRITISH NINE-PIN

9B

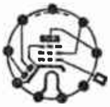


9B1

9B2

9B3

9B5

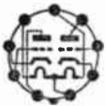


9B6

MINIATURE BASE NINE-PIN

B9A

B9A1



B9A2

B9A3

NINE-PIN (THIN PINS)

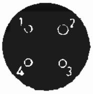
B9G

B9G1

B9G2

BRITISH SPECIALS

4D

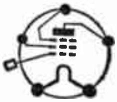


4D1

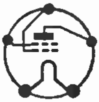
4D2

4D3

5D



5D1

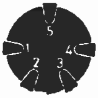


5D2

4DS

4DS1

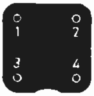
5S

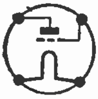


5S1

5S2

4L

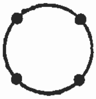


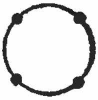


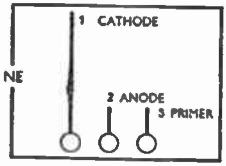
4L1

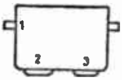
4M

4M1

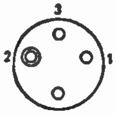




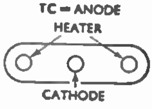




NE1



NE2



B3G

INTERNAL CONNEXIONS (IC)—IMPORTANT NOTE

In many miniature-valve bases, such as B7G and B8A, the pins which would otherwise be spare have been used for making internal connexions or, in some cases, for additional electrode supports. Details of such connexions are not shown in the diagrams because they vary in the products of different manufacturers. Valve-holder connexions corresponding to pins marked IC must never be used as wiring supports.

VALVE DETECTOR. Detector using a valve as the non-linear element. See ANODE RECTIFICATION, DIODE DETECTOR, GRID DETECTION.

VALVE DRIVE. See RESONANT-CIRCUIT DRIVE.

VALVE HISS. See FLICKER EFFECT, SHOT EFFECT.

VALVE HOLDER. Mounting for a valve or vacuum tube by means of which it is supported and connected in circuit. The holder incorporates a number of insulated contacts, permanently wired into the circuit, which engage with corresponding contacts on the valve or tube base or envelope. Small valves are adequately supported by the engagement of the contacts, but large types require auxiliary supports.

This method of connexion facilitates removal of the valve or tube for testing or replacement. See VALVE BASE, VALVE SOCKET.

VALVE LIFE. Length of time that a valve continues to function efficiently. The limit set to the life of a valve is usually determined by the length of time that the cathode continues to emit electrons in sufficient quantity. The ordinary indirectly heated cathode valve, such as is commonly used in radio receivers, may be counted upon for a 5,000-hour life, and it is common for this figure to be greatly exceeded. The proposal to include valve repeaters in a transatlantic cable shows that it is quite possible to build valves having a much longer life than 5,000 hours. A water-cooled valve, as typically used in senders, averages about 1,000 hours. Obviously, the greater the demands upon the cathode, the greater the heater power for a given electrode current. See CATHODE, EMISSION.

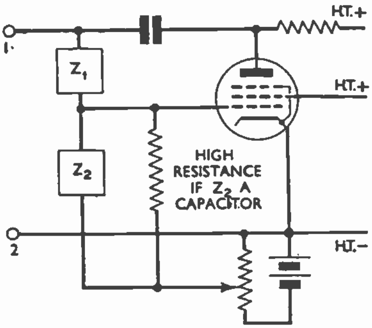


Fig. 3. Basic connexions of a valve-reactor circuit. Z_1 and Z_2 are impedances; the input terminals may be regarded as having between them a reactance in parallel with a resistance.

VALVE NOISE. See FLICKER EFFECT, MICROPHONY, SHOT EFFECT.

VALVE NOMENCLATURE. Description of valve types by the number of electrodes they possess:

Diode. Valve with 2 electrodes.
Triode. Valve with 3 electrodes.
Tetrode. Valve with 4 electrodes.
Pentode. Valve with 5 electrodes.
Hexode. Valve with 6 electrodes.
Heptode. Valve with 7 electrodes.
Octode. Valve with 8 electrodes.
See DIODE, TRIODE, ETC.

VALVE OSCILLATOR. See OSCILLATOR.

VALVE REACTOR. Valve with an associated circuit of inductance and resistance, or capacitance and resistance, the terminals of which have the nature of a reactance in parallel with a resistance. The values of the reactance and resistance are different as the mutual conductance of the valve is varied. A variable-mu valve is commonly used to enable the reactance of the circuit terminals to be varied by the variation of a direct voltage applied to the grid. Fig. 3 shows a valve-reactor circuit. The input terminals have the nature of a reactance in parallel with a resistance.

When the valve is biased to cut-off and has zero mutual conductance, the equivalent reactance and resistance are infinite. The equivalent reactance and resistance are reduced as the grid potential is made less negative. The circuit is used in a FREQUENCY MODULATOR (q.v.). The frequency of a beat-frequency oscillator may be varied by changing the potential of the grid in a valve reactor, this being connected in parallel with one of the radio-frequency oscillators. See BEAT-FREQUENCY OSCILLATOR, OSCILLATOR.

VALVE-REACTOR FREQUENCY MODULATOR. Circuit, containing a valve reactor, used to produce frequency-modulated waves. See FREQUENCY MODULATION, VALVE REACTOR.

VALVE-REACTOR PHASE MODULATOR. Circuit, containing a valve reactor, used to produce phase-modulated waves. See PHASE MODULATION, VALVE REACTOR.

VALVE RECTIFIER. Valve used as a rectifier. The term may be confusing if used without qualification; thus the mercury-vapour (hot-cathode) valve is probably one form and the vacuum valve a distinctly different form of valve rectifier. See MERCURY-VAPOUR (HOT-CATHODE) RECTIFIER, VACUUM-VALVE RECTIFIER.

VALVE SHIELD. Electrostatic shield made of metal sheet, formed to fit over the bulb of a valve (Fig. 4). This prevents external electrostatic fields from affecting the electric fields within the valve and prevents the fields within the valve from inducing voltages in external circuits. Tubular valves may be shielded by cylinders, valves with curved bulbs are screened by two separate metal pieces shaped to go over them and held in place by spring clips. See METALLIZED VALVE, METAL VALVE, SCREENING.

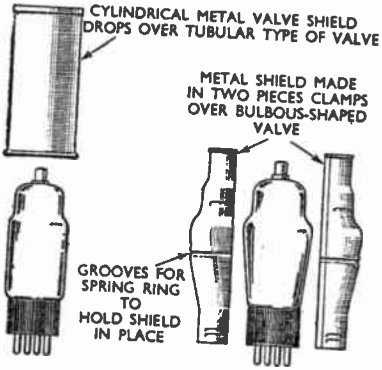


Fig. 4. Two examples of a metal shield used to surround the bulb of a valve.

VALVE SOCKET. Particular kind of valve holder in which the contacts are tubular in form so that they may receive and engage with pin-type contacts on the valve base. See VALVE BASE, VALVE HOLDER.

VALVE STABILIZER. Voltage stabilizer for a mains unit using multi-electrode valves. The term distinguishes a valve-stabilizer system from a glow-tube stabilizer. See VOLTAGE-STABILIZED MAINS UNIT.

VALVE VOLTMETER. Standard instrument for the accurate measurement of voltages at audio and radio frequencies. It is essentially a valve, operating as a detector, in which the magnitude of the rectified direct current is used as an indication of the applied alternating voltage. If carefully designed, it may be calibrated at 50 c/s and used up to very high frequencies (for example, 50 Mc/s) without any corrections.

The power taken by a valve voltmeter from the source under measurement is usually very small and can be made nearly zero; in other words, the input impedance of the instrument is very high, and accurate measurements can be made across very high-impedance sources.

Almost any form of detector circuit can be used in a valve voltmeter, and the various types may be grouped according to the value of the wave form of the applied voltage to which the readings are directly proportional, namely r.m.s., mean or peak values.

R.M.S.-READING VOLTMETER. If the relationship between mean rectified current and input voltage of the detector is a square law, the response of the valve voltmeter is directly proportional to the r.m.s. value of the applied voltage. Such a voltmeter may be used to measure r.m.s. values irrespective of wave form. If the signal applied to the instrument is sinusoidal, the peak and mean values may be obtained by multiplying the readings by 1·414 and 0·9 respectively.

An anode-bend detector has a square-law characteristic for small input voltages, provided that anode current flows during the whole of the cycle of the input signal, and such a detector may be used as an r.m.s.-reading valve voltmeter. These instruments have an extremely high input impedance, but the square-law relationship holds only for a limited range (about 1 volt) of input signal amplitude.

MEAN-READING VOLTMETER. If the relationship between mean rectified current and input voltage of the detector is linear, the response of the valve voltmeter is directly proportional to the mean value of the positive peaks of the applied voltage and is hence dependent on the wave form of the signal. For sinusoidal voltages, the voltmeter may be calibrated to read r.m.s. values directly by multiplying the readings by 1·11.

The rectifier may take the form of a diode with a resistive load which is not shunted by a capacitor, or of an anode-bend detector biased precisely so as to cut off the anode current. In the latter type of detector, the non-linearity of the characteristic near cut-off causes inaccuracies in the calibration for small signals, and the accuracy improves with increase in the amplitude of the signal to be measured.

PEAK-READING VOLTMETER. A voltmeter of this type has a reading directly proportional to the peak value of the applied voltage and, provided the readings are taken as peak values, its indications are independent of the wave form. For sinusoidal inputs the instrument may be calibrated in r.m.s. values by multiplying the readings by 0·707. A diode detector with the usual diode load and shunt capacitor can be used as a peak voltmeter. The slide-back valve voltmeter is another example of this type.

DIODE PEAK VOLTMETER. In its simplest form, a diode peak voltmeter has the circuit given in Fig. 5. It is a simple diode detector in which a resistor and a micro-ammeter behave as a voltmeter indicating the p.d. across the capacitor. Provided the resistance and the signal are large, the micro-ammeter indicates the value of the positive peak of the signal; but the instrument may be used with accuracy for small signals provided it is suitably calibrated.

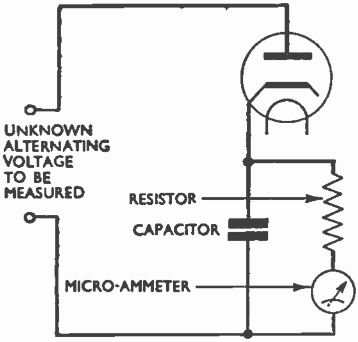


Fig. 5. Simplest form of the diode peak type of valve voltmeter, in which the combination of resistor and micro-ammeter provides an indication of the p.d. across the capacitor.

If the connexions to the diode are reversed, the micro-ammeter registers the negative peaks of the applied signal. With very small signals, the reading of the micro-ammeter may be too small to be read accurately: the p.d. across resistor and capacitor may then be connected to the input of a D.C. amplifier, the output of which is registered by a suitable meter.

In valve voltmeters in which the output indication is a change in the anode current of a valve, if the latter has a comparatively large value in the absence of a signal, the accuracy of the instrument is poor unless some means is adopted of balancing-out the steady current so that the meter registers only the change in anode current.

One circuit for achieving this result

is given in Fig. 6. The meter is connected so that it carries the anode current of the valve and an additional direct current from the filament battery, the magnitude of the latter being adjustable by means of the potential divider. In practice, the potential divider is adjusted with the input terminals short-circuited until the micro-ammeter reads zero.

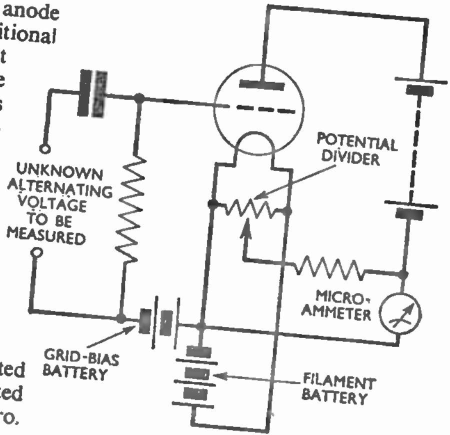


Fig. 6. Valve voltmeter in which the steady anode current of the valve is balanced out, the meter indicating only the change in anode current.

The indications of a valve voltmeter are modified at high frequencies by the effects of stray capacitance in the wiring and valves, by series resonance of the inductance of the input lead with the input capacitance, and by transit-time effects. By using acorn types of valve (see MINIATURE VALVE) and careful design, the error in the readings from all these causes can be reduced to 10 per cent at 100 Mc/s.

VARIABLE-AREA RECORDING. In film recording (see ELECTRICAL RECORDING), a system in which the recorded sound track has constant density, the sound-wave variations giving rise to variations in the area of the track.

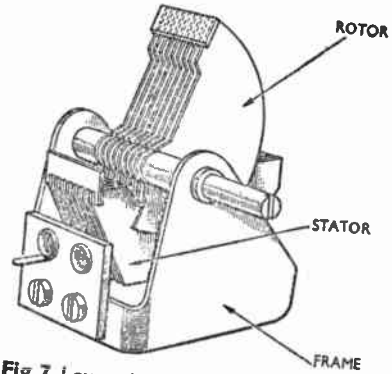


Fig. 7. Low-voltage type of straight-line-wavelength variable capacitor, which has specially shaped vanes.

VARIABLE CAPACITOR. Capacitor, the capacitance of which may be varied, usually continuously, either by changing the overlapping area of the electrodes, or by changing the distance between them. In conjunction with a fixed inductor, it is most commonly used for capacitance tuning, that is, for adjusting the resonant frequency of a circuit. The relative movement of the electrode system requires that the dielectric should be fluid (or partly fluid), and, with few exceptions, air is used.

In a common form of low-voltage capacitor the electrodes are specially shaped metal vanes (Fig. 7). One set of equally spaced vanes is fixed to the framework by means of insulators; the other is mounted on a rotatable spindle. In one type of component the capacitance is proportional to the angle of rotation of the spindle, so that, on a dial marked with capacitance, the scale divisions are spaced at equal intervals. If capacitance is plotted against angle of rotation, the graph is a straight line (Fig. 8). For this reason it is termed a straight-line capacitor (abbreviated to SLC).

There are two other types widely

used for tuning inductors in resonant circuits. In one of them, termed "square-law" or straight-line wavelength (abbreviated to SLW), the vanes are so shaped that the wavelength at resonance is proportional to the angle of rotation. In the other type, called straight-line frequency (SLF), the vanes of the capacitor are so shaped that the resonant frequency is proportional to the angle of rotation.

In these latter types, graphs of resonant wavelength and frequency, respectively, when plotted against angle of rotation, would be straight lines; and wavelength and frequency marked on a dial would have uniformly spaced divisions. The capacitance, in contrast, when plotted against angle of movement, would have curved graphs.

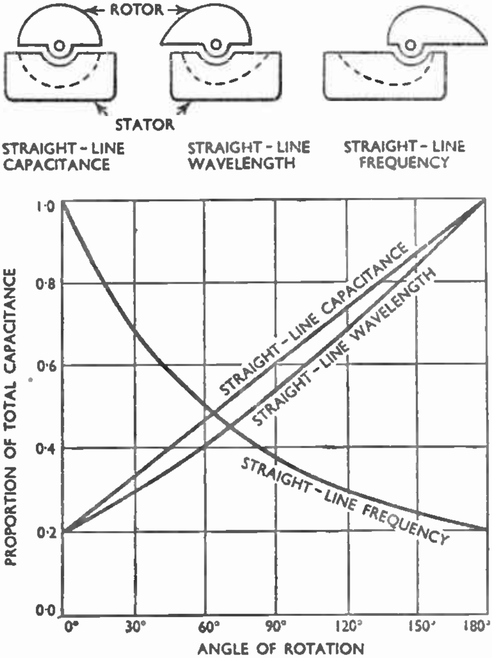


Fig. 8. Vane shapes and capacitance variations as a function of the angle of rotation for straight-line-capacitance, straight-line-wavelength and straight-line-frequency variable capacitors designed for a circuit in which the total residual capacitance from all causes is 20 per cent of the total capacitance.

The ideal vane shapes and capacitance-angle characteristics of the three types are shown in Fig. 8. Other forms, however, are sometimes used for special purposes, such as in beat-frequency oscillators.

A straight-line frequency tuning device is particularly desirable in a broadcast receiver because the broadcast-channel allocations are spaced at equal intervals of frequency, and the station markings on the tuning dial can then be uniformly spaced. In practice, the residual capacitance of the circuit —which includes the wiring capacitance, the self-capacitance of the inductor and the capacitance of the variable capacitor at minimum setting —limits the range of variation (ratio of maximum to minimum capacitance) to about 9 : 1. This corresponds to a wavelength or frequency variation in the ratio of 3 : 1.

In theory a special profile would be required for each application, but in broadcast receivers a compromise design is commonly used without causing undue end-cramping of the wavelength or frequency scales.

Although air as a dielectric is virtually loss-free, the two sets of vanes must be positioned with respect to one another by means of solid insulators which introduce losses, especially at high frequencies and at low settings of capacitance. To ensure good discrimination in a resonant circuit, the Q-factor of the components must be high and, therefore, the power-factor of the capacitor must be low.

To achieve this end, the material of the insulators is carefully selected. A low-loss ceramic is used for general purposes, and quartz for laboratory capacitors. The losses are further minimized by positioning the insulators so that the part of the residual capacitance due to them is as small as possible.

The resistance of the vanes and also the dust upon their surfaces both contribute to the losses, particularly at high frequencies. The Q-factor of a good-quality variable air capacitor at two frequencies is shown in Fig. 9.

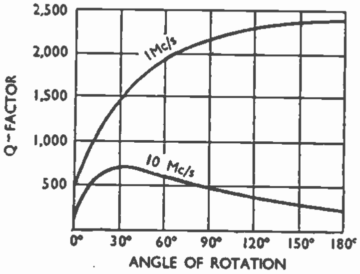


Fig. 9. Graphs showing the variation, at two different frequencies, of Q-factor with setting of a good-quality variable capacitor with air dielectric.

The moving vanes are usually connected to the capacitor framework and both are joined to earth or to the low-potential side of the circuit in which the capacitor is used. In this way, the framework partially screens the fixed vanes from other components and what little stray capacitance may exist is of fixed amount. On the other hand, the variable stray capacitance between the moving vanes and the framework or the chassis is short-circuited.

The arrangement also has the advantage that it is unnecessary to insulate the spindle either from the moving vanes or from the chassis on which the capacitor may be mounted and at the same time "hand effects" are largely eliminated.

Two or three variable capacitors are often ganged together, i.e., driven by a common spindle. They are usually of similar design and carefully matched for capacitance, small pre-set trimmers being associated with them for this purpose.

Solid dielectrics were sometimes used in the early days of radio, but their use is now limited to trimmers.

High-voltage types are, in principle, similar to those already described for use with low voltages but, because of the higher potential differences applied to them, greater care is exercised in the detail of their design. For example, the edges of the vanes are rounded and all sharp corners and other features avoided which might cause local increases of potential gradient sufficient to start corona discharges. The vanes are often silver-plated to reduce resistance losses, and the whole structure is much larger.

Pressure and oil-filled types similar to those described under FIXED CAPACITOR are sometimes employed. See CAPACITOR, TRIMMER, VERNIER CAPACITOR.

VARIABLE CONDENSER. Synonym for VARIABLE CAPACITOR.

VARIABLE-DENSITY RECORDING. In film recording, a system in which the sound track has a constant area, the sound-wave variations giving rise to variations in the light intensity to which the film is exposed on recording. See ELECTRICAL RECORDING.

VARIABLE-IMPEDANCE MODULATION. In linear modulation, modulation in which the modulating wave varies the impedance of an impedor connected in series with the carrier wave. In non-linear modulation, the term describes modulation in which an impedor offers an impedance which varies with the amplitude of a wave, and so rectifies the wave produced by adding carrier and modulating waves. The term is used for magnetic modulation in its two forms. See LINEAR MODULATION, MAGNETIC MODULATION, NON-LINEAR MODULATION.

VARIABLE INDUCTOR. Inductor provided with means for readily varying the magnitude of its inductance either continuously or in successive steps. Variable inductors may be used as tuning elements in the resonant circuits of radio senders and receivers (the system is called inductive tuning), but variable capacitors are more commonly employed for this purpose, particularly in radio receivers. Variable inductors are also used for laboratory measurement, such as in A.F. bridge circuits.

A type used in radio senders consists of a helical air-spaced coil of copper tube. Inside the helix is a movable contact arm which may be rotated along a screwed spindle. The screw thread has the same pitch as the coil conductor so that contact can be made with the coil at any point. Another method of continuous variation makes use of two coils, or two systems of coils, one of which is fixed and the other movable. When the coils are connected in series the total inductance L is provided by the formula $L = L_1 + L_2 \pm 2M$, where L_1 and L_2 are the self-inductances of the two coil systems, and M is the mutual inductance between them.

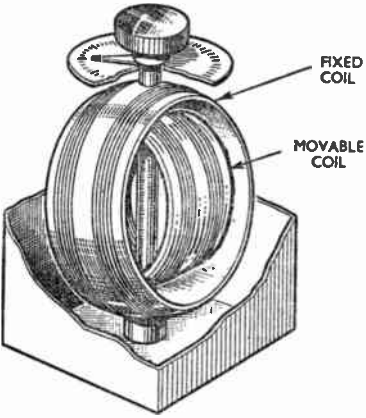


Fig. 10. Variable inductor comprising two coils in series; the inner coil is rotatable about the axis.

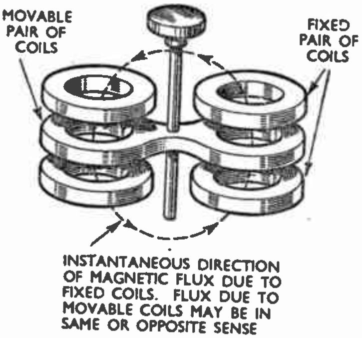


Fig. 11. Principle of the Brooks precision variable inductor for A.F. measurements; in practice the coils of each pair are usually shaped like two D's back-to-back to provide a more uniform inductance scale.

By relative movement of the coil systems the mutual inductance may be varied, not only in magnitude but also in sense. If L_1 and L_2 are equal and the coupling between them is so good that the value of M approaches the ideal value $\sqrt{L_1 L_2}$, an inductance range of over 10 : 1 may be attained. A simple type (Fig. 10) much used in early radio receivers, and often referred to as a "variometer," consists of two concentric coils of wire, the inner being so mounted that it can be rotated inside the other about a common diameter. The formers are sometimes shaped as sections of concentric spheres so that the coupling may be increased by reducing the clearance between the coils.

More elaborate designs are used for measurement purposes at A.F. The Brooks inductometer (Fig. 11) has three pairs of co-planar coils fixed side by side. The three pairs are stacked in sandwich form one on the other but spaced slightly apart. The outer pairs are fixed and the inner pair can be rotated about an axis perpendicular to the plane of the coils and midway between them. The inner pair has twice as many turns of wire as each of the outer pairs, and all coils are connected in series astatically to reduce interference from extraneous magnetic fields. The control spindle is associated with a calibrated dial marked with inductance.

In another form of laboratory instrument, a coil has nine tappings arranged in equal inductance steps. The tappings and the two ends of the coil are connected to an eleven-way switch to form a decade unit. The leads to the tappings include resistors of such value that the total resistance remains unchanged as the switch is moved. The range can be extended by mounting in the same box a second unit having ten times the inductance of the first. The two coils are assembled with their axes at right-angles so that there is no mutual coupling. Alternatively, the coils may be of toroid form which makes the system astatic.

Iron-cored variable inductors are also employed, particularly for inductive tuning at R.F., these being designed so that the inductance may be varied by the movement of a rod-shaped iron-dust core in and out of the coil along its axis. This is sometimes referred to as "permeability tuning." A similar arrangement having a very limited range of variation is used, in superheterodyne receivers in particular, for trimming or tracking. See FIXED INDUCTOR, INDUCTOR.

VARIABLE MUTUAL-CONDUCTANCE VALVE. Name sometimes given to a VARIABLE-MU VALVE.

VARIABLE-MU VALVE. Valve so constructed that its amplification factor is determined by its grid bias, and can thus be varied. The grid bias may be given different values to produce different amplification factors. The more the negative bias, the less the amplification factor. The control grid of a variable-mu valve is a helix, the pitch of which varies along its length (Fig. 12). With a strong negative bias, the electrons pass through the portions of the grid with widely spaced turns; they cannot flow through the finer mesh parts of the grid. Thus the valve with a large negative grid bias is equivalent to one with a widely spaced grid mesh, and hence one in which changes in grid potential make relatively little change in anode current; when the grid-cathode potential is small, the flow of electrons can be controlled by a fine mesh grid and the mutual conductance of the valve is large. CONVERSION CONDUCTANCE (q.v.) as well as mutual conductance can be varied by variation of the bias of an electrode. See GRID-VOLTS/ANODE-CURRENT CHARACTERISTIC, MUTUAL CONDUCTANCE.

Fig. 12. The control grid of a variable-mu valve is a helix, the pitch of which changes along its length.

VARIABLE-RESISTANCE MODULATION. Linear amplitude modulation in which the modulating wave varies a resistance which is connected in series with the carrier wave. The carbon microphone is an example of a variable-resistance modulator if it is arranged to vary the amplitude of a carrier wave. See MICROPHONE MODULATOR.

VARIABLE RESISTOR. Resistor provided with means for readily varying the magnitude of its resistance either continuously or in discrete steps. It may be used for varying the current I flowing from a source of constant potential E, or for maintaining a uniform value of current from a varying source of potential according to the formula $I = E/R$. The latter application was the origin of the term rheostat (literally, a device for maintaining a constant current), which, particularly in power engineering, is still somewhat loosely used as a general synonym for variable resistor.

When provided with terminals for access to both its electrical extremities as well as an adjustable tapping point for subdividing the resistance, a variable resistor may be used as a variable potential divider. This is its most common application in telecommunication equipment, particularly when connected in circuit as a gain or volume control.

A design for large power dissipation consists of a ceramic former, either circular or rectangular in section, on which is wound a single layer of close turns of resistance wire (Fig. 13a). The wire is oxidized or enamelled to insulate adjacent turns and the insulation is removed from the track of a sliding contact. Such designs have a maximum resistance of only a few thousand ohms. They are capable of dissipating 20 watts or more according to size, but their use is limited to power frequencies or to D.C. because of their self-inductance.

A more compact design (Fig. 13b) is much used in electronic circuits, mainly as a potential divider. Enamelled resistance wire is wound on to a long flexible strip of insulating material, which is then bent and fixed in the form of a ring. The enamel is removed from the wire on one edge of the strip where a rotatable radial arm makes contact. Variable resistors of this kind can be wound to have a resistance of from 5 to 100,000 ohms and are made to dissipate from $\frac{1}{2}$ to 10 watts. The residual reactance tends to be inductive for low values of resistance and capacitive for high values. This reactance has a negligible effect at audio frequencies and, usually, it is not very serious at carrier frequencies.

Variation of resistance with angle of rotation can be made to follow non-linear laws by tapering the former so that the length of the turn varies, or by using a different gauge of wire in different parts of the winding. Such an arrangement is desirable when the variable resistor is used as a potential divider for purposes of gain control, because decibel level is proportional to the logarithm of the voltage and hence of the resistance between the movable contact and the common end of the potential divider. Practical difficulties limit the use of this technique, which is more commonly applied to composition designs.

In laboratory measurement work a form of variable resistor called a resistance box is used. It contains one or more decade units, each consisting of ten wire-wound resistors and an eleven-way switch. For use at frequencies up to about 100 kc/s all the resistors in one decade unit are of equal value and the switch connects from 0 to 10 of them in series. The values of resistance in each unit are chosen to be powers of ten: 0·1, 1, 10, 100, etc. For example, a

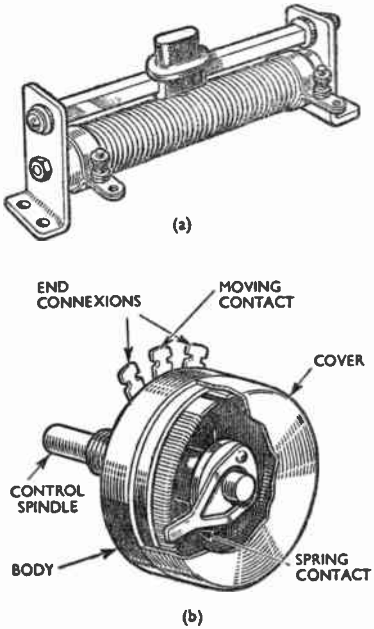


Fig. 13. Two forms of wire-wound variable resistor: (*a*) for high-power and (*b*) for low-power dissipation.

resistance box might have three decade units for adjusting the resistance in steps of 1, 10, and 100 ohms respectively so that, by manipulation of the switches, the resistance in circuit can be adjusted in steps of 1 ohm from 0 to 1,110 ohms.

Values of less than 0·1 ohm are usually varied continuously; a movable contact slides along a single turn of resistance wire or strip mounted on the edge of a disc of insulating material. At radio frequencies another form of decade unit is used, in which the ten fixed resistors have values of resistance arranged in decade steps. The resistors are mounted on a drum which can be rotated past fixed contacts so that one resistor at a time is connected in circuit. In this way the residual reactance associated with long leads and a variable number of resistors is reduced.

Composition-type variable resistors have an element cut from a thin sheet of absorbent material impregnated with a high-resistance compound, or of insulating material coated with a thin conducting film. The element is shaped in the form of a ring which has a radial cut or other discontinuity; terminals are connected on either side of this cut. In order to prevent abrasion, the movable contact is usually in the form of a roller or a very thin flexible metallic disc which is deflected into contact with the active surface by means of a roller. The element can be readily shaped so that resistance and rotation may be connected by a non-linear law of the kind described previously.

The design is suitable for low-power dissipation only (¼ to ¾ W), but the maximum resistance can be made as high as 2·5 megohms. Variable resistors of the composition type are commonly used as gain controls in radio receivers. They are cheaper than wire-wound types but tend to wear more quickly and are often a serious source of circuit noise.

An early type of variable resistor capable of handling large currents consisted of a stack of carbon plates; the resistance between the ends of the stack was adjusted by varying the mechanical pressure upon it. The design is still used in certain kinds of stabilizer for power-supply systems, the pressure being varied automatically by an electromagnet. See FIXED RESISTOR.

VARIABLE-SPEED SCANNING. Method of scanning in which the picture at the receiver is built up by varying the length of time for which the scanning spot affects each successive part of the cathode-ray-tube screen. In the usual systems of scanning, the light and shade of the received picture is obtained by modulating the electron-beam density, making the spot brighter or less bright in accordance with the amplitude modulation applied to the control electrode of the tube.

In the case of variable-speed scanning, however, the modulation is applied to the deflector system, and the speed of the line scan of the spot is varied, the spot moving more slowly for brighter portions of the picture and more rapidly for the darker portions. Since the brightness of the spot on the screen depends not only on the beam current, but on the duration of the bombardment of the screen at that spot, the beam current can be made constant and the duration of the bombardment varied to give light and shade.

VARIAC. Trade term for a transformer which has a transformation ratio that may be varied by manual operation.

VARIO COUPLER. Device consisting of two coils with provision for varying the mutual inductance between them; it is used where control of the degree of coupling between two circuits is necessary. See COUPLING, MUTUAL INDUCTANCE, VARIOMETER.

VARIOMETER. Inductor, the inductance value of which may be varied by variation of the mutual inductance between two coils, one fixed and the other movable about the axis of the fixed coil (Fig. 14). The coefficient of coupling between the two coils varies as the position of the movable coil relative to the fixed is varied. The total inductance of the combination is made up of the sum of the values of the inductance of the coils by themselves, plus twice the mutual inductance of the coils.

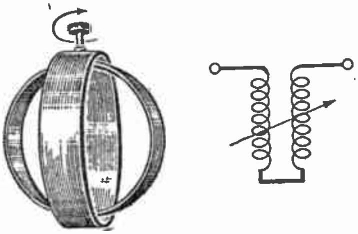


Fig. 14. Simple variometer and its diagrammatic symbol. One coil is fixed; the other can be rotated so that the coupling coefficient may be varied between positive and negative maxima.

The mutual inductance is maximum when the relative sense of the windings is such as to make a positive mutual inductance; it is minimum when the movable coil is rotated through 180 deg. to reverse the relative senses of the windings, and so make the mutual inductance a negative value. Thus the total inductance of the variometer is $L_1 + L_2 \pm 2K\sqrt{L_1 L_2}$, where K is the coupling coefficient. The Q-factor of a variometer is small when the total inductance value is small, because the resistance remains the same and the inductance is reduced. See COUPLING COEFFICIENT, INDUCTANCE, MUTUAL INDUCTANCE, VARIABLE INDUCTOR.

VECTOR. Straight line representing an alternating voltage or current, its length corresponding, on a chosen scale, with the amplitude of the voltage or current, and its direction corresponding to the phase of the voltage or current.

Many problems in radio engineering can be solved graphically or by trigonometry, using vectors to represent the voltages and currents involved. A vector quantity is one with magnitude and direction.

VECTOR POTENTIAL. Vector quantity used in the theory of electromagnetic fields.

VELOCITY MICROPHONE. Microphone in which both sides of the diaphragm are exposed to the sound-waves, the movement of the diaphragm being proportional to the difference in pressure between the two faces. See MICROPHONE.

VELOCITY-MODULATED ELECTRON STREAM. Electron stream in which the electrons are alternately accelerated and retarded so as to group them into bunches. This occurs in the rhumbatron of a klystron (q.v.). See also BUNCHER.

VELOCITY-MODULATION VALVE. See KLYSTRON.

VERNIER CAPACITOR. Term loosely used to describe a form of variable capacitor in which special provision is made to facilitate fine adjustment. In early types, a small part of the total capacitance (for example, one vane) was adjustable under separate control. Now it is more usual to effect control through a reduction gear or its equivalent, and to describe it as a "slow-motion drive."

Strictly, the term *vernier* capacitor should be limited to a form of precision variable capacitor in which the movement of the control is read on a vernier scale.

VERNIER CONDENSER. Synonym for VERNIER CAPACITOR.

VERTICAL AERIAL. Aerial in which the major radiating, or receiving, portion is arranged vertically. The term is more particularly applied to such aerials as the half-wave dipole, with which it is possible to obtain vertical or horizontal polarization by appropriate positioning of the aerial; when it is set vertically, the half-wave dipole radiates or receives vertically polarized waves.

VERTICAL EFFECT. Synonym for ANTENNA EFFECT.

VERTICALLY POLARIZED WAVE. Radio-wave in which the plane of polarization of the electric field is vertical. See POLARIZATION.

VERTICAL POLARIZATION. See PLANE OF POLARIZATION, POLARIZATION, VERTICALLY POLARIZED WAVE.

VERTICAL SCANNING. Method of scanning usually employed in mechanical systems, such as the disc method (see DISC SCANNING), in which the line scan of a scene being televised is carried out from top to bottom or bottom to top, instead of across the picture horizontally.

VERY HIGH-FREQUENCY WAVE. Radio-wave between the frequency limits of 30 Mc/s and 300 Mc/s, that is, within a wavelength range of 1–10 metres. Up to a frequency of about 30 Mc/s, the ionization intensity of the F-layer is sufficient to reflect the rays back to earth, but above this frequency the bending becomes insufficient to reflect the rays, so that they travel straight through the layer and are lost in outer space. The exact frequency at which this occurs depends upon the density of the layer at any particular time; although it is not usually safe to use wavelengths below 13 metres for long-distance work, the B.B.C. television sound transmissions on 7·23 metres have been received in the U.S.A. and in South Africa. Such freak reception is due to reflection from densely ionized patches in the F-layer at periods of maximum sunspot activity. Apart from such erratic reception it is generally accepted that waves of less than 10 metres wavelength can only be received with reliability within optical range of the sender.

The optical range, which is the distance from the sender to the horizon, may be calculated from the formula: *distance in miles = 1·22 times height of sender in feet.*

The field strength within the optical range is almost exactly inversely proportional to the square of the distance; hence, if the distance is doubled, the field strength is reduced to one quarter. In practice, there is considerable attenuation due to buildings, towns, trees and irregular terrain, and the actual signal strength is less than the theoretical amount. If the sender and receiver are located at levels higher than the surrounding country, the theoretical value of field strength can be closely approached.

The signal does not disappear suddenly beyond the horizon, but is still evident at rapidly decreasing strength, due to diffraction at the earth's surface. Because the earth has resistance, it must absorb a certain amount of power from the wave, giving rise to a dragging effect on the lower edge of the wave front and tending to keep part of the wave close to earth beyond the normal optical range. Although the signal strength falls off very rapidly, signals can still be detected at distances of up to three times the optical range. It has been shown that at wavelengths of about 10 metres the post-horizon attenuation is roughly proportional to the cube of the distance, while at wavelengths of about 1 metre the attenuation is proportional to the 8th power of the distance.

Very high-frequency (abbreviated V.H.F.) waves received in the post-horizon region show a tendency to fade. There are two causes of such fading, both due to weather conditions: first, changes in the rate with which the refractive index of the earth's atmosphere varies with height; and second, refraction in the atmosphere due to temperature inversion. Normally, the temperature of the air falls approximately 1 deg. C. for every 300 ft. rise above the earth's surface, and this fall continues more or less uniformly throughout the lower atmosphere.

Under certain atmospheric conditions, however, this procedure is reversed and in some localities the temperature rises with increasing height. This rise is limited and is ultimately succeeded by a rapid fall to restore equilibrium. If any area where temperature inversion is present be located between the sender and receiver, atmospheric refraction of the ray occurs, and both direct and indirect rays are present at the receiver. giving rise to fading.

Within the optical range, very high-frequency waves have distinct advantages over those of lower frequencies. High power is not necessary and fading does not occur. Interference from stations beyond the optical range is limited; which means that stations separated by some hundreds of miles can operate on the same frequencies. A further advantage is that, because of the high carrier frequency employed, high-modulation frequencies can be used without sideband interference. This is particularly advantageous for high-quality transmission of sound and television. See ABSORPTION, DIFFRACTION, FADING, GROUND RAY.

VERY LOW-FREQUENCY WAVE. Radio-wave of a frequency below 30 kc/s, that is, above 10,000 metres wavelength. In the days before the advent of short waves for long-distance communication, it was found that the ground wave of short-wave senders was rapidly absorbed by houses, hills, and similar obstructions, and longer and longer wavelengths were used without regard for the enormous power required to give adequate field strength. At one time Bordeaux was using a wavelength of 23,000 metres, and even today the British G.P.O. use 18,000 metres for their long-distance communication station at Rugby.

V.F. Abbreviation for VOICE FREQUENCY.

V.H.F. Abbreviation for very high frequency.

VIBRATOR. Mechanical device which incorporates a reed driven as in an electric bell and which, in effect, generates alternating current by regularly interrupting or reversing a direct current.

Some vibrators are fitted with contacts to rectify the generated A.C.; in this way it is possible to obtain high-tension D.C. from a low-tension D.C. supply. Vibrators of this type are used to generate the high-tension supply for the valve anodes in car radio receivers, the low-tension supply being obtained from the car battery.

VIDEO-FREQUENCY. Synonym for VISION FREQUENCY.

VIDEO-FREQUENCY AMPLIFIER. Synonym for VISION-FREQUENCY AMPLIFIER.

VIDEO SIGNAL. Synonym for VISION SIGNAL.

VIRTUAL CATHODE. Stationary concentration of electrons formed around or between electrodes other than the cathode. This concentration forms a supply of electrons for electrodes near it and is as satisfactory as a normal cathode. Normally, the electrons are emitted by the hot cathode before they form into a virtual cathode. In Fig. 15 it is assumed that between anode and screen grid there is a potential gradient which changes sign. Electrons entering this space have inertia and so shoot onwards, but the retarding field slows them down. Some overshoot the minimum potential point and go on to the anode;

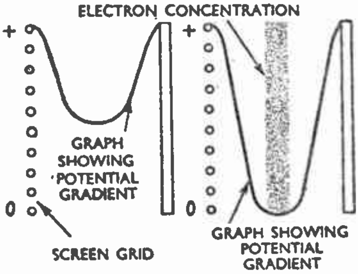


Fig. 15. On the left is shown the potential gradient between the screen grid and anode of a valve; this is assumed to be the condition before electrons enter the inter-electrode space. On the right there is a concentration of electrons in the space, and the potential gradient shows a zero minimum. The concentration is a virtual cathode.

some go to the screen before reaching the minimum potential point. There is a tendency, therefore, for the movement of electrons to stop at and around the point of inflection of the curve of potential gradient, and a surplus of almost stationary electrons forms around this point. The existence of the concentration lowers still further the potential minimum, which may be of nearly zero potential. This in turn further enhances the slowing-down effect.

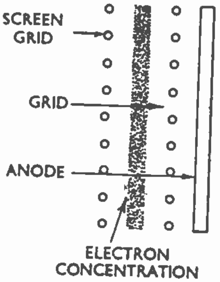


Fig. 16. If a grid be placed between virtual cathode and anode, the virtual cathode, grid and anode act as a triode.

The anode is positive with respect to the electron concentration, and can draw electrons from it just as though it were a hot cathode emitting electrons in the normal way. The concentration is always being replenished by electrons shooting into one side of it through the screen; electrons are drawn away on the other side by the anode. The concentration is called a virtual cathode.

If a grid electrode (Fig. 16) is placed in the space between virtual cathode and anode a triode is formed. The action of the frequency-changer valve is often dependent upon the formation of a virtual cathode. The transitron works by the same principle. The screen of a kinkless tetrode is shielded from secondary electrons by a virtual cathode between anode and screen. See BEAM-POWER VALVE, ELECTRON VELOCITY, RETARDING FIELD, SPAC CHARGE, TRANSITRON.

VIRTUAL HEIGHT. Synonym for EFFECTIVE HEIGHT.

VISEOGENIC. Television counterpart of the term photogenic, meaning of such shape and colouring as to favour the making of a good photograph or, in television, of a good television image.

In television, the term is usually applied to a person or to definite objects and not to general scenes. For an object to be viseogenic, the contrast between white and black should not be too great. Large patches of white and large patches of dark should be avoided, since this makes it difficult to tilt the picture (see TILT AND BEND). In the case of human faces, it is preferable that the face be rounded rather than angular so that gradual moulding may be achieved, by well-placed lighting, instead of the heavy shadows caused by steep features.

VISION FREQUENCY. Modulation frequency of a television sender, representing the picture detail. Vision frequency is the equivalent of audio frequency in sound transmission, but the actual range of frequencies is considerably wider, ranging from a theoretical zero to several megacycles per second in high-definition work. See TELEVISION SENDER.

VISION-FREQUENCY AMPLIFIER. Section of a television receiver which amplifies the picture signals after detection; it is the equivalent of the audio-frequency amplifier in a sound receiver. It differs from an ordinary audio-frequency amplifier in being required to cover a much wider range of frequencies (from zero to 2 Mc/s) and in the need for some attention to the *phase* of the signal. Vision-frequency amplifiers are usually resistance-coupled, with coupling resistors of quite low value to minimize high-frequency loss. See RESISTANCE-CAPACITANCE COUPLING.

VISION MODULATION. Fluctuations in output voltage of a storage camera caused by the potentials provided by the discharge of the minute capacitors of the mosaic as the electron beam scans it, or, in the case of the mechanical systems, by the potential variations provided by the photocell as the image is scanned by the rotating disc or mirror drum.

Vision modulation potentials vary between zero (full black) and a maximum (full white) and are applied to the modulator stage of the vision sender, after amplification, to vary the modulation between 30 per cent for black and 100 per cent for full white (see HIGH-DEFINITION TELEVISION).

On reception, the vision modulation is applied to the control electrode of the cathode-ray tube to provide variation of the density of the electron beam and thus of the brightness of the elements constituting the picture.

VISION PICK-UP. Television camera. Normally, the term is applied to an electron camera or storage camera, for although it might be said that the lens arrangements of the mechanical scanner could strictly be termed a vision pick-up, the term is not usually understood to refer to this type.

VISION SIGNAL. Signal comprising waves which lie within a frequency range from zero to about 4 Mc/s, and representative of the signals generated by a typical vision pick-up. Special amplifiers are required to give a minimum attenuation distortion and time delay over this very wide range of frequencies; transmission networks must be similarly designed if the picture is not to be distorted. See VISION FREQUENCY, VISION-FREQUENCY AMPLIFIER, VISION PICK-UP.

VISUAL INDICATOR. Device which, while not giving a quantitative reading of a quantity, shows a maximum or a minimum by change of some visible characteristic. A cathode-ray tube might be used as a visual indicator to compare the amplitudes of two waves; the "magic-eye" tuning indicator, in which the width of a dark segment of the "eye" varies as the amplitude applied to it changes, is typically a visual indicator.

VOGAD. Name applied to a *vo*ice-*o*perated *g*ain *ad*juster, being made up of the initial letters of that term. It is an AUTOMATIC GAIN-CONTROL (q.v.) operating on speech currents.

VOGT LOUDSPEAKER. Capacitive stretched-diaphragm loudspeaker, operating on push-pull principles, the diaphragm being clamped at its periphery between two grills. See CAPACITIVE LOUDSPEAKER.

VOICE FREQUENCY. Audible frequency lying within the speech-frequency range of the human voice.

VOICE-FREQUENCY TELEGRAPHY. Telegraph system in which the transmitted signals have a frequency within the audio range.

VOIGT LOUDSPEAKER. Moving-coil loudspeaker with intense gap flux and a twin diaphragm consisting of a normal cone and a smaller cone for improving high-frequency response. The twin diaphragm is loaded with a

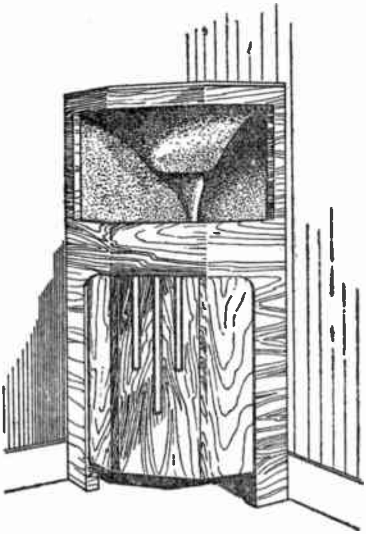


Fig. 17. Voigt loudspeaker, showing the horn, in a cabinet designed especially to stand in a corner of the room.

specially shaped horn, pointing upward to a distributing reflector.

The horn, as shown in Fig. 17, is designed to stand in a corner so that the walls increase the effective horn size, damping and frequency range. A damped resonator, driven from the back of the diaphragm, permits reproduction of frequencies below the cut-off frequency of the horn.

VOLT. Practical unit of electromotive force, related to the other practical units by the relationship that one volt (abbreviated V) will drive one ampere of current through a resistance of one ohm. The name is derived from that of the eighteenth-century pioneer in electrical discovery, Alessandro Volta. See PRACTICAL SYSTEM OF UNITS.

VOLTA EFFECT. Effect produced when two dissimilar metals are placed in contact with one another, one metal acquiring a positive and the other a negative potential.

VOLTAGE. Measure of electromotive force in the practical unit, namely, the volt.

VOLTAGE AMPLIFICATION FACTOR. See AMPLIFICATION FACTOR.

VOLTAGE AMPLIFIER. Valve or stage, or combination of valves or stages, arranged to deliver an amplified voltage swing (Fig. 18), rather than an output of appreciable power, as would be the case if the valve or stage were intended to drive a power-operated device such as a loudspeaker. A voltage amplifier, therefore, is normally one of the earlier stages or sections of a receiver or other piece of apparatus, and supplies the voltage swing which drives, say, an output stage. See POWER AMPLIFIER.

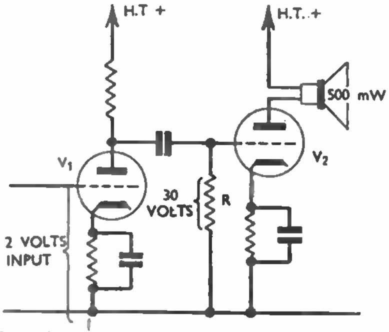


Fig. 18. Diagram which distinguishes a voltage-amplifier stage from one delivering a power output. The triode V_1 receives an input of 2 volts and delivers a voltage swing of 30 volts across R, the grid leak of V_2, so causing the latter to transmit 500 mW of power into the loudspeaker.

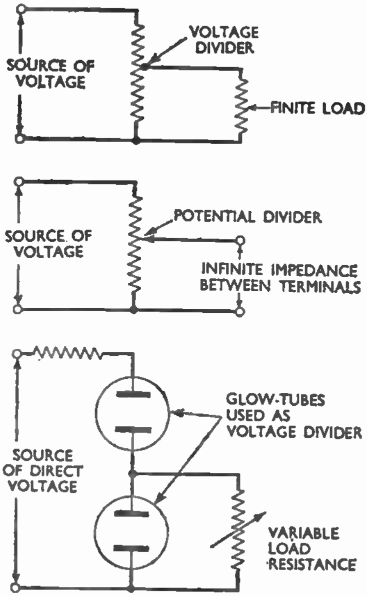


Fig. 19. Diagrams drawing the distinction between a voltage divider and a potential divider. When glow-tubes are employed the voltage across one tube tends to remain constant when the resistance of the load is varied.

VOLTAGE DIVIDER. Any variable resistor connected so that the voltage between the slider and one end of the resistor is variable, and in which current flows from the slider through an external circuit. The connexions of a voltage divider are shown in Fig. 19.

The distinction is made between a voltage divider and a potential divider;

in the former, as shown, current flows from the slider on the variable resistor, while in a potential divider it does not. The distinction is perhaps pedantic and it is usual to find the term potential divider used whether current flows from the slider or not. It should be noted, however, that a potential divider becomes a potentiometer only when the value of the potential on the slider can be measured in terms of the position of the slider on the resistor. See POTENTIAL DIVIDER, POTENTIOMETER.

VOLTAGE-DOUBLER. Rectifier and smoothing circuit, for converting alternating to direct current, in which the D.C. voltage is of the order of twice the peak value of the alternating voltage. The circuits of typical voltage-doublers are illustrated; the action can be seen from Fig. 20.

In practice it is usual to earth the output circuit, as shown in Fig. 21. The open-circuit voltage across the two capacitors is twice the peak volts of the transformer if no current is drawn from the output. Obviously, when current is taken, the D.C. voltage is reduced from its maximum value of twice the peak A.C. input voltage, just as in any of the more conventional types of rectifier (see SMOOTHING CIRCUIT).

The practical value of the arrangement is that the transformer may be designed with insulation suitable for only half the voltage it would have to supply if a more conventional type of rectifier were used, and, when the D.C. voltage is of the order of thousands of volts, a consequent saving of cost is an advantage of the arrangement.

The voltage-doubler circuit has the disadvantage, however, that, when vacuum-tube and gas-filled-tube rectifiers are used, the two rectifiers cannot have a common cathode, and two rectifiers, each with a separate cathode circuit, are necessary, with consequent elaboration. Metal rectifiers are particularly suited for use in the voltage-

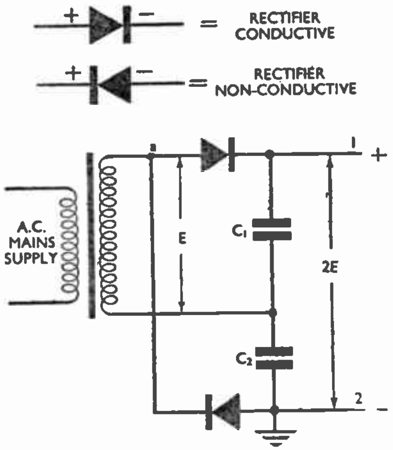


Fig. 20. Basic principle of the voltage-doubler. When point *a* is positive a voltage *E* is applied to C_1, and when it is negative a voltage *E* is applied to C_2, where *E* is the peak value of the alternating voltage; the voltage available is 2*E* when the load between terminals 1 and 2 is infinite.

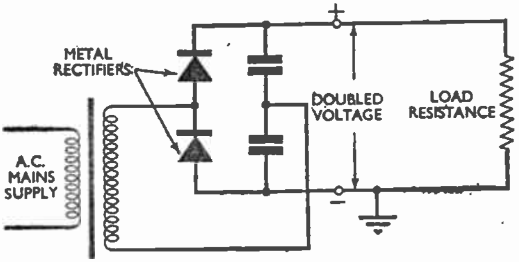


Fig. 21. Use of metal rectifiers in a voltage-doubler circuit. A smoothing circuit may be added across the output terminals (marked + and −) if necessary to reduce hum, but the capacitors shown tend to give a smoothed output.

doubler circuit and, as is seen from Fig. 21, the whole arrangement of metal rectifier, transformer and capacitors, is compact. Such a circuit has the great advantage that very little maintenance is necessary. Fig. 22 shows a voltage-doubler circuit employing rectifier valves.

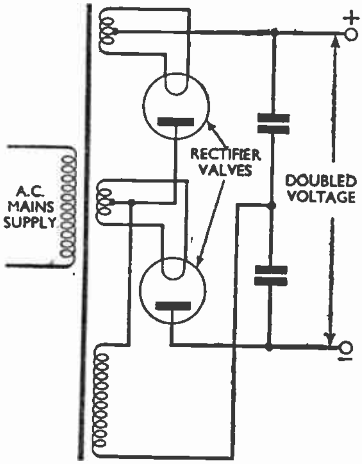


Fig. 22. Rectifier valves in a voltage-doubler. It is essential to use separate diodes, and separate heater windings insulated from each other.

For a fixed load, medium power and small maintenance cost, the voltage-doubler circuit using a metal rectifier makes a highly satisfactory arrangement. See MAINS UNIT, RECTIFIER, SMOOTHING CIRCUIT.

VOLTAGE DROP. Fall in potential between certain circuit points resulting from the passage of a current through resistance connecting those points. This term is almost synonymous with POTENTIAL DIFFERENCE (q.v.), but is more commonly used when referring to differences of potential produced by resistance. Fig. 23 shows a case in which potential differences are produced across resistors, with figures which indicate the voltage drops round the circuit.

VOLTAGE FACTOR. Term synonymous with AMPLIFICATION FACTOR (q.v.) except that it applies to any two electrodes, one of which is neither the anode nor the control grid. The amplification factor of a valve is defined in terms of voltage changes on control grid and anode; the voltage factor is the amplification factor of other electrodes. Thus there may be amplification of voltage between control grid and screen grid of a pentode, or between screen grid and anode. See ANODE SLOPE-RESISTANCE, MUTUAL CONDUCTANCE, SLOPE RESISTANCE, TRANSCONDUCTANCE.

VOLTAGE-FED AERIAL. Aerial to which power is fed at some point which is in a maximum-voltage region, for instance, the end of a half-wave dipole (Fig. 24). In the case illustrated, it may also be said to be end-fed.

VOLTAGE FEEDBACK. Negative feedback in which the voltage fed back is directly proportional to the output voltage of the amplifier. Such an arrangement is extensively used in the design of electronic equipment in order to obtain low harmonic distortion, improved frequency response and greater constancy of amplification with change of supply voltages.

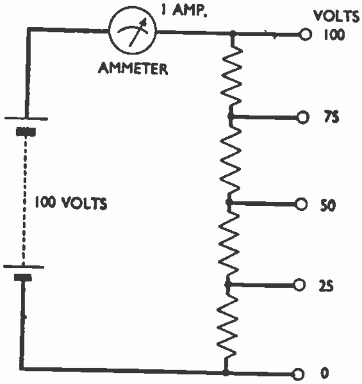


Fig. 23. Voltage drops produced when a current of 1 amp. passes through a succession of 25-ohm resistors.

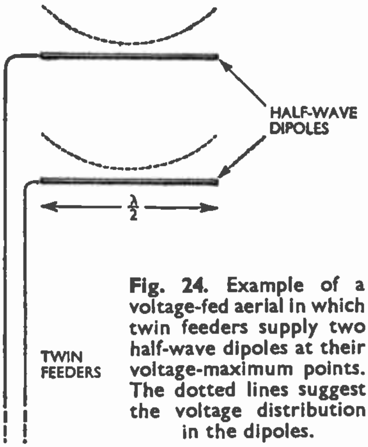


Fig. 24. Example of a voltage-fed aerial in which twin feeders supply two half-wave dipoles at their voltage-maximum points. The dotted lines suggest the voltage distribution in the dipoles.

The basic circuit for providing voltage feedback is shown in Fig. 25. A fixed potential divider R_1R_2 is connected in parallel with the output load, and the p.d. developed across R_2 is returned to the input of the amplifier, where it is connected in series with, but so as to oppose in phase, the normal input signal.

In this way, a fraction $\frac{R_2}{R_1 + R_2}$, usually represented by β, of the output voltage of the amplifier is fed back to the input. The effect of voltage feedback is to reduce the gain, attenuation distortion, harmonic and intermodulation distortion, phase distortion and noise occurring in the amplifier, to $\frac{1}{1 + A\beta}$ of the value given without feedback, where A is the gain obtained without feedback.

An important feature of voltage feedback is that it reduces the effective output impedance of the amplifier, that is, the apparent internal impedance of the output terminals of the amplifier considered as a source of power (see INTERNAL IMPEDANCE, MATCHING).

For example, voltage feedback tends to make a pentode or tetrode behave like a triode. If the amplifier drives an electromechanical or electro-acoustic device, such as a recording head or a loudspeaker which may have mechanical resonances, the reduction in output impedance is beneficial since it tends to damp out the rise in output at these resonances.

One method of applying voltage feedback is illustrated in Fig. 26. A fixed potential divider R_1R_2 is connected across the output of the valve and the p.d. developed across R_2 is connected in series with the secondary voltage of the input transformer to form the grid-cathode signal for the valve. A capacitor C is connected in series with R_1 and R_2 to prevent flow of direct current through the feedback circuit, and the reactance of C is small compared with $R_1 + R_2$ at the lowest frequency to be amplified. The value of $R_1 + R_2$ is equal to several times the anode load of the valve, and the ratio of R_1 to R_2 should be such that $R_2/(R_1 + R_2)$ is equal to the desired value of β.

Another method of applying voltage feedback to an amplifier is shown in Fig. 27. The output transformer has a tertiary winding which is connected in the cathode circuit of the valve so as to oppose the grid signal in phase. For this circuit the value of β is determined by the turns ratio between the primary and tertiary windings of the output transformer. Provided, however, that

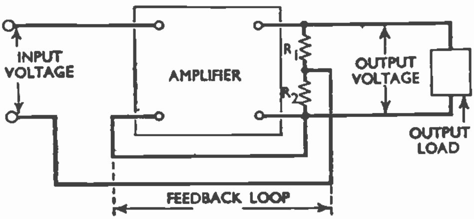


Fig. 25. Basic circuit for the provision of voltage feedback; R_1R_2 is a fixed potential divider.

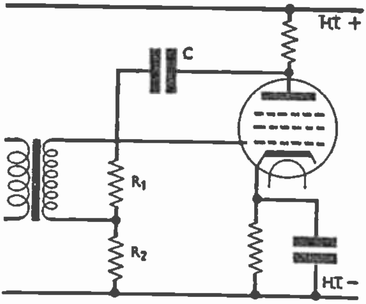


Fig. 26. Negative voltage feedback obtained by the use of a fixed potential divider R_1R_2 across the valve output.

the turns ratio is suitable for feedback purposes, there is no reason why the secondary winding should not be connected in the cathode circuit in this way, in addition to feeding the external load, thus rendering a tertiary winding unnecessary.

A method of applying negative voltage feedback to a two-valve amplifier is illustrated in Fig. 28. The method bears a resemblance to that of Fig. 26, but the resistor R_2 is included in the cathode circuit of the previous stage. The value of β is given by $R_2/(R_1 + R_2)$ as before. Provided that R_2 is small compared with R_1, it is often possible to omit the capacitor C, the steady p.d. across R_2 supplying part of the grid-bias potential for V_1.

Sometimes the capacitor C is retained and R_2 is made equal to the correct value of bias resistor for V_1. There is then no need for R_3C_3, but R_2 now provides appreciable current feedback in addition to voltage feedback. The only effect this current feedback has is slightly to increase the output impedance compared with its value for the circuit of Fig. 28.

These are only some of a number of circuits that may be used to give voltage feedback and they may be applied over a number of amplifying stages. When the reduction in gain due to feedback exceeds about 20 or 30 db., and in particular when there are one or more transformers in the amplifier, there is a possibility that feedback may cause the amplifier to become unstable and generate continuous oscillations at a frequency outside the pass band of the amplifier. This is because inter-valve coupling circuits, no matter what their nature, introduce phase-shifts at very low and very high frequencies.

If the total phase-shift within the amplifier and feedback circuit exceeds 180 deg. at any frequency for which the over-all gain of amplifier and feedback (known as the loop gain) exceeds unity, the feedback voltage becomes positive and is sufficient to cause oscillation.

To avoid oscillation caused in this way great attention must be paid to all circuits in the amplifier capable of causing phase-shifts, in particular inter-valve couplings; these must be so designed that the total phase-shift does not exceed 180 deg. at any frequency where the loop gain exceeds unity. In practice this usually involves controlling the shape of the frequency-response graph of the amplifier for several octaves above and below the wanted cut-off frequencies. By careful design it is possible to build quite stable amplifiers with 60 or even 70 db. of negative voltage feedback.

Since the application of negative

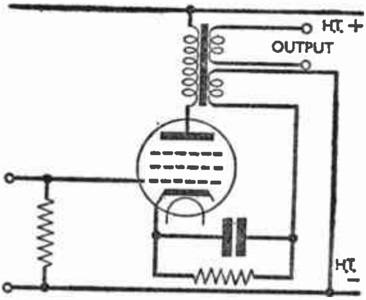
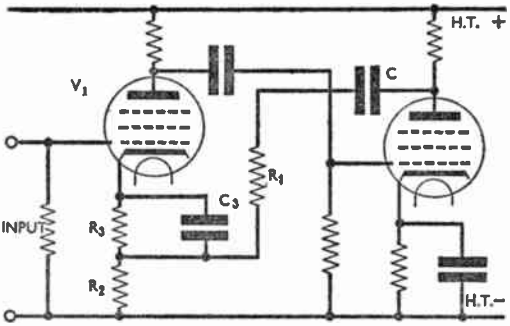


Fig. 27. Circuit in which negative voltage feedback applied to the amplifier is obtained from a tertiary winding on the output transformer.

Fig. 28. Method of applying negative voltage feedback over a two-stage amplifier.



feedback reduces the gain of an amplifier, gain can be controlled, within limits, by varying the attenuation in the feedback circuit. One possible circuit is shown in Fig. 29. It is similar to Fig. 26 except that R_2 is replaced by a variable potential divider and the secondary winding of the transformer is returned to the slider. When the slider is at the top of its travel, feedback is at a maximum and gain at a minimum; when the slider is at earth potential there is no feedback but maximum gain. The range of such a gain control is limited by the degree of feedback used, and gain is not zero when the feedback control is set to minimum.

By including reactance in the feedback circuit, the frequency response of the amplifier can be varied to suit particular needs—perhaps to offset certain losses occurring elsewhere in the amplifier. For example, if R_2 in Fig. 26 is shunted by a capacitor, the value of β falls and the gain of the amplifier rises as frequency increases. By use of a small capacitor this rise may be made to occur at a high frequency to provide a "top lift"; by use of a large capacitor the rise occurs at a low frequency and gives a "bass cut."

Alternatively, if an inductor is connected across R_2, the opposite effects of "top cut" or "bass lift" can be obtained depending whether the inductor is small or large. The extent of lift or cut is, of course, limited by the degree of feedback used.

VOLTAGE SATURATION. See EMISSION LIMITATION.

VOLTAGE-STABILIZED MAINS UNIT. Mains unit of conventional design associated with circuits to maintain the output voltage substantially constant as the D.C. current is varied. A mains unit can be considered as a D.C. generator with a certain internal resistance; variations of the output voltage are due to (1) variations in the alternating input voltage, and (2) variations of the load resistance (see MATCHING).

There are three advantages in arranging to stabilize the output voltage from a mains unit; the first is that variations in the input A.C. voltage result in less variation of the D.C. output voltage; second, that if the load in the D.C. side is variable, regulation is better; and third, that the apparent internal resistance of the device, considered as a D.C. generator, is reduced.

If the voltage stabilization of a mains unit were so good that between full-load and no-load current the output voltage never varied, the apparent input impedance would be zero. All

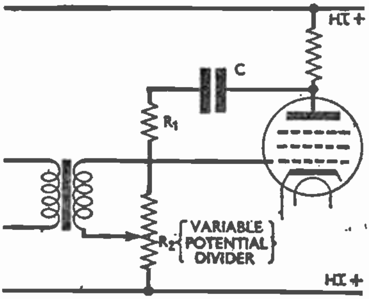


Fig. 29. Gain control effected by varying the degree of voltage feedback.

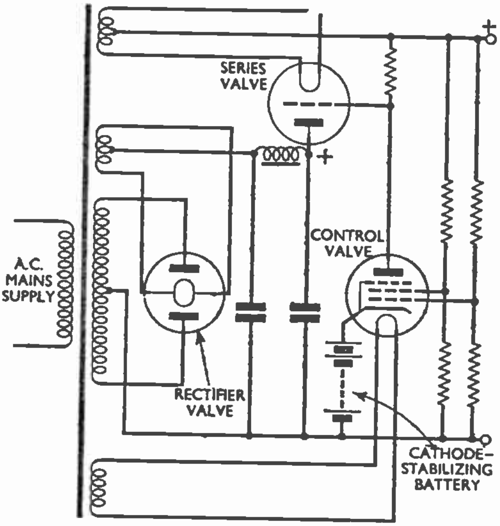


Fig. 30. Voltage-stabilized mains unit in which resistance of the series valve varies in accordance with its grid-cathode potential, which is controlled by the anode current of the pentode.

too often, amplifiers become unstable because of the coupling introduced between the stages of amplification by the common impedance of the mains unit (see AMPLIFIER, MOTOR-BOATING). The reduction of this impedance by voltage stabilization has substantial advantages in circumstances in which the mains unit supplies power to, notably, sensitive and wide-frequency-range audio amplifiers. A typical battery has an internal resistance of between 0·3 and 0·6 ohm per volt, and a mains unit of an ordinary kind has an internal resistance of the order of ten times this value. A stabilized mains unit may have an internal resistance of 0·05 ohm per volt.

There are, in general, two ways in which the voltage from a mains unit may be stabilized. One method depends on the property of a glow-tube that its voltage drop varies very little with the variation of current flowing through it. In another method a valve is placed in series with the supply from the rectifier to the smoothing circuit. The resistance of this (series) valve is automatically changed by the action of another valve, so that the output voltage remains nearly constant. This is called a valve stabilizer.

Fig. 30 shows a voltage-stabilized mains unit in which the resistance of the series valve is varied according to the potential between its grid and cathode. This potential is controlled by the anode current of the control valve: a pentode. If the voltage at the output terminals falls, the grid-cathode potential of the control valve alters to make the valve take less current. This decreases the grid-cathode potential of the series valve, which therefore has less resistance, tending to increase the output voltage. To get a wide range of control, the series valve must be capable of dealing with at least half the total power that is supplied by the mains unit.

It is essential that the cathode of the control valve should be maintained at a constant voltage. A battery is the best means to ensure this, but glow-tube regulators may be used (Fig. 31). The glow-tube tends to take the same current whatever, within limits, the voltage acting across it. Since the current in the glow-tube tends to be constant, and because it is fed through a series resistance and voltage across it tends to be constant, a glow-tube will not function unless the voltage across it exceeds a value of about 100 volts.

The regulation with either arrangement is vastly better than that given by an ordinary mains unit, and is of great benefit when energizing multi-valve amplifiers designed to amplify very low frequencies, for example, for cathode-ray tubes and for television receivers. See MAINS UNIT, MOTOR-BOATING.

VOLTAGE STABILIZER. Device, usually used in connexion with mains units, designed to maintain a constant output voltage in spite of different values of output power. Examples of voltage stabilizers are glow-tubes, constant-voltage transformers and valve circuits in which the resistance of a valve in series with the output is reduced as the load current is increased. See MAINS UNIT, VOLTAGE-STABILIZED MAINS UNIT.

VOLTAGE TRANSFORMER. Term that might be used to distinguish a normal type of transformer, when used with an open-circuited secondary, from one which supplies power to a load. See CURRENT TRANSFORMER, TRANSFORMER.

VOLTAIC CELL. Cell in which chemical action takes place between electrodes in contact with an electrolyte resulting in the establishment of an electromotive force between the electrodes. The term "voltaic" cell is seldom used nowadays; instead, we differentiate between the accumulator, or secondary, cell and the primary cell, both of which are voltaic cells. Thus the term is all-embracing and can be used only in a generalized way. See ACCUMULATOR CELL, PRIMARY CELL, SECONDARY CELL.

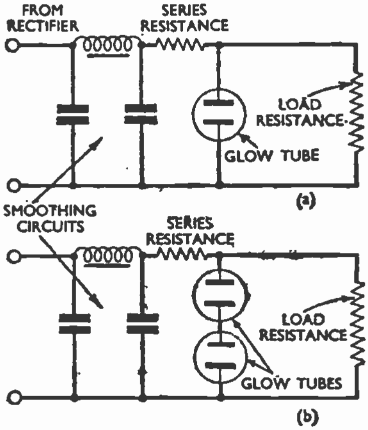


Fig. 31. Voltage-stabilized mains units using glow-tubes. With only one glow-tube (*a*), the output voltage would not exceed, say, 90 volts or 130 volts, depending on the type of tube. For higher voltages two glow-tubes (*b*) or even more may be employed.

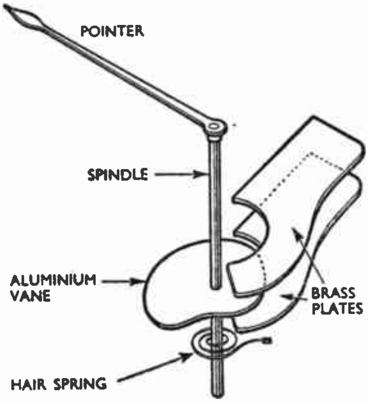


Fig. 32. Component parts of an electrostatic voltmeter; the principle of operation is described in the text.

VOLT-AMPERE. Unit of nominal or apparent power, being the product of current and voltage without regard to phase angle. The volt-ampere (abbreviated VA) is, therefore, a complete indication of power only in resistive circuits.

VOLTMETER. High-resistance electrical device used for direct measurement of differences of potential and calibrated in volts. Most voltmeters operate on the moving-coil or moving-iron principles, and are similar to ammeters; but the voltmeter is normally used in parallel with the circuit to be tested, whereas the ammeter is connected in series.

The electrostatic voltmeter, however, works on different principles, as shown in Fig. 32. A spindle carries a pointer and a light aluminium vane which is free to move between two brass plates; these plates are insulated from the aluminium vane. The construction is similar to that of a tuning capacitor.

When a charge exists between the plates and the vane, that is to say, when there is a p.d. between them, attraction occurs and the vane is caused to move into place between the plates and carries the pointer with it, causing the latter to move over the scale. The pointer comes to rest when the torque due to a spring balances the moment of the electrostatic forces causing motion of the vane.

The attractive force, and hence the deflection of the pointer, is proportional to the square of the p.d.; therefore, the scale on such voltmeters is not uniform, being crowded towards the ends. These voltmeters give full-scale deflection of from 250 to 25,000 volts and can be used for A.C. or D.C. measurements. Such an instrument must be shielded from external electrostatic charges, which would affect its accuracy, but it is not sensitive to temperature changes and takes no current to operate it.

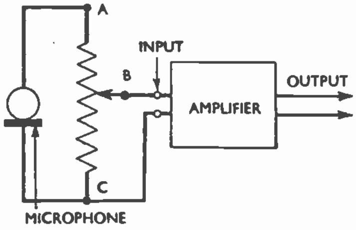


Fig. 33. Simple volume control connected across the output terminals *A* and *C* of a microphone. The signal volume fed to the amplifier is maximum with the slider *B* at *A* and decreases as *B* is moved towards *C*, where it is zero.

VOLUME. In telecommunications, the acoustical power output from a loudspeaker or headphones. See GAIN CONTROL, VOLUME CONTROL.

VOLUME CONTRACTOR. Synonym for COMPRESSOR.

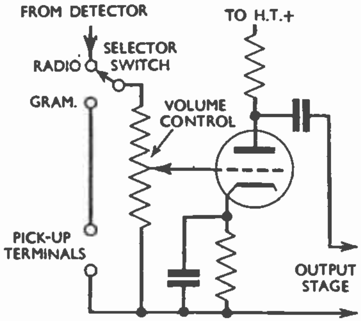


Fig. 34. Typical volume control for a radio receiver. The switch connects radio or gramophone as required.

VOLUME CONTROL. Variable resistor or potential divider, used in all forms of telecommunication for adjusting the level of the signal to the required value; the term also denotes the function which such a device performs.

The maximum range of sound volume which the ear can appreciate is that between the threshold of hearing, where a weak sound just becomes audible, and the threshold of feeling, where the high pressure of the sound wave can be felt. The difference between these two extremes is of the order of 130 decibels at 1,000 c/s (see SPEECH AND HEARING).

In broadcasting, however, this range has to be greatly compressed; very weak sounds are swamped by incidental noise, for example, room noises, microphone hiss, atmospherics, etc. Very loud sounds may seriously overload the microphone, amplifier, sender or loudspeaker, producing unpleasant distortion.

The maximum volume range of a full orchestra approximates 60 decibels between pianissimo and crescendo; this range is still too great to be reproduced without excessive extraneous noise on weaker sounds and risk of overloading on loud sounds. A range of 24 to 30 decibels is regarded as maximum for purposes of broadcasting, and this is achieved by raising the volume of the weaker and reducing that of the louder sounds.

The simplest form of volume control is a variable potential divider connected across the microphone, pick-up or other electrical device forming the first link in the sound-reproducing chain. In Fig. 33 the microphone is connected to terminals *A* and *C* of a potential divider; e.m.f.s proportional to the sound intensity are generated by the microphone across the resistor.

If the amplifier were connected also to points *A* and *C*, its input e.m.f.s would be equal to those developed across the resistor. Between any other two points along the resistor, the amplifier-input e.m.f.s will be less than those between *A* and *C*. If the amplifier input is connected between the slider *B* and the point *C*, its input e.m.f. will depend upon the position of the slider; thus, if the slider is set to the point *A*, the input e.m.f. will be at maximum.

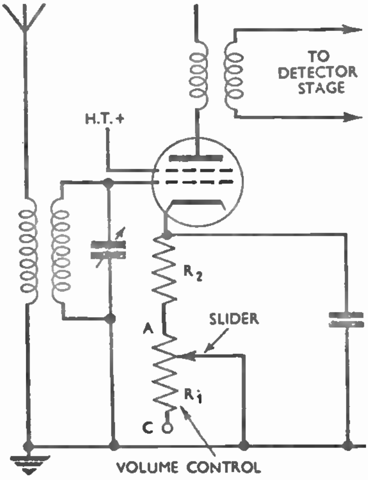


Fig. 35. Volume control in the R.F. stage of a radio receiver. Volume is decreased by moving the slider towards *C*, thus increasing the bias on the grid of the valve. R_2 ensures minimum bias when the slider is at the point *A*.

If the slider is set at *C*, points *B* and *C* will be at the same potential and no e.m.f. will be transferred to the amplifier. The same kind of volume control may be connected in the amplifier itself, or at any intermediate stage between microphone and loudspeaker.

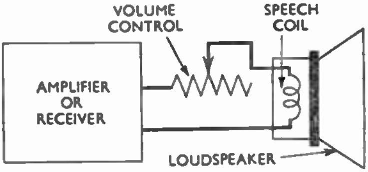


Fig. 36. Volume control for an extension loudspeaker; suitable resistance values are 50 ohms for use with a moving-coil loudspeaker and 5,000 ohms for use with a moving-iron loudspeaker.

In a radio receiver, the volume control usually takes a similar form. Fig. 34 shows a volume control in the A.F. stage of a receiver provided with gramophone-pick-up terminals. Operation of the selector switch changes the control from radio to gramophone or vice versa. Normal values of resistance for potential dividers thus connected are from 100,000 ohms to 1 megohm, a common value being 0·5 megohm.

A volume control in the R.F. stage of a receiver may consist of a variable cathode resistor, connected as in Fig. 35. In such cases, care must be taken that when the resistance R_1 is at minimum the valve still has a few volts bias; this can be assured by connecting a fixed resistor R_2 in series with the volume control.

Where it is necessary to include a volume control in the loudspeaker itself, one possible method is to include a variable resistor in series with the speech coil (Fig. 36). The value of such a resistor must be large with relation to the impedance of the coil, and may be of the order of 50 ohms for moving-coil and 5,000 ohms for moving-iron loudspeakers.

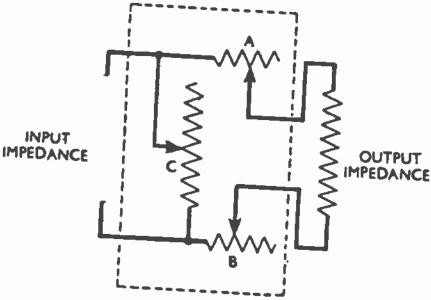


Fig. 37. With this form of volume control, provided that it is terminated by the correct value of impedance (the load impedance), variation of the setting does not change the input impedance of the volume control. Similarly, if the volume control is fed from the correct value of impedance (the output impedance of preceding apparatus), variation in the setting does not change the output impedance of the volume control.

This method is unsatisfactory, however, because the loudspeaker is, in effect, fed from a generator the internal resistance of which varies with the volume-control setting. Even more unsatisfactory is the fact that the amplifier feeding the loudspeaker works into a load, the value of which also varies with adjustment of the volume control.

The most satisfactory method, when a volume control must be situated at the loudspeaker, is to use a constant-impedance type of control, designed to keep the effective generator and load impedances sensibly constant when the control is operated. Such a control is shown in Fig. 37. With this arrangement, the three sliders of the resistors are coupled mechanically and the circuits so connected that, when the series elements *A* and *B* are decreased in value, the value of the shunt element *C* is increased (or vice versa). The resistance values in these units are calculated so that, whatever the position of the sliders, the impedance of the network as a whole remains onstant.

An objection to the term "volume control" as commonly used is based n the fact that the volume must be constantly varying to give reality to production. The variation of sound power is, in fact, a part of faithful reproduction. This variation should not be controlled, but the average acoustical power can be; thus the term "gain control" is more accurate as it implies that the average sound power, rather than the instantaneous sound power, is controlled. A true "volume" control levels out, or decreases, the light and shade in speech and music, and thus is more properly called a compressor.

See AUTOMATIC GAIN-CONTROL, COMPANDER, COMPRESSOR, EXPANDER, FADE-UNIT.

VOLUME EXPANDER. See EXPANDER.

VOLUME INDICATOR. Term applied to any instrument used for comparative measurement of programme volume in a radio receiver or amplifier.

VOLUME LIMITER. See LIMITER.

VOLUME METER. Synonym for VOLUME INDICATOR.

VOLUME MIXER. See FADE-UNIT.

VOLUME RESISTIVITY. Measure of the characteristic resistance of a given material. It is defined as the resistance between opposite faces of a cube of the material having unit dimensions, and is sometimes called the specific resistance of the material. See RESISTANCE.

W

W. Abbreviation for WATT(s).

WAGNER EARTH. Special method of earthing a bridge-measuring circuit by using an extra pair of ratio arms to ensure a perfect balance to earth.

WALL-PLUG. Plug part of a plug and socket designed for wall fixing. See PLUG AND SOCKET.

WALL-SOCKET. Socket designed for wall fixing and usually wired to the mains supply. See PLUG AND SOCKET.

WANDER PLUG. Single-pole plug for making an electrical connexion to one of a group of sockets wired to various points in a circuit, such as the tapping points of a dry battery. See PLUG AND SOCKET.

WARBLER. Device used for varying the frequency of an oscillator or sender. It may consist of a rotating capacitor, or other convenient form of device by means of which the frequency of an oscillator can be automatically varied. When applied to an audio-frequency oscillator, a note which has a fluctuating pitch or warble is produced.

WATER-COOLED VALVE. Valve in which the anode is cooled by passing a thin stream of water over it. It is essential to get rid of the heat developed at the anode of a valve when the valve is handling tens or hundreds of kilowatts of power (see COOLED VALVE). In a water-cooled valve, the anode is spun on to glass where the electrode connexions are taken through to form a gas-tight seal. The water jacket fits over the anode and care is taken in the design to ensure that the water is uniformly distributed over the surface of the anode, otherwise there may be hot spots which may produce arcing inside the valve. (see FLASH ARC).

Bringing the water to the anode (which is raised to kilovolts of potential) and taking it away again, involves insulation problems. The usual practice is to circulate pure water through curled up rubber tubing. The same water is circulated continuously and is cooled in an external radiator immersed in cold water. See AIR-COOLED VALVE, ANODE DISSIPATION.

WATT. Unit of power, equal to the product of voltage and current in the sense that a current of one ampere driven by a pressure of one volt represents a power of one watt. A watt (abbreviated W) is equal to a rate of work of one Joule per second. For the rating of machinery the larger kilowatt (1,000 watts) is generally used, as this unit is comparable in magnitude with the horsepower; one horsepower is equal to 746 watts; thus the kilowatt is greater by about a third. The power in a D.C. circuit can be found by multiplying the current in amperes by the e.m.f. in volts, but in an A.C. circuit this product must also be multiplied by the POWER FACTOR (q.v.).

WATT-HOUR. Unit of power-delivery or consumption. One watt-hour (abbreviated Wh) is the measure of the power delivered or consumed when a current of one ampere flows at a pressure of one volt for one hour. Thus, if an electric lamp rated at 100 watts is switched on continuously for 5 hours the consumption of energy recorded is 500 watt-hours, or half a kilowatt-hour. A kilowatt-hour is what the electricity-supply Authority calls a "unit."

WATTLESS COMPONENT. Component in an A.C. system which has a phase angle of 90 deg. with another component. Thus, current which lags or leads the voltage by 90 deg. is sometimes called wattless current. See REACTIVE COMPONENT.

WATTLESS CURRENT. See WATTLESS COMPONENT.

WATTMETER. Electrical measuring device giving a direct reading of power in watts. Wattmeters are seldom used in D.C. work, where power can be calculated by multiplying together the ammeter and voltmeter readings.

In A.C. work, power = $EI \cos \theta$, where E = voltage, I = current in amperes, and θ = phase angle between voltage and current. It is essential, therefore, for wattmeters used in A.C. measurements to give deflections proportional to $EI \cos \theta$.

Wattmeters are usually of the *dynamometer* type (which can also be used for D.C. measurements) or of the *induction* type. The former is similar in construction to the dynamometer ammeter (see AMMETER), as it contains both a fixed and a moving coil; the fixed coils are termed the current coils, and the moving coil is shunted across the source of supply.

In the wattmeter, this latter coil is referred to as the pressure coil. The deflection of the pressure coil will be proportional to the currents in both current coils and the pressure coil; that is, it will be proportional to the product (watts) of the current and the p.d. across the coils.

The principle on which the induction wattmeter operates is somewhat different. In Fig. 1 a highly inductive coil is wound on a laminated iron core, while a coil of lower inductance is wound on another laminated iron core. The first coil is connected as a voltmeter and the second as an ammeter. A plate of aluminium is free to rotate between the two coils and carries the pointer.

When current is passed through the coils the current lags behind the voltage in the first coil, owing to its highly inductive nature; this results in a lag in the flux. The flux due to the second coil is in phase with and proportional to the current in the circuit under test. The plate is subjected to the resultant of the fluxes due to the two cores; that is to say, the turning torque on the plate is proportional to $EI \cos \theta$, as in the case of the dynamometer wattmeter.

WAVE. Progressive disturbance, in any medium, formed by the propagation of alternating pressures and tensions, without any permanent displacement of the medium itself in the direction in which these stresses are propagated. Radio-waves consist of alternating electrostatic lines of force travelling through space and are of the type known as transverse waves. See RADIATION.

WAVE AERIAL. Directive aerial the length of which is equal to or greater than the length of wave in use. See BEVERAGE AERIAL.

WAVE ANALYSER. Apparatus for determining the magnitude and phase angle of the harmonics present in an alternating wave form.

WAVE ANTENNA. Synonym for WAVE AERIAL.

WAVE BAND. Band of carrier wavelengths allocated to a specific radio service. In European broadcasting, wave bands (and corresponding frequencies) are as follows:

	WAVE-LENGTHS (Metres)	FREQUENCIES (Kilocycles per second)
Long-wave band		
	2,000–1,053	150–285
Medium-wave band		
	571–187	525–1,605
Short-wave bands		
Metre Band		
49	50·00–48·39	6,000–6,299
41	41·67–41·10	7,200–7,300
31	31·58–30·93	9,500–9,700
25	25·63–25·21	11,700–11,900
19	19·87–19·54	15,100–15,350
16	16·90–16·81	17,750–17,850
13	13·99–13·79	21,450–21,759
11	11·72–11·28	25,600–26,600

Maritime services share frequencies at each end of the long-wave band.

WAVE FILTER. Synonym for FILTER.

WAVE FORM. Shape of the curve obtained when the instantaneous values of a varying quantity are plotted against time. If the varying quantity is a voltage, the wave form is also the shape of the trace obtained on an oscilloscope screen when the varying voltage is applied to one pair of plates and the output of a linear time base is applied to the other pair.

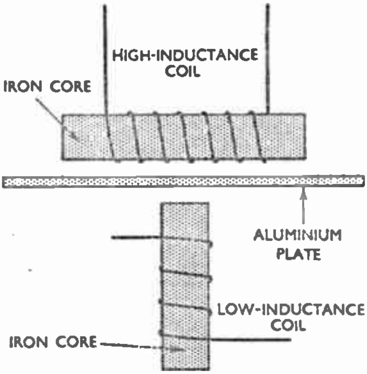


Fig. 1. Diagrammatic representation of components comprising an induction wattmeter, the operating principle of which is fully described in the text.

If the wave form is cyclic, and is repeated indefinitely, it is described as *steady-state*; if it varies without a regular pattern it is called *transient*. If a steady-state wave form is not sinusoidal it is usually described as *distorted*. See SINUSOID, TRANSIENT.

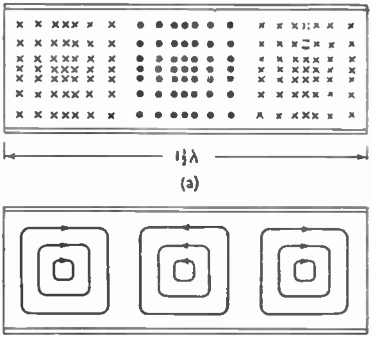
WAVE FRONT. Plane parallel to the mutually perpendicular lines of electric and magnetic lines of flux of an electromagnetic wave. The wave travels in a direction at right-angles to the wave front, the actual direction of travel depending upon the relative direction of the electric and magnetic lines of flux. See RADIATION.

WAVE-GUIDE. Hollow conducting tube used for the transmission of very high-frequency electromagnetic waves. Electromagnetic waves may be classified as either guided or unguided waves. Guided waves are those which follow a feeder line, such as a pair of parallel conductors or a coaxial cable; unguided waves are those which are radiated by an aerial.

Radio-waves that are unguided travel along straight lines, but they may be concentrated into a relatively narrow beam by the use of directional aerial-systems. But the energy in even the narrowest beam is distributed over an increasing cross-sectional area as the distance from the aerial increases. The energy in a guided wave, however, is distributed over a relatively constant cross-sectional area throughout the guiding system so that nearly all the transmitted energy reaches its destination.

Any surface which separates two regions of different electric properties can exert a guiding effect on electromagnetic waves, and some important types of wave-guides are open wires, shielded wires, coaxial cable, and hollow metal pipes. Although all these are, in effect, wave-guides, the term wave-guide is usually reserved for hollow metal pipes. The energy that is transmitted by a wave-guide is carried in the electromagnetic fields within the guide.

Since the electric field is zero wherever it is parallel to the metal surface of the guide, no part of this field can penetrate the metal. Similarly, the varying magnetic field is zero at the surface of the metal, so that no part of the magnetic field can get outside the guide. Therefore, all of the energy in



(a)

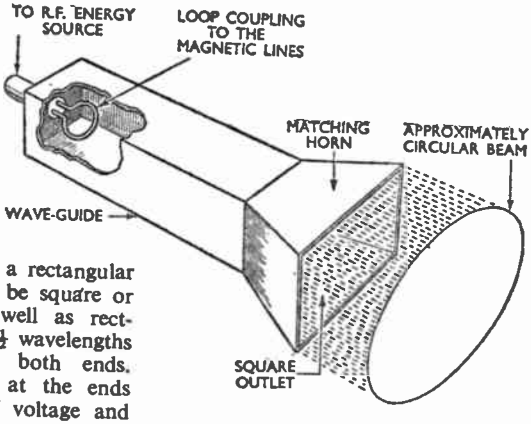
(b)

Fig. 2. Sectional side views of a rectangular wave-guide, showing distribution of (*a*) the electric and (*b*) the magnetic lines of force. In (*a*) the crosses indicate lines on which the direction of the force is away from the reader and the dots those on which direction of the force is towards him.

the field is wholly contained by the guide.

The way in which energy can be transmitted through a wave-guide is indicated in Fig. 2. The illustration shows the side view of a rectangular tube (wave-guides may be square or round in section, as well as rectangular). The tube is 1½ wavelengths long and shorted at both ends. Reflections take place at the ends and standing waves of voltage and current occur. Although the electric and magnetic fields are shown separately, both exist at the same time and in the same space within the wave-guide.

Fig. 3. Diagram of radiation from a wave-guide; it shows one method of coupling the wave-guide to the R.F. oscillator, which may be another wave-guide that is operating under resonant conditions.



There are several methods of introducing energy into the wave-guide, but only the two most important will be mentioned here. The first method employs magnetic coupling, as in a transformer, by the use of a small loop of wire placed inside the wave-guide at the end. The second involves the provision of an "aerial," or pole, which is placed parallel to the electric field.

So far we have been dealing with a closed wave-guide; if one end is opened, travelling waves tend to form; some of the energy is radiated into space, but the remaining energy is reflected and standing waves form once more. In order to eliminate the reflections and to terminate the guide properly for maximum energy radiation, the opening is flared in the shape of a horn. This flaring matches the impedance of the guide to free space. Fig. 3 shows a wave-guide being fed with R.F. energy and radiating into free space.

Wave-guides are used for three purposes: as a means of energy transmission, as a means of energy radiation, and to obtain resonant conditions. For energy transmission at centimetric wavelengths the wave-guide is reasonably small; it has less losses than other forms of transmission line, and is the principal means employed. Wave-guides are superior to other forms of transmission line as they do not involve dielectric losses; the copper losses are lower than those of a coaxial line; complete screening is obtained, and they are of simple construction.

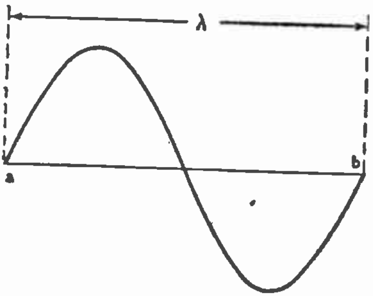


Fig. 4. In this typical wave form the curved line from *a* to *b* constitutes one complete cycle, the cycle being, of course, one wavelength long.

The minimum size of wave-guide that can be used at a certain frequency is proportional to the wavelength for that frequency. There is a minimum frequency, called the cut-off frequency, that can be sent; so wave-guides are not used extensively below about 3,000 Mc/s (10 cm.). At lower frequencies, the physical size of the guide becomes too large; for example, to send 10-cm. waves, a rectangular pipe would have to be wider than 5 cm., but for 1-metre waves the pipe would have to be about 2½ ft. wide.

The installation and operation of a wave-guide system is somewhat more difficult than for other types of line; the radius of any bends in the guide must be greater than 2 wavelengths to avoid excessive attenuation. If the guide is dented or soldered so that the joints are not perfectly flat, the attenuation is greatly increased. Unless great care is exercised in installation, one or two poorly made joints may nullify completely the advantage to be obtained from the use of the wave-guide. See RADIATION, STANDING WAVE.

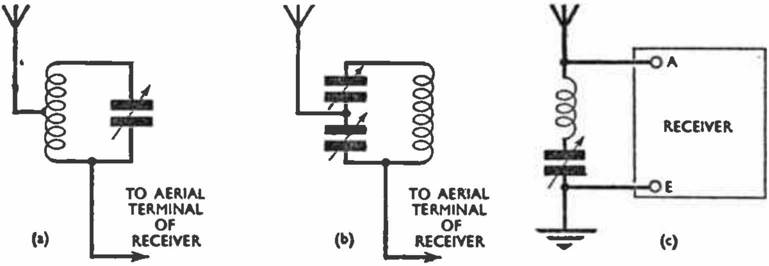


Fig. 5. Three types of wave-trap: (*a*) practical form of rejector wave-trap in which only part of the inductor is included in the aerial circuit; (*b*) capacitance-coupled form of rejector wave-trap, and (*c*) the acceptor type of wave-trap, which is connected across aerial and earth terminals of the receiver.

WAVELENGTH. Distance between corresponding points in consecutive waves in a wave-train, measured, at any instant, in the direction of propagation. Symbol λ. Fig. 4 illustrates one complete cycle of a sinusoidal wave, and from this certain important relationships may be deduced. The *period* is the time occupied by the sequence of one complete wave, and f (the frequency) is the number of waves per second; the period is given by $1/f$ seconds.

As the frequency is the number of waves per second and the wavelength λ is the distance between them, the product of these two quantities gives the speed at which the waves are travelling, or their velocity v. Thus $f \times \lambda = v$; therefore $f = \frac{v}{\lambda}$, and $\lambda = \frac{v}{f}$. See FREQUENCY, RADIATION, WAVE VELOCITY.

WAVELENGTH CONSTANT. Synonym for PHASE-CHANGE COEFFICIENT.

WAVELENGTH METER. Synonym for WAVEMETER.

WAVEMETER. Instrument for measuring the wavelength of electromagnetic waves either directly or, more usually, indirectly by determination of frequency (see FREQUENCY MEASUREMENT).

WAVE PROPAGATION. Propagation of electromagnetic waves from the aerial of a sender through space to distant receiving points. See RADIATION.

WAVE-TRAIN. Unbroken group of waves. See WAVE.

WAVE-TRAP. Tuned circuit designed to reduce the effect of interfering signals, either by impeding their entry into the receiving circuits, or by shunting them past the receiver-input by providing a parallel path which is of low impedance at the interfering frequency but of high impedance at the wanted frequency. Three forms of wave-trap are shown in Fig. 5. Generally the wave-traps represented by (a) and (b) are used when the receiver-input impedance is low, and (c) is used when the input impedance is high. See RESONANCE.

WAVE VELOCITY. Velocity of electromagnetic waves travelling through a particular medium. The velocity of these waves in ether or free space is 3×10^8 metres per second, which is approximately 186,000 miles per second. Their velocity in air is almost exactly the same. The wave velocity is related to FREQUENCY (q.v.) and WAVELENGTH (q.v.) by the formula:

Velocity = Frequency × Wavelength.

WAVE-WINDING. Method of winding a coil on to a cylindrical former using a machine in which the wire feed has a reciprocating motion, parallel to the axis of the former, at a rate having a fixed ratio to the speed of rotation of the former. This ratio is so chosen that each turn lies diagonally across the turn below it. This not only causes the turns to interlock and to become self-supporting, but also greatly reduces the self-capacitance of the coil and the influence of the proximity effect upon its effective resistance.

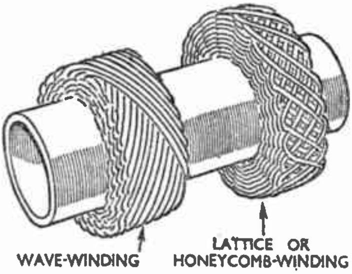


Fig. 6. Examples of wave-winding and lattice- or honeycomb-winding.

For certain values of the ratio ther are relatively few widely spaced turn per layer, leaving regularly space diamond-shaped air-spaces in the coil as shown in Fig. 6. This type of wave-winding is called lattice- or honeycomb-winding. If the ratio is mad small enough, each layer becomes a close-turn helix, and the method ceases to be wave-winding and becomes layer-winding. Wave-wound coils are commonly used in R.F. inductors and I.F. transformers.

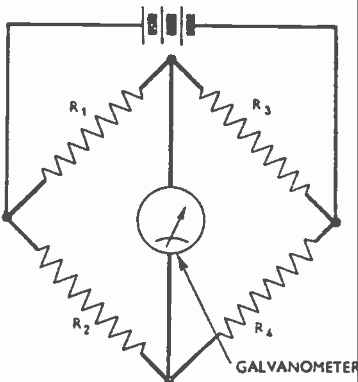


Fig. 7. Wheatstone bridge, employe for the measurement of resistance

WAX BLANK. In gramophone recording, the circular block of soft wax on which the sound track is inscribed. A matrix is taken from the recorded wax, from which discs, or records, are processed for commercial distribution. See DIRECT-DISC RECORDING, ELECTRICAL RECORDING.

WEAK COUPLING. See LOOSE COUPLING.

WESTON CELL. Synonym fo CADMIUM CELL.

Wh. Abbreviation for WATT-HOUR(S).

WHEATSTONE AUTOMATIC SYSTEM. Telegraph system in which the Morse signals are first punched on a strip, then transmitted at high speed and recorded automatically at the receiver.

WHEATSTONE BRIDGE. Bridge circuit consisting of four resistors, arranged as shown in Fig. 7, and used for the measurement of resistance. When the bridge is balanced, no current is indicated by the galvanometer and the following equation applies:

$$\frac{R_1}{R_4} = \frac{R_3}{R_4}.$$

If the values of any three resistors are known, the fourth may thus be calculated.

WHEATSTONE TRANSMITTER. Apparatus used at the transmitting end of a Wheatstone automatic system. The perforated strip is driven through a mechanism causing electrical circuits to be intermittent, such intermission having the character of the Morse code punched on the strip.

WHIP AERIAL. Self-supporting but flexible rod aerial used for the higher frequencies, particularly on vehicles, often as an end-fed half-wave dipole but in some cases as a quarter-wave aerial.

WIEN BRIDGE. A.C. bridge circuit, of the form indicated in Fig. 8, enabling capacitance to be measured with great accuracy in terms of resistance and frequency. When the bridge is balanced, minimum sound is heard in the headphones, and the following equations, where ω represents 2π times the frequency, apply:

$$C_1^2 = \frac{R_2R_3 - R_1R_4}{R_1R_3^2\,R_3\omega^2};$$

$$C_2^2 = \frac{R_1}{(R_2R_3 - R_1R_4)\,R_4\omega^2}.$$

This type of bridge also provides a convenient means of measuring frequency in the A.F. range. The two capacitors C_1 and C_2 are made equal, and the resistor R_2 is made twice R_1, while R_3 and R_4 are made variable but equal. It may then be said that:

$$f = \frac{1}{2\pi R_3C_1}.$$

Some commercial frequency meters use this principle.

WINDING. General term applied to a coil or to the process of making a coil, or other systematic arrangement of an insulated wire about a core, intended either to produce or to be acted upon by a magnetic field as in an inductor, transformer, electromagnet or electrical machine, or else merely to confine the wire to a convenient small volume as in a wire-wound resistor. See MULTI-LAYER WINDING, SINGLE-LAYER WINDING, WAVE-WINDING.

WIRE BROADCASTING. System of broadcasting in which the link between a sender and listeners' receivers is formed by a conductive network instead of by radio-waves radiated into space, as in radio broadcasting. For example, households can be linked to a central point of programme distribution by means of the electricity mains or telephone network; modulated-carrier systems of transmission can be used, and a simple selective receiver connected to the wire network can select one of several programmes and reproduce it.

The system differs from a RADIO RELAY SYSTEM (q.v.) in that the latter employs a radio link between sender and central receiver, although the audio-frequency link to loudspeakers is by wire. See BROADCASTING.

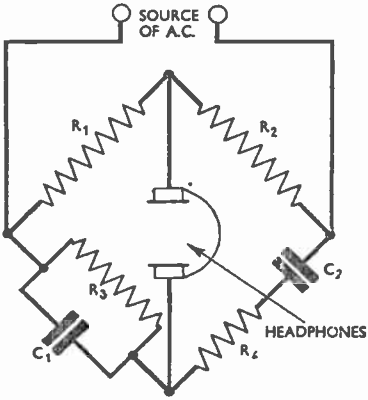


Fig. 8. A.C. bridge circuit, known as the Wien bridge, by which capacitance may be accurately measured by reference to frequency and resistance.

WIRED WIRELESS. Signal transmission using electromagnetic waves at radio frequencies guided by conductors.

WIRE GAUGE. Designation of wire sizes by means of numbers. Wire diameter is reduced by drawing it through holes of successively decreasing diameter in a steel die block, and wire-gauge numbers originally indicated the number of times that wire of a specific diameter had been drawn through the die.

WIRELESS. Obsolescent term for RADIOCOMMUNICATION.

WIRELESS TELEGRAPHY. See RADIO TELEGRAPHY.

WIREWOUND RESISTOR. Form of resistor in which the resistance element consists of an alloy wire wound on to a spool or former of insulating material. Size and cost are usually greater than those of metallized or composition types. Apart from very low values of resistance, for which there is no alternative, its use is limited to low frequencies and to applications where a high order of resistance stability is required, or a high power dissipation is necessary. See FIXED RESISTOR, VARIABLE RESISTOR.

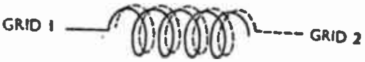


Fig. 9. Formation of the co-planar grids of the Wunderlich valve; for clarity one grid is represented in this diagram by a broken line.

WORD ARTICULATION. Percentage of random words correctly received over a speech-transmitting or reproducing system.

WORK FUNCTION. Energy, in electron volts, that must be given to an electron before it can escape the boundaries of a metal conductor (see EMISSION). When a conductor is raised to a high temperature, electrons escape from it. This they can do only if given enough kinetic energy. The work function of a metal expresses, in quantitative terms, the amounts of energy that must be given to electrons in different metals to allow the electrons to escape, or be emitted from the hot metal.

The work functions of various metals and oxides used for valve cathodes are given in the table below.

Material	*Work Function (Electron Volts)*
Tungsten	4·5
Thorium	3·4
Thoriated tungsten	2·6
Oxide coating ..	1·0 (approx.)

The lower the work function, the higher the emission efficiency. The better emitters cannot always be used, because the cathodes they form in valves are liable to be destroyed by ion bombardment when the anode voltage is high. See CATHODE, FILAMENT, INDIRECTLY HEATED CATHODE.

W.T. Abbreviation for wireless telegraphy, also known as RADIO TELEGRAPHY.

WUNDERLICH VALVE. Valve with two co-planar control grids. The space-charge-grid valve has two concentric control grids; the Wunderlich has co-planar control grids (Fig. 9). The Wunderlich valve can be connected to work as a space-charge-grid valve. The advantage of using co-planar grids in this case is that the control grid which is positively biased does not absorb so much current (provided the anode volts are relatively great) as when the grids are concentric. On the other hand, the mutual conductance is not so great. The compromise may score in general application.

The Wunderlich valve, like the duplex valve, lends itself to balanced valve-operation. See DUPLEX VALVE, SPACE-CHARGE-GRID VALVE.

X

X AMPLIFIER. Amplifier used in an oscilloscope to supply the potentials for horizontal deflection of the electron beam. The input of the amplifier is normally connected to a time base, but there is usually a facility enabling the input to be connected to an external terminal so that the beam can be deflected by external potentials when necessary.

In small oscilloscopes it is sometimes possible to obtain a voltage adequate for full horizontal deflection from a single valve, but in larger instruments it is often necessary to use a push-pull stage to obtain adequate deflection. This circuit arrangement has the incidental advantage of minimizing trapezium distortion. Thus a high-grade X amplifier might employ three valves, comprising a push-pull output stage and a pre-amplifying stage.

If the oscilloscope is to be used mainly at audio frequencies, the upper frequency limit of the X amplifier need not exceed about 10 kc/s; if, however, it is to be used at higher frequencies, it may be necessary to extend the response up to 100 kc/s or even 1 Mc/s, and thus extending the upper frequency limit will involve the use of more amplifying stages to give a wanted gain.

Often the X amplifier is direct-coupled so that the response is level down to zero frequency; this is an advantage, for it means that the spot can be deflected horizontally by steady voltages applied externally to the X terminal. It provides a convenient means of calibrating the instrument for horizontal deflection. See OSCILLOSCOPE, TIME BASE, Y AMPLIFIER.

X PLATE. In a cathode-ray tube, one of the pair of plates to which voltages are applied to deflect the electron beam horizontally. It is named in accordance with the Cartesian system of co-ordinates.

For the purpose of examining wave forms, the X plates are commonly connected to the output of an amplifier, known as the X amplifier, the input of which is connected to a time base. See X AMPLIFIER, Y PLATE.

X-RAYS. Paths followed by electromagnetic wave forms having wavelengths of 0·01 to 50 Angström units (1 Angström unit equals 10^{-8} cm.). Such rays can penetrate matter opaque to white light, and they are employed, therefore, to produce X-ray photographs of the interior of the human body, etc. See RAYS.

X's. Obsolete name for ATMOSPHERICS.

X SHIFT. In an oscilloscope, the name given to a control by operation of which the trace on the screen can be moved horizontally to the left or the right. In effect the control applies a steady bias to the X plates. See OSCILLOGRAPH, X PLATE.

Y

YAGI AERIAL. End-fire array giving a fairly narrow beam and used at the higher frequencies. The active element is a half-wave dipole; a reflector is placed behind it, and one or more directors in front (Fig. 1 on page 740). See PASSIVE AERIAL.

Y AMPLIFIER. Amplifier used in an oscilloscope to supply the potentials for vertical deflection of the electron beam. The input of the amplifier is brought out to an external terminal, to which the voltage to be investigated is connected.

In simple oscilloscopes and, in particular, when the voltages to be investigated are at audio frequencies, a single valve can supply an output voltage giving adequate vertical deflection; but in more ambitious instruments a push-pull output stage is often used, this having the advantage of minimizing trapezium distortion. In addition to the push-pull stage, there are one or more pre-amplifying stages, the number of stages necessary depending on the gain and upper frequency limit required.

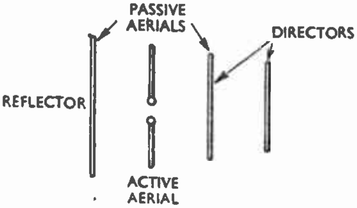


Fig. 1. Combination of active aerial, reflector and one or more directors, which makes up a Yagi aerial. The direction of maximum radiation from the aerial is to the right of the diagram.

Most Y amplifiers have a good response up to several hundred kilocycles per second; some extend to 2 or 3 Mc/s and the best up to 7 Mc/s. Often the Y amplifier is direct-coupled so that the response is level down to zero frequency; this is an advantage, for it means that the screen can be calibrated by steady voltages applied to the Y terminal. See OSCILLOSCOPE, TRAPEZIUM DISTORTION, X AMPLIFIER.

Y-NETWORK. Network comprising three impedance arms which radiate from one common connexion point. The arrangement, sometimes referred to as the three-impedance star network, is better known as the T-network.

YOKE. Piece of iron or steel which completes a magnetic circuit by bridging two points. Fig. 2 shows an example in which the yoke joins one pair of ends of the cores of two electromagnets. The term is also applied to a loose piece of iron placed on the poles of a permanent magnet when it is not in use, although "keeper" is a more usual word in this case.

In reference to the core of a transformer, the term *yokes* may be employed to denote those parts of the core which are not surrounded by windings, as distinct from the *legs*, which are surrounded by the windings.

Y PLATE. In a cathode-ray tube, one of the pair of plates to which voltages are applied to deflect the electron beam vertically. It is named in accordance with the Cartesian system of coordinates. When examining wave forms the Y plates are connected to the source of the signal under investigation, or to the output of an amplifier, known as the Y amplifier, the input of which is connected to the signal under investigation. See X PLATE, Y AMPLIFIER.

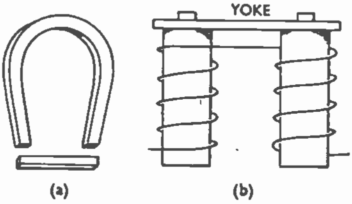


Fig. 2. The "keeper" on an ordinary horseshoe magnet (*a*) is an example of a yoke; a more typical one (*b*) is that linking the cores of an electromagnet.

Y SHIFT. In an oscilloscope, the name given to a control by operation of which the trace can be moved vertically up or down the screen. In effect the control applies a steady bias to the Y plates. See Y PLATE.

Z

ZEPPELIN AERIAL. Horizontal half-wave dipole, end-fed and operated under standing-wave conditions with tuned feeders (Fig. 1). This aerial is much used by amateurs, and is generally known as a "Zepp" aerial. See STANDING-WAVE AERIAL.

ZERO BEAT. Condition which results when the frequency of one oscillation is adjusted to precise equality with that of another. For example, a locally generated oscillation may be set to the same frequency as that of an incoming signal, as in homodyne reception. See BEAT RECEPTION.

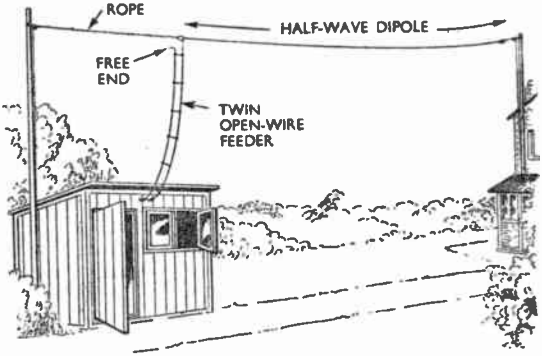


Fig. 1. Zeppelin aerial, the twin feeder of which is operated as a "tuned" or standing-wave system and is carefully adjusted for length to ensure maximum input to the end-fed dipole. The free end, here shown floating because it is not connected to the aerial, would in practice be suitably anchored.

ZERO-BEAT RECEPTION. Synonym for HOMODYNE RECEPTION.

ZERO CLEARING. Synonym for MINIMUM CLEARING.

ZERO-CUT CRYSTAL. Piezo-electric quartz crystal so cut in relation to the crystallographic axes as to have a zero temperature/frequency coefficient.

ZERO-FREQUENCY CURRENT. Term signifying a direct current. It arises in the following manner: a capacitor has a reactance that is inversely proportional to the frequency of the voltages applied to it; if this frequency is zero, the capacitor has an infinite reactance. Direct current cannot flow through a capacitor.

If transmission is based upon modulating a carrier wave, then ordinary telephony, in which the output from a microphone, is transmitted through a line, can be considered as a carrier-wave-transmission system in which the carrier-wave frequency is zero. See CARRIER WAVE, CARRIER-WAVE TRANSMISSION, REACTANCE.

ZERO LEVEL. Term denoting a power or voltage with which other powers or voltages are compared, when these are expressed in decibel notation. The reference power or voltage is called the zero level. Zero power level is usually taken as 1 mW, and zero voltage level as 0·775 volt (equivalent to a power of 1 mW in 600 ohms) or 1 volt. For example, +16 db. means a power that is 16 decibels above 1 mW, i.e., 40 mW, and −20 db. means a power that is 20 db. less than 1 mW, or one hundredth of a milliwatt.

ZERO-LEVEL SENSITIVITY. Of an echo-suppressor, the voltage level necessary at a point of zero relative level in the circuit containing the echo-suppressor to give a suppression loss of 6 db. It is expressed in decibels relative to 0·775 volt and is measured at the frequency of maximum sensitivity. See ECHO-SUPPRESSOR, RELATIVE LEVEL.

ZERO-LOSS CIRCUIT. Circuit containing amplifiers the gain of which is adjusted so that the power obtained at the receiving end is substantially the same as that introduced at the sending end over the voice-frequency range.

ZERO-TRANSMISSION NETWORK. Synonym for NULL NETWORK.

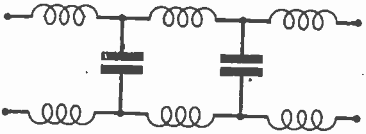


Fig. 2. One example of a Zobel filter. It is a low-pass type with series inductance and shunt capacitance.

z.f. Abbreviation for zero frequency. See ZERO-FREQUENCY CURRENT.

ZINCITE. Oxide of zinc which occurs occasionally in the crystalline form. In some forms of permanent and semi-permanent crystal detector, such as the perikon detector, a zincite crystal is held in contact with a bornite crystal. See CRYSTAL DETECTOR.

ZOBEL FILTER. Filter circuit of the type described by Zobel and designed according to the principles laid down by him. Such filters are built up of inductance and capacitance arranged as series and shunt elements. The low-pass filter illustrated in Fig. 2 is one example of a Zobel filter. See FILTER, LOW-PASS FILTER.

ZONE TELEVISION. Television service given from many senders radiating the same programme, as in SIMULTANEOUS BROADCASTING (q.v.). The difficulties in spreading a television service throughout a country are twofold: first, the very short waves that have to be used have a reception range limited to, at most, 75 miles; second, the wide band of frequencies representing a television programme cannot be transmitted over ordinary telephone lines, as can sound programmes. Thus a number of senders, each serving a zone, are required, and the transmission lines for simultaneous broadcasting of television programmes have to take the form of co-axial cables. See HIGH-DEFINITION TELEVISION, SERVICE AREA, TRANSMISSION LINE.

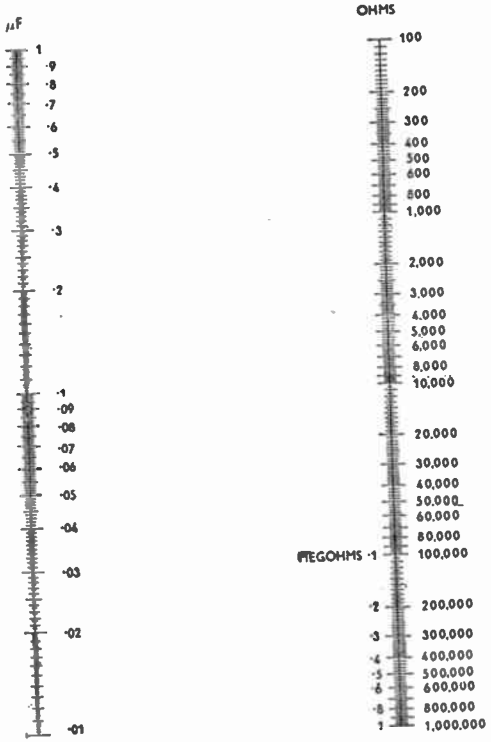
REFERENCE SECTION

ABACS

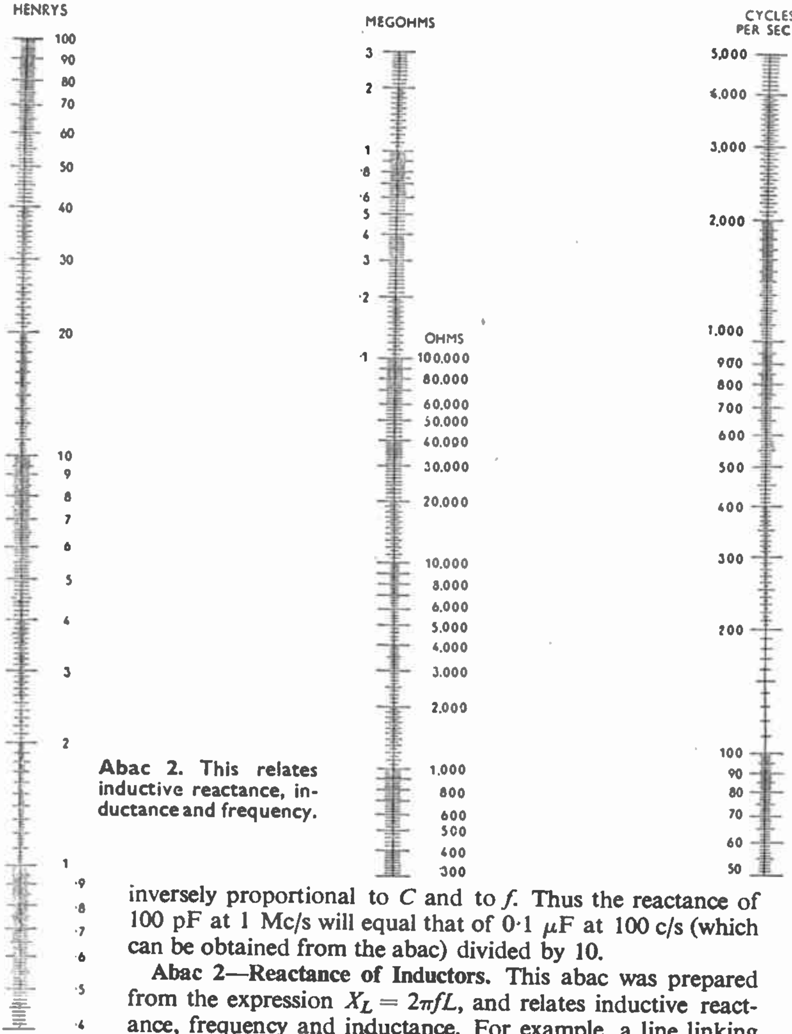
If any two of three related quantities are known, the third can be determined by use of a suitable abac. To determine an unknown, draw a straight line, or place the straight edge of a ruler, across the abac to intersect the two appropriate vertical scales at the known values. Where this line or straight edge meets the third scale it indicates the wanted value.

Abac 1—Reactance of Capacitors. Prepared from the expression $X_C = 1/2\pi fC$, this abac relates capacitive reactance, frequency and capacitance. If any two of these quantities are known, the third can be found as explained above. For example, a line linking 0·1 μF with 10,000 ohms cuts the right-hand scale at 160 c/s, showing that the frequency at which 0·1 μF has a reactance of 10,000 ohms is 160 c/s.

Although the scales are drawn for low audio frequencies only, they can be used for calculations at any frequencies because capacitive reactance is



Abac 1. Relationship between capacitive reactance, frequency and capacitance.

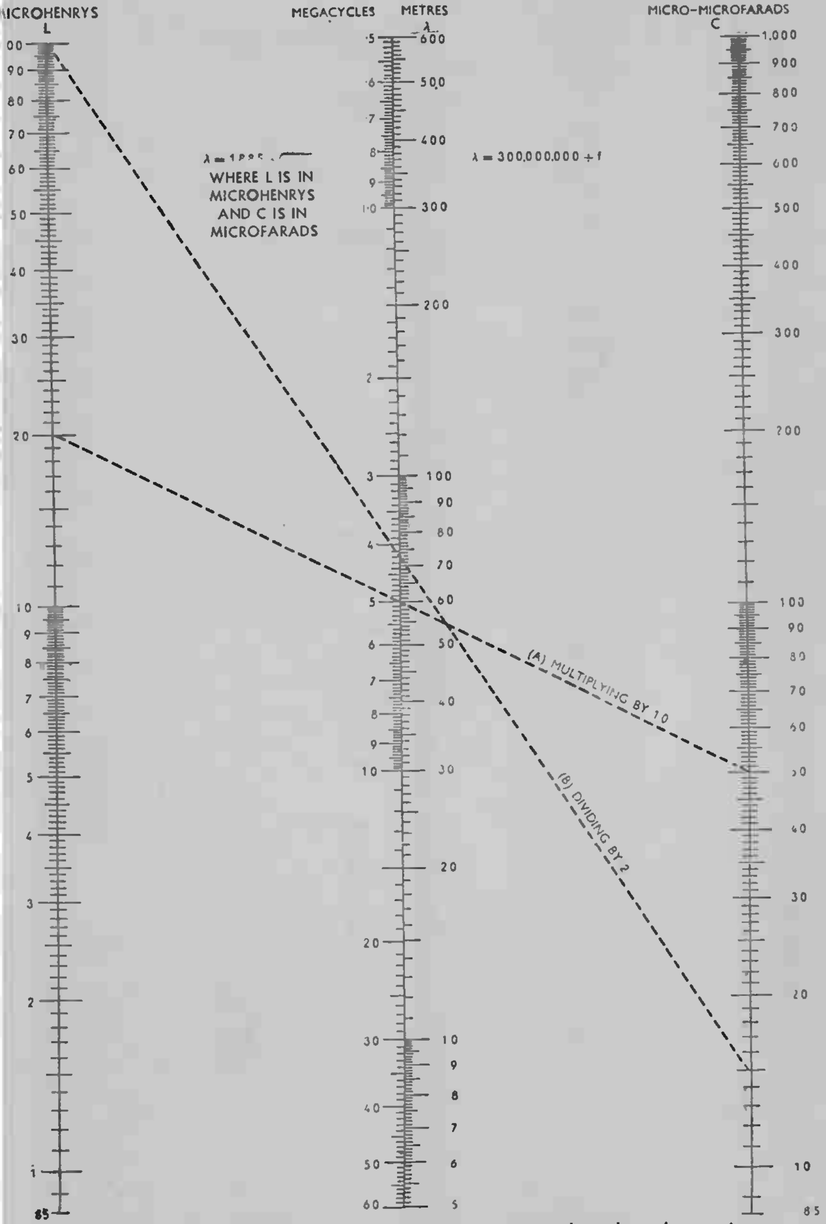


Abac 2. This relates inductive reactance, inductance and frequency.

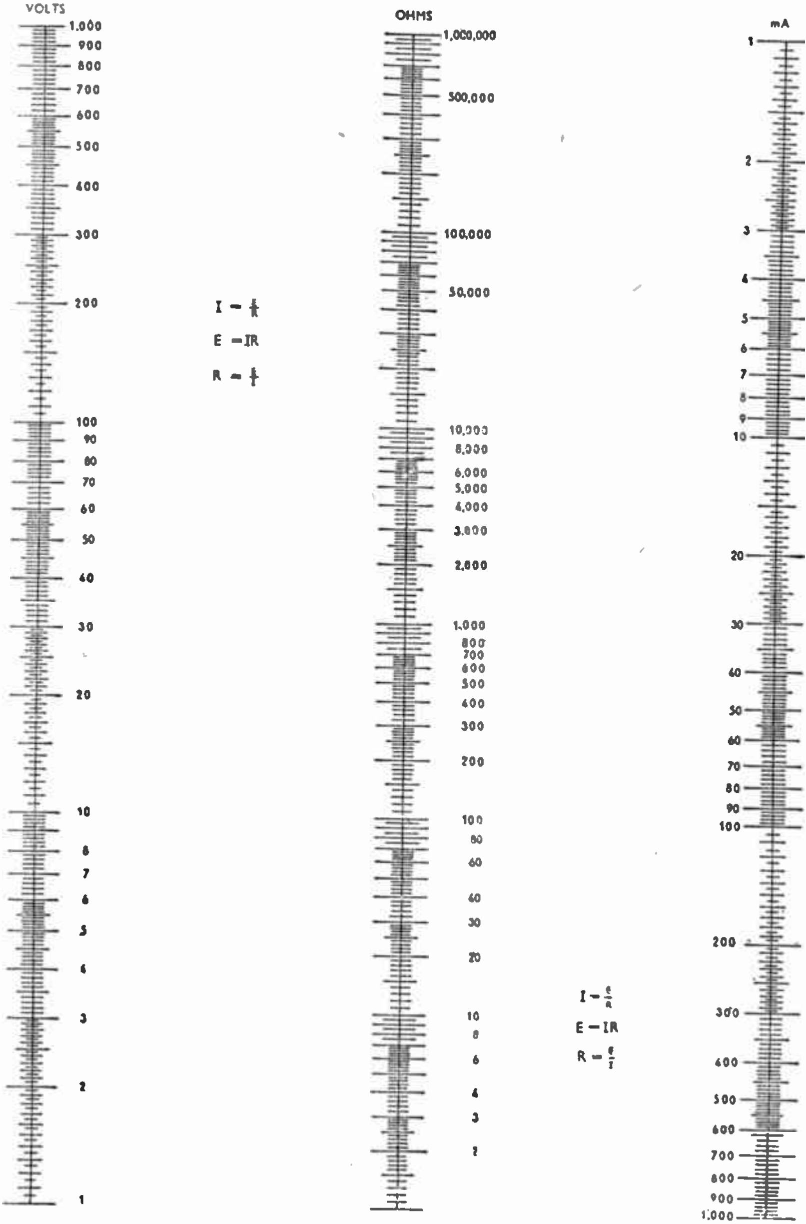
inversely proportional to *C* and to *f*. Thus the reactance of 100 pF at 1 Mc/s will equal that of 0·1 μF at 100 c/s (which can be obtained from the abac) divided by 10.

Abac 2—Reactance of Inductors. This abac was prepared from the expression $X_L = 2\pi f L$, and relates inductive reactance, frequency and inductance. For example, a line linking 1 H with 1,000 c/s cuts the centre scale just above 6,000 ohms, showing that the reactance of 1 H at 1,000 c/s is just over 6,000 ohms. Although the scales are drawn for audio frequencies only, they can be readily adapted for any frequencies or values of *L*, because inductive reactance is directly proportional to *L* and to *f*. Thus the reactance of 1 μH at 1 Mc/s will equal that of 1 H at 1,000 c/s (which can be obtained from the abac) divided by 1,000.

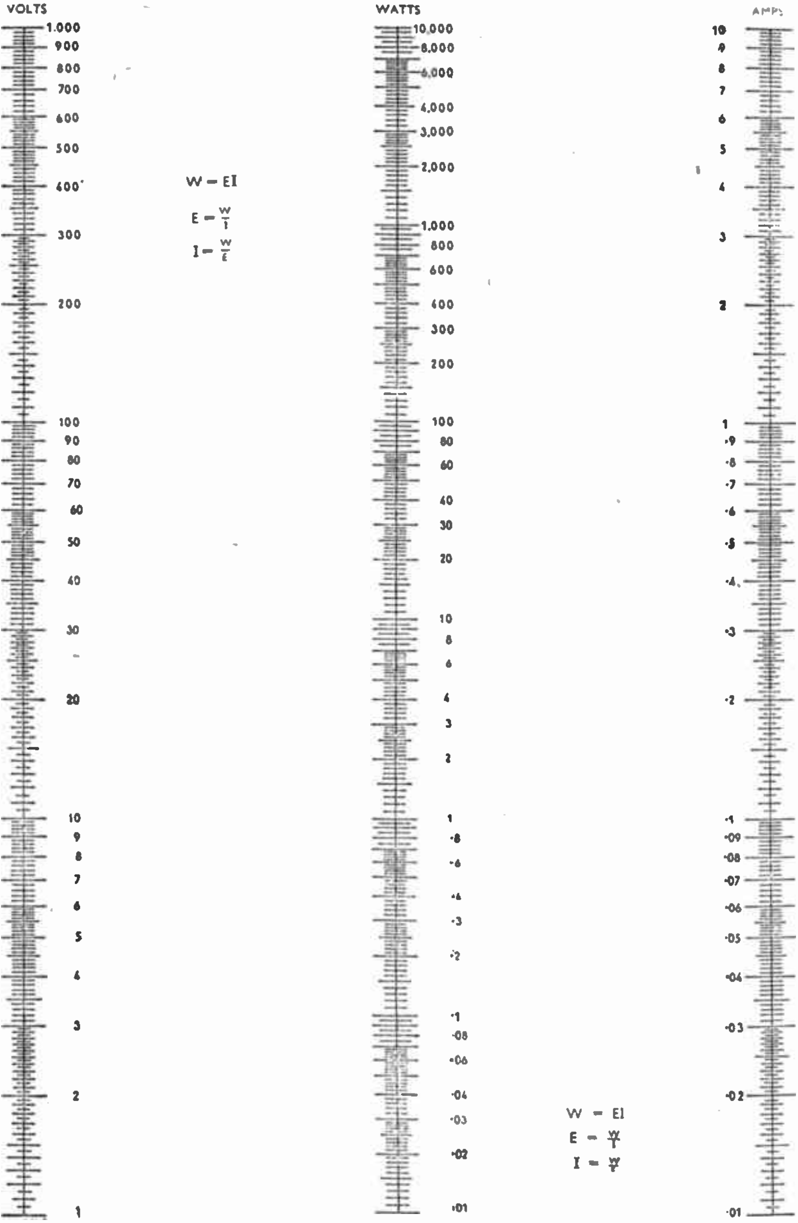
Abac 3—Resonant Frequencies. The centre column of this abac was



Abac 3. This relates inductance, frequency, wavelength and capacitance.



Abac 4. Relationship between voltage, resistance and current.



Abac 5. This relates voltage and current to power in watts.

prepared from the expression $\lambda = v/f$; it relates wavelength in metres with frequency in Mc/s, and shows, for example, that a wavelength of 100 metres corresponds to 3 Mc/s. The outer columns were prepared from the expression $\lambda = 1{,}885\sqrt{LC}$ and relate inductance, capacitance and frequency (or wavelength). If any two of these quantities are known the third can be found. For example, a straight line linking 30 μH with 3 Mc/s passes through the third column at 93 pF showing that to tune 30 μH to 3 Mc/s requires a capacitance of 93 pF.

The scales can be used to cover any range of L, C and f, because f is inversely proportional to the square root of L and of C. Thus, if L and C are both multiplied by 10, the frequency is divided by 10. As an example, the resonant frequency of 200 μH and 500 pF is equal to that of 20 μH and 50 pF (indicated by dotted line *A*) divided by 10; it is thus 500 kc/s. Similarly, the resonant frequency of 200 μH and 30 pF is equal to that of 100 μH and 15 pF (dotted line *B*) divided by 2, and is thus 2·1 Mc/s.

Abac 4—Ohm's Law. This abac, based on Ohm's law, relates current, voltage and resistance. When any two of these three quantities are known, the third can be determined as explained in the introductory paragraph to this section. The scales can be used for quantities of any magnitude because current is directly proportional to voltage and inversely proportional to resistance. Thus, the current which 0·1 volt drives through 100 ohms is 1/100th of that which 10 volts drives through 100 ohms, which can be read off directly from the abac as 100 mA. The required value is therefore 1 mA.

Abac 5—Power. This abac relates current, voltage and power in watts. When any two of these quantities are given the third can be determined from the abac as explained in the first paragraph of this section. The scales can be used for quantities of any magnitude because the power is directly proportional to voltage and to current. Thus the power dissipated by 100 volts and 5 mA is 1/100th of that dissipated by 100 volts and 0·5 amp., which can be read off directly from the abac as 50 watts. The answer to the problem is therefore 0·5 watt.

USEFUL FORMULAE

The formulae given on this and the following pages are representative of those most likely to be required by both the practising radio engineer and student. They are grouped conveniently under main headings and a worked example is given in respect of each. Although the formulae are not specifically explained, the examples, based on practical requirements, will themselves demonstrate the applications of the equations, all of which can be solved arithmetically. Trigonometrical ratios are not required, but the use of logarithms (see pages 766–767) or a slide rule may be a convenience.

INDUCTANCE

Parallel-wire Line.

$$L = 0{\cdot}276 \log_{10}\frac{2D}{d},$$

where L is the inductance in microhenrys per foot length of line, d is the diameter of the conductors (assumed equal) in any units, and D is the distance between the centres of the conductors in the same units.

Example. If the line consists of two 16-S.W.G. conductors spaced 6 in. apart, the inductance is given by:

$$L = 0{\cdot}276 \log_{10} \frac{12}{0{\cdot}064} = 0{\cdot}276 \times 2{\cdot}2730 = 0{\cdot}6273\ \mu\text{H / ft.}$$

Concentric Line.

$$L = 0{\cdot}138 \log_{10} \frac{D}{d},$$

where L is the inductance in microhenrys per foot length of line, d is the outer diameter of the inner conductor in any units, and D is the inner diameter of the outer conductor in the same units.

Example. If the outer diameter is 2 in. and the inner diameter 1 in., the inductance is given by:

$$L = 0{\cdot}138 \log_{10} \frac{2}{1} = 0{\cdot}138 \times 0{\cdot}3010 = 0{\cdot}04154\ \mu\text{H / ft.}$$

Single-layer Coil.

$$L \approx \frac{0{\cdot}2N^2D^2}{3{\cdot}5D + 8l},$$

where L is the inductance in microhenrys, N is the total number of turns, D is the external diameter in inches, and l is the length of the winding in inches. To obtain the number of turns necessary to give a required inductance in a coil of given shape, the expression may be rewritten thus:

$$\text{N} \approx \frac{\sqrt{5L(3{\cdot}5D + 8l)}}{D}.$$

Example. How many turns are required to give an inductance of 170 μH if the coil has a diameter of 1 in. and if the winding is to occupy 1 in.?

$$N = \frac{\sqrt{5 \times 170(3{\cdot}5 + 8)}}{1} = \sqrt{5 \times 170 \times 11{\cdot}5} = 98.$$

Multi-layer Coil.

$$L \approx \frac{0{\cdot}2N^2D^2}{3{\cdot}5D + 8l} \times \frac{D - 2{\cdot}25d}{D},$$

where the symbols have the meanings given under "Single-layer Coil," and d is the thickness of the winding in inches. To obtain the number of turns necessary to give a required inductance in a coil of given shape, the expression may be rewritten thus:

$$N \approx \sqrt{\frac{5L(3{\cdot}5D + 8l)}{D(D - 2{\cdot}25d)}}.$$

Example. A long-wave coil is required to have an inductance of 2,200 μH. The diameter is 1 in., the winding thickness ¼ in. and the winding length ¼ in. How many turns are necessary?

$$N \approx \sqrt{\frac{5 \times 2{,}200(3{\cdot}5 + 2)}{1(1 - 2{\cdot}25 \times 0{\cdot}25)}} \approx \sqrt{\frac{11{,}000 \times 5{\cdot}5}{0{\cdot}44}} \approx 370.$$

Coil with Closed Magnetic Circuit.

$$L = \frac{3{\cdot}19N^2\mu a \times 10^{-8}}{l},$$

where L is the inductance in henrys, N is the total number of turns, μ is the permeability (at the working flux density), a is the cross-sectional area of the magnetic circuit in square inches, and l is the mean length of the magnetic circuit in inches. To obtain the number of turns necessary to give a required inductance in a coil of given shape, the expression may be rewritten thus:

$$N = 10^4 \times \sqrt{\frac{Ll}{3{\cdot}19\mu a}}.$$

Example. An iron-cored inductor is required to have an inductance of 10 H. The magnetic circuit has a length of 6 in. and a cross-sectional area of 1 sq. in. If the permeability is 2,000, how many turns are necessary?

$$N = 10^4 \times \sqrt{\frac{10 \times 6}{3{\cdot}19 \times 2{,}000 \times 1}} = 10^4 \times \sqrt{\frac{60}{6{,}380}} = 970.$$

Coil with Magnetic Circuit including Air-gap.

$$L = \frac{3{\cdot}19N^2 \times 10^{-8}}{\dfrac{l_1}{\mu_1 a_1} + \dfrac{l_2}{a_2}},$$

where L, N, μ_1, a_1 and l_1 are as defined under "Coil with Closed Magnetic Circuit," l_2 is the length of the magnetic path in the air-gap in inches, and a_2 is the cross-sectional area of the air-gap in square inches. To obtain the number of turns necessary to give a required inductance in a coil of given shape, the expression may be rewritten thus:

$$N = 10^4 \times \sqrt{\frac{L\left(\dfrac{l_1}{\mu_1 a_1} + \dfrac{l_2}{a_2}\right)}{3{\cdot}19}}.$$

Example. Suppose that in the previous example the magnetic circuit includes an air-gap of 10 mil thickness. How many turns now are necessary to produce the 10-H. inductance?

$$N = 10^4 \times \sqrt{\frac{10\left(\dfrac{6}{2{,}000 \times 1} + \dfrac{0{\cdot}01}{1}\right)}{3{\cdot}19}} = 10^4 \times \sqrt{\frac{10(0{\cdot}003 + 0{\cdot}01)}{3{\cdot}19}}$$

$$= 10^4 \times \sqrt{\frac{10 \times 0{\cdot}013}{3{\cdot}19}} = 2{,}020.$$

Maximum Flux Density and Applied Voltage in an Inductor.

$$V = 4{\cdot}44fNaB_{max.} \times 10^{-8},$$

where V is the applied potential in volts r.m.s., f is the frequency of the potential in cycles per second, N is the total number of turns, a is the cross-sectional area of the core in square inches, and $B_{max.}$ is the maximum flux density in lines per square inch.

Example. An inductor to be connected across 230-volt, 50-c/s mains has a cross-sectional area of 1 sq. in., and the maximum flux density is 50,000 lines/sq. in. How many turns are necessary?

$$N = \frac{V \times 10^8}{4{\cdot}44faB_{max.}} = \frac{230 \times 10^8}{4{\cdot}44 \times 50 \times 1 \times 50{,}000} = 2{,}072.$$

Turns per Volt of an Inductor.

$$T = \frac{10^8}{4{\cdot}44fa\mathrm{B}_{max.}},$$

where T is the number of turns per volt; f, a and $B_{max.}$ are as defined for the previous formula.

Example. If, in the previous example, a is 2 sq. in., how many turns per volt are necessary?

$$T = \frac{10^8}{4{\cdot}44 \times 50 \times 2 \times 50{,}000} = 4{\cdot}5.$$

CAPACITANCE

Capacitance of a Multiple-plate Capacitor.

$$C = \frac{2{\cdot}24 n\kappa A \times 10^{-7}}{t},$$

where C is the capacitance in microfarads, n is the number of thicknesses of insulating material, κ is the permittivity of the insulating material, A is the area in square inches of one plate (all plates are assumed of equal area), and t is the thickness of one sheet of insulating material in inches.

Example. A tuning capacitor has 25 plates in the shape of semicircles of diameter $2\frac{1}{2}$ in. The average thickness of the air dielectric is 0·025 in. The capacitance is given by:

$$C = \frac{2{\cdot}24 \times 24 \times 1 \times 3{\cdot}142 \times 2{\cdot}5^2 \times 10^{-7}}{8 \times 0{\cdot}025} = 0{\cdot}000528\,\mu\text{F}.$$

Parallel-wire Line.

$$C = \frac{3{\cdot}677}{\log_{10}\dfrac{2D}{d}},$$

where C is the capacitance in picofarads per foot length of line, d is the diameter of the conductors (assumed equal) in any units, and D is the distance between the centres of the conductors in the same units.

Example. Find the capacitance per foot of a line consisting of two 16-S.W.G. conductors spaced 6 in. apart.

$$C = \frac{3{\cdot}677}{\log_{10}\dfrac{12}{0{\cdot}064}} = \frac{3{\cdot}677}{2{\cdot}2730} = 1{\cdot}618\text{ pF/ft.}$$

Concentric Line.

$$C = \frac{7{\cdot}354\kappa}{\log_{10}\dfrac{D}{d}},$$

where C is the capacitance in picofarads per foot length of line, d is the outer diameter of the inner conductor in any units, D is the inner diameter of the outer conductor in the same units, and κ is the permittivity of the separating medium.

Example. Find the capacitance per foot of a concentric line where the outer diameter is 2 in. and the inner diameter 1 in., the permittivity being assumed equal to 2·5.

$$C = \frac{7{\cdot}354 \times 2{\cdot}5}{\log_{10}\dfrac{2}{1}} = \frac{7{\cdot}354 \times 2{\cdot}5}{0{\cdot}3010} = 61{\cdot}1\text{ pF/ft.}$$

Effective Series Resistance of a Capacitor.

$$R_s = \frac{\text{power factor}}{2\pi fC},$$

where R_s is the effective series resistance in ohms, f is the frequency in cycles per second, and C is the capacitance in farads.

Example. What is the effective series resistance for a capacitor of 100 pF having a power factor of 0·001 at 1 Mc/s?

$$R_s = \frac{0{\cdot}001 \times 10^{12}}{2 \times 3{\cdot}142 \times 10^6 \times 100} = 1{\cdot}6 \text{ ohms.}$$

Effective Parallel Resistance of a Capacitor.

$$R_p = \frac{1}{\text{power factor} \times 2\pi fC},$$

where R_p is the effective parallel resistance in ohms; f and C are as defined for the previous formula.

Example. Find the effective parallel resistance of the capacitor mentioned above. $R_p = \dfrac{1}{0{\cdot}001 \times 6{\cdot}284 \times 10^6 \times 100 \times 10^{-12}} = 16\text{M}\Omega.$

RESONANT CIRCUITS

Resonant Frequency of a Tuned Circuit.

$$f = \frac{159{\cdot}2}{\sqrt{LC}}.$$

At audio frequencies, f is the frequency in cycles per second, L is the inductance in henrys, and C is the capacitance in microfarads. At low radio frequencies, f is in kilocycles per second, L is in microhenrys, and C is in microfarads. At high radio frequencies, f is in megacycles per second, L is in microhenrys, and C is in picofarads.

Example 1. To what frequency does a capacitor of 0·01 μF tune an inductor of 1·5 H? $f = \dfrac{159{\cdot}2}{\sqrt{1{\cdot}5 \times 0{\cdot}01}} = \dfrac{159{\cdot}2}{\sqrt{0{\cdot}015}} = 1{,}300$ c/s.

Example 2. What capacitance is necessary to tune an inductor of 160 μH to 877 kc/s?

$$C = \frac{159{\cdot}2^2}{f^2L} = \frac{159{\cdot}2^2}{877^2 \times 160} = 0{\cdot}000206\ \mu\text{F}.$$

Example 3. What inductance is necessary to tune a capacitor of 100 pF to 5·7 Mc/s?

$$L = \frac{159{\cdot}2^2}{f^2C} = \frac{159{\cdot}2^2}{5{\cdot}7^2 \times 100} = 7{\cdot}8\ \mu\text{H}.$$

Wavelength of a Tuned Circuit.

$$\lambda = 1{,}885\sqrt{LC},$$

where λ is the wavelength in metres, L is the inductance in microhenrys, and C is the capacitance in microfarads.

Example. What capacitance is necessary to tune a coil of 2,200 μH inductance to 1,500 metres?

$$C = \frac{\lambda^2}{1{,}885^2 \times L} = \frac{1{,}500^2}{1{,}885^2 \times 2{,}200} = 0{\cdot}0002877\ \mu\text{F}.$$

Impedance or Dynamic Resistance of Parallel-tuned Circuit at Resonance.

$$Z_R = QL\omega = \frac{L^2\omega^2}{R} = \frac{L}{CR},$$

where Z_R is the impedance in ohms, Q is the Q-factor of the inductor, L is the inductance in henrys, $\omega = 2\pi \times$ resonant frequency in cycles per second, R is the radio-frequency resistance of the inductor in ohms, and C is the capacitance in farads.

Example. What is the dynamic resistance of a tuned circuit containing an inductance of 160 μH and a capacitance of 200 pF, the radio-frequency resistance being 15 ohms?

$$Z_R = \frac{L}{CR} = \frac{160 \times 10^{-6}}{200 \times 10^{-12} \times 15} = 53{,}340 \text{ ohms.}$$

Selectivity of Series-tuned Circuit.

$$\frac{I}{I_R} = \frac{1}{\sqrt{1 + \left(\frac{2Q\,\Delta f}{f_o}\right)^2}},$$

where I is the current in any units at a frequency displaced by Δf c/s from the resonant frequency, I_R is the current in the same units at resonance, Q is the Q-factor of the inductor, and f_o is the resonant frequency in cycles per second.

Example. Find the ratio of off-tune current to resonant current for a tuned circuit with a Q-factor of 100, tuned to 1 Mc/s, for a frequency displaced by 10 kc/s from resonance.

$$\frac{I}{I_R} = \frac{1}{\sqrt{1 + \left(\frac{2 \times 100 \times 10}{1{,}000}\right)^2}} = \frac{1}{\sqrt{1+2^2}} = \frac{1}{\sqrt{5}} = 0{\cdot}447.$$

Selectivity of Parallel-tuned Circuit.

$$\frac{Z}{Z_R} = \frac{1}{\sqrt{1 + \left(\frac{2Q\Delta f}{f_o}\right)^2}},$$

where Z is the impedance in any units at a frequency displaced by Δf c/s from the resonant frequency, and Z_R is the impedance at resonance (see expression for "Impedance of Parallel-tuned Circuit at Resonance").

Example. By how many kilocycles per second from resonance must a circuit be mistuned for the impedance to fall to one-half its resonant value? Assume a Q value of 100 and a resonant frequency of 1 Mc/s.

$$\text{If } \frac{Z}{Z_R} = \frac{1}{2}, \text{ clearly } \sqrt{1 + \left(\frac{2Q\,\Delta f}{f_o}\right)^2} = 2, \text{ and } \left(\frac{2Q\,\Delta f}{f_o}\right)^2 = 3,$$

$$\therefore \Delta f = \frac{\sqrt{3}\,f_o}{2Q} = \frac{1{\cdot}732 \times 1{,}000}{200} = 8{\cdot}66 \text{ kc/s.}$$

Mutual-inductance Coupling.

$$k = \frac{M}{\sqrt{L_1 L_2}},$$

where k is the coupling coefficient, M is the mutual inductance in any units, and L_1, L_2 are the inductances of the coupled inductors in the same units.

Example. What must be the mutual inductance between two inductors of 170-μH. inductance to give a coupling coefficient of 0·01?

$$M = k\sqrt{L_1L_2} = 0{\cdot}01 \times 170 = 1{\cdot}7\,\mu\text{H}.$$

Peak Frequencies of two similar Over-coupled Tuned Circuits.

$$f_1 = \frac{f_o}{\sqrt{1+k}};\ f_2 = \frac{f_o}{\sqrt{1-k}};$$

where f_1 is the lower of the two peak frequencies in any units, f_o is the resonant frequency of the tuned circuits in the absence of coupling and in the same units, f_2 is the higher of the peak frequencies, again in the same units, and k is the coefficient of coupling between the circuits.

Example. Find the peak frequencies when the resonant frequency is 1 Mc/s and the coefficient of coupling is 0·015.

$$f_1 = \frac{1{,}000}{\sqrt{1+0{\cdot}015}} \approx \frac{1{,}000}{1{\cdot}0075} \approx 992{\cdot}5\ \text{kc/s};$$

$$f_2 = \frac{1{,}000}{\sqrt{1-0{\cdot}015}} \approx \frac{1{,}000}{\sqrt{0{\cdot}985}} \approx \frac{1{,}000}{0{\cdot}9925} \approx 1{,}007{\cdot}5\ \text{kc/s}.$$

Peak Separation of two similar Over-coupled Tuned Circuits.

$$\Delta f = kf_o,$$

where Δf is the peak separation in any units, f_o is the resonant frequency of the tuned circuits in the absence of coupling and in the same units, and k is the coefficient of coupling between the circuits.

Example. What must be the coefficient of coupling between two tuned circuits resonant at 800 kc/s to give a peak separation of 14 kc/s?

$$k = \frac{\Delta f}{f_o} = \frac{14}{800} = 0{\cdot}0175.$$

Band Width of two similar Over-coupled Tuned Circuits.

$$\Delta f = \sqrt{2}kf_o,$$

where the symbols have the meanings given for the previous expression.

Example. A pair of over-coupled long-wave coils are required to give a band width of 12 kc/s when tuned to 200 kc/s. What must be the value of k?

$$k = \frac{\Delta f}{\sqrt{2}f_o} = \frac{12}{200 \times \sqrt{2}} = 0{\cdot}0425.$$

A.F. AND R.F.

Total Emission Current of a Valve.

$$I = aT^2e^{-b/T},$$

where I is the total emission current in amperes per square inch of cathode surface, T is the temperature of the cathode in degrees absolute, a and b are constants characteristic of the emitting surface, and e is the base of Napierian logarithms, 2·71828...

Example. For a particular cathode material a = 0·1 and b = 11,600. The total emission for a cathode temperature of 600 deg. C. is given by:

$$T = 273 + 600 = 873;$$

$$I = 0{\cdot}1 \times 873^2 \times e^{-\frac{11{,}600}{873}} = \frac{0{\cdot}1 \times 873^2}{e^{13{\cdot}16}} = \frac{0{\cdot}1 \times 873^2}{5{\cdot}26 \times 10^5} = 145\text{mA}.$$

Stage Gain of a Valve with Direct-coupled Resistive Load.

(*a*) *At Medium Frequencies:* $A_{mf} = \dfrac{\mu R_l}{r_a + R_l}$,

where A_{mf} is the stage gain at medium frequencies, μ is the amplification factor of the valve, R_l is the effective load resistance in ohms, and r_a is the anode slope-resistance of the valve in ohms. If R_l is small compared with r_a,

$$A_{mf} \approx \frac{\mu R_l}{r_a} = g_m R_l,$$

where g_m is the mutual conductance of the valve in amperes per volt. R_l is given by:

$$R_l = \frac{R_a R_{gl}}{R_a + R_{gl}},$$

where R_a is the value of the anode load resistor in ohms, and R_{gl} is the value of the following grid leak in ohms.

Example. A valve has an r_a of 20,000 ohms and a μ of 50. What must be the value of effective anode load to give a stage gain of 35? By rearrangement of the first expression,

$$R_l = \frac{A_{mf} r_a}{\mu - A_{mf}} = \frac{35 \times 20{,}000}{50 - 35} = \frac{35 \times 20{,}000}{15} \approx 47{,}000 \text{ ohms.}$$

(*b*) *At High Frequencies:* $A_{hf} = \dfrac{A_{mf}}{\sqrt{1 + \omega^2 C^2 R^2}}$,

where A_{hf} is the stage gain at high frequencies, A_{mf} is the stage gain at medium frequencies [see (*a*)], $\omega = 2\pi$ times the frequency in cycles per second, C is the capacitance in farads shunting R_a, and R is defined by:

$$\frac{1}{R} = \frac{1}{r_a} + \frac{1}{R_a} + \frac{1}{R_{gl}}.$$

Example. In the previous example the total capacitance shunting the anode circuit is 200 pF. Find the ratio of the response at 10 kc/s to that at 1 kc/s. Neglect R_{gl}.

$$R = \frac{R_a r_a}{r_a + R_a} = \frac{20{,}000 \times 47{,}000}{67{,}000} = 14{,}000,$$

$$\frac{A_{hf}}{A_{mf}} = \frac{1}{\sqrt{1 + \omega^2 C^2 R^2}} = \frac{1}{\sqrt{1 + 6{\cdot}284^2 \times 10^8 \times 200^2 \times 10^{-24} \times 14^2 \times 10^6}}$$

$$= \frac{1}{\sqrt{1{\cdot}031}} = \frac{1}{1{\cdot}016} = 0{\cdot}984.$$

(*c*) *At Low Frequencies:* $A_{lf} = \dfrac{A_{mf}}{\sqrt{1 + 1/\omega^2 C^2 R_{gl}^2}}$,

where A_{lf} is the stage gain at low frequencies, A_{mf} is the stage gain at medium frequencies [see (*a*)], $\omega = 2\pi$ times the frequency in cycles per second, C is the capacitance of the coupling capacitor in farads, and R_{gl} is the resistance in ohms of the following grid leak.

Example. The stage gain of an amplifier at 30 c/s is required to be one half that at 1 kc/s. If the value of the grid leak is 0·5 MΩ, what must be the value of the coupling capacitor?

If $A_{lf} = \frac{1}{2} A_{mf}$, $\sqrt{1 + 1/\omega^2 C^2 R_{gl}^2}$ must equal 2, and $1/\omega^2 C^2 R_{gl}$ must equal 3.

$$\therefore 1/\omega C R_{gl} = \sqrt{3}, \text{ and } C = \frac{1}{\sqrt{3}\,\omega R_{gl}} = \frac{1}{1{\cdot}732 \times 6{\cdot}284 \times 30 \times 0{\cdot}5 \times 10^6}$$
$$= 0{\cdot}00612\,\mu\text{F}.$$

Stage Gain—Valve with Unloaded Transformer.

$$A = \frac{\mu K \sqrt{L^2\omega^2 + R^2}}{\sqrt{(r_a + R)^2 + L^2\omega^2}},$$

where μ is the amplification factor of the valve, $1 : K$ is the turns ratio of the transformer, R is the primary resistance of the transformer, $\omega = 2\pi$ times the frequency in cycles per second, L is the incremental primary inductance of the transformer, and r_a is the anode slope-resistance of the valve.

Example. An inter-valve transformer has a primary inductance of 100 H, and a primary resistance of 10,000 ohms. If the turns ratio is 1 : 5, what stage gain will be obtained at 100 c/s using a valve with a μ of 50 and an r_a of 20,000 ohms?

$$A = \frac{50 \times 5 \times \sqrt{6{\cdot}284^2 \times 100^2 \times 100^2 + 10{,}000^2}}{\sqrt{(10{,}000 + 20{,}000)^2 + 6{\cdot}284^2 \times 100^2 \times 100^2}}$$
$$\approx \frac{50 \times 5 \times 6{\cdot}284 \times 100 \times 100}{7 \times 10{,}000} \approx \frac{50 \times 5 \times 6{\cdot}284}{7} \approx 224.$$

Power Output—Class-A Operation with Direct-coupled Resistive Load.

$$P = \frac{1}{8}\mu V_g^2 g_m,$$

where P is the power output in watts, μ is the amplification factor of the valve, V_g is the peak grid input signal in volts, and g_m is the mutual conductance in amperes per volt.

Example. Find the output power from a small triode having $\mu = 10$ and $g_m = 2{\cdot}0$ mA/V for an input signal of 4 volts peak.

$$P = \frac{1}{8} \times 10 \times 4^2 \times \frac{2}{1{,}000} = \frac{2 \times 16 \times 10}{8 \times 1{,}000} = 40 \text{ mW}.$$

Power Output—Class-A Operation.

$$P = \frac{(V_{max.} - V_{min.})\,(I_{max.} - I_{min.})}{8},$$

where P is the power output in watts, $V_{max.}$ is the maximum instantaneous value of anode potential in volts, $V_{min.}$ is the minimum instantaneous value of anode potential in volts, $I_{max.}$ is the maximum instantaneous value of anode current in amperes, and $I_{min.}$ is the minimum instantaneous value of anode current in amperes.

Example. Find the power output from a pentode valve in which the anode potential swings between 50 and 450 volts, and the anode current between 10 and 75 mA.

$$P = \frac{(450 - 50)\,(75 - 10)}{8 \times 1{,}000} = \frac{400 \times 65}{8{,}000} = \frac{65}{20} = 3{\cdot}25 \text{ watts}.$$

Optimum Load—Class-A Operation.

$$R = \frac{V_{max.} - V_{min.}}{I_{max.} - I_{min.}},$$

where R is the value of the optimum load in ohms; other symbols as

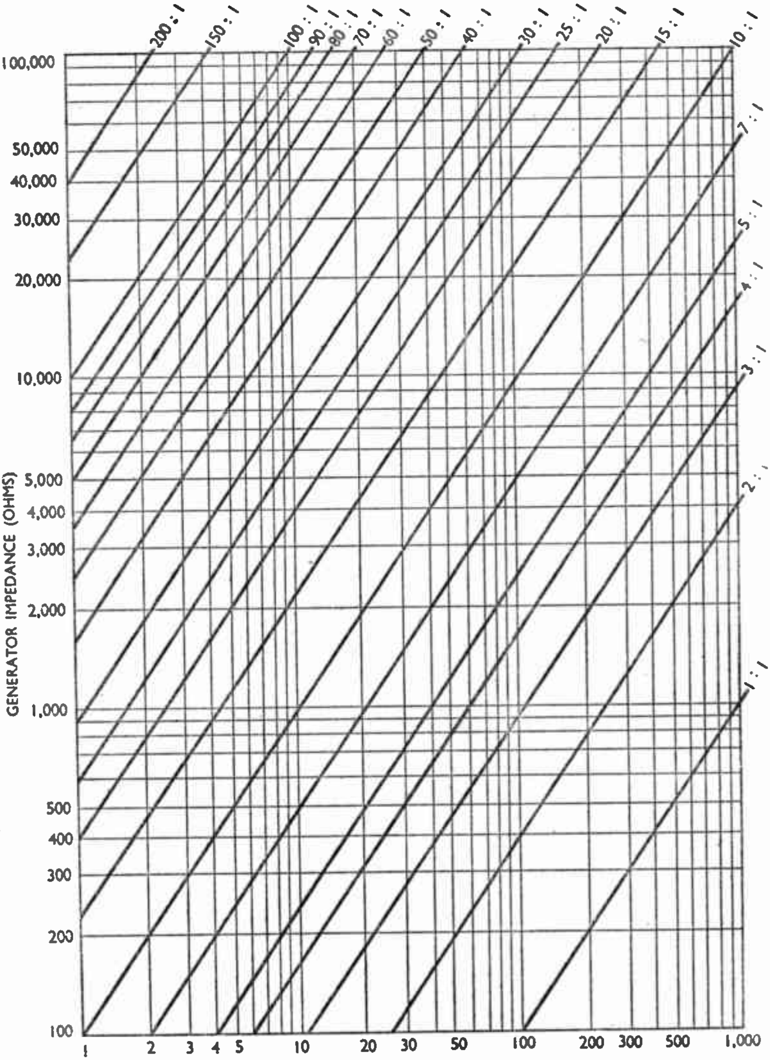


Fig. 1.

defined for the previous expression for calculating the power output.

Example. Calculate the optimum load for the valve mentioned in the previous example.

$$R = \frac{(450 - 50) \times 1{,}000}{75 - 10} = \frac{400 \times 1{,}000}{65} = 6{,}150 \text{ ohms.}$$

Turns Ratio of an Output Transformer.

$$K = \sqrt{\frac{R_l}{R}},$$

where $K : 1$ is the turns ratio of the output transformer for perfect matching, R_l is the optimum load of the valve in ohms, and R is the impedance of the load in ohms. To simplify calculation of output transformer ratios, Fig. 1 has been prepared. From it the correct ratio can be determined for any optimum load (or generator impedance) between 100 and 100,000 ohms, and for any load impedance between 1 and 1,000 ohms.

Example. An output valve has an optimum load of 5,000 ohms. What should be the turns ratio of an output transformer to connect this valve to a loudspeaker having an impedance of 4 ohms? From Fig. 1 the ordinate through 4 ohms meets the horizontal line through 5,000 ohms midway between 30 : 1 and 40 : 1. Thus the correct ratio is 35 : 1.

Anode Efficiency—Class-A Operation.

$$\eta = \frac{100\,(V_{max.} - V_{min.})\ (I_{max.} - I_{min.})}{8V_aI_a},$$

where η is the percentage efficiency, $V_{max.}$, $V_{min.}$, $I_{max.}$ and $I_{min.}$ are as previously defined, V_a is the steady component of anode potential in volts and I_a is the steady component of anode current in volts.

Example. Calculate the efficiency of the valve mentioned in the example of calculating power output, given that the steady anode potential is 250 volts and the steady anode current 45 mA.

$$\eta = \frac{100\,(450 - 50)\,(75 - 10)}{8 \times 250 \times 45} = \frac{100 \times 400 \times 65}{8 \times 250 \times 45} = 28{\cdot}8 \text{ per cent.}$$

Second-harmonic Distortion.

$$H_2 = 100 \times \frac{I_{max.} + I_{min.} - 2I_a}{I_{max.} - I_{min.}},$$

where H_2 is the percentage of second-harmonic distortion, $I_{max.}$ is the maximum instantaneous value of anode current in any units, $I_{min.}$ is the minimum instantaneous value of anode current in the same units, and I_a is the mean value of the anode current in the same units. The expression may also be written: $H_2 = 100 \times \dfrac{I_{max.} + I_{min.} - 2I_o}{2(I_{max.} - I_{min.})}$,

where I_o is the anode current in the absence of an input signal in the same units as used for $I_{max.}$ and $I_{min.}$

Example. The no-signal current of an output valve is 45 mA. This rises to 85 mA and falls to 10 mA when a sinusoidal signal is applied. The second-harmonic distortion is given by:

$$H_2 = 100 \times \frac{85 + 10 - 90}{2\,(85 - 10)} = 100 \times \frac{5}{2 \times 75} = \frac{500}{150} = 3{\cdot}3 \text{ per cent.}$$

Input Impedance of a Valve.

$$C = c_{gk} + c_{ag}\,(1 + A\cos\theta),$$

$$R = -\frac{1}{\omega\, c_{ag}\, A\ \sin\ \theta},$$

in which C is the input capacitance in picofarads, c_{gk} is the grid–cathode capacitance of the valve in picofarads, c_{ag} is the grid–anode capacitance in picofarads, A is the stage gain of the valve (excluding any gain due to a transformer), θ is the phase angle by which the anode potential leads the anode current, $\omega = 2\pi$ times the frequency in cycles per second, and R is the input resistance in megohms.

Example. A valve has c_{gk} of 20 pF and c_{ag} of 0·02 pF. Find the input capacitance and resistance at 1 Mc/s, if the stage gain is 100 and the phase angle 30 deg.

$$C = 20 + 0{\cdot}02\,(1 + 100\cos 30) = 20 + 0{\cdot}02\,(1 + 100 \times 0{\cdot}866)$$
$$= 20 + 0{\cdot}02 \times 87{\cdot}6 = 20 + 1{\cdot}752 = 21{\cdot}75 \text{ pF.}$$
$$R = -\frac{10^{12}}{6{\cdot}284 \times 10^{6} \times 0{\cdot}02 \times 100 \times 0{\cdot}5} = -\,159{,}000 \text{ ohms.}$$

Maximum Stage Gain of Single-stage R.F. Amplifier.

$$A = \frac{2}{\omega Z_d c_{ag}},$$

where A is the maximum stage gain obtainable without instability, $\omega = 2\pi$ times the frequency in cycles per second, Z_d is the dynamic resistance in ohms of the tuned circuits in grid and anode circuits (assumed identical), and c_{ag} is the anode–grid capacitance in farads.

Example. Find the maximum stage gain obtainable from a valve at 200 kc/s if c_{ag} is 0·01 pF, and $Z_d = 100{,}000$ ohms.

$$A = \frac{2 \times 10^{12}}{6{\cdot}284 \times 200 \times 10^{3} \times 100{,}000 \times 0{\cdot}01} = 1{,}592.$$

Stage Gain of Tuned-anode or Tuned-grid R.F. Amplifier.

$$A = \frac{\mu L\omega Q}{r_a + L\omega Q},$$

where A is the stage gain, L is the inductance in henrys in the tuned circuit, $\omega = 2\pi$ times the frequency in cycles per second, Q is the Q-factor of the tuned circuit, r_a is the anode slope-resistance of the valve in ohms, and μ is the amplification factor. If r_a greatly exceeds the dynamic resistance ($L\omega Q$) of the tuned circuit, the stage gain becomes $A \approx g_m L\omega Q$, where g_m is the mutual conductance of the valve in amperes per volt.

Example. An R.F. valve has a slope of 2 mA/V and an r_a of 1 MΩ. What gain can be obtained from a medium-wave circuit having a Q-value of 100, and an inductance of 160 μH, at 1·5 Mc/s?

$$L\omega Q = 160 \times 10^{-6} \times 6{\cdot}284 \times 1{\cdot}5 \times 10^{6} \times 100 = 151{,}000 \text{ ohms.}$$

This is small compared with r_a, and use may be made of the simplified expression: $A \approx 2 \times 10^{-3} \times 151{,}000 = 302$.

Stage Gain of R.F. Amplifier—R.F. Transformer with Tuned Secondary.

$$A = \frac{\mu M L\omega^2}{r_a R + M^2\omega^2},$$

where A is the stage gain, M is the mutual inductance, in henrys, between the windings of the R.F. transformer, L is the inductance in henrys of the tuned secondary winding, $\omega = 2\pi$ times the frequency in cycles per second, r_a is the anode slope-resistance in ohms, μ the amplification factor, and R the radio-frequency resistance in ohms of the tuned circuit.

Example. In the previous example, let $\mu = 2{,}000$ and $M = 50\ \mu\text{H}$. Find the stage gain at 500 kc/s where R is 10 ohms.

$$A = \frac{2{,}000 \times 50 \times 10^{-6} \times 160 \times 10^{-6} \times 500^2 \times 10^6 \times 6{\cdot}284^2}{10^6 \times 10 + 50^2 \times 10^{-12} \times 500^2 \times 10^6 \times 6{\cdot}284^2}$$

$$\approx \frac{2 \times 160 \times 1{\cdot}25 \times 6{\cdot}284^2 \times 10^4}{10^7} \approx 16.$$

Optimum Coupling—R.F. Transformer with Tuned Primary and Secondary.

$$k = \frac{1}{\sqrt{Q_1 Q_2}},$$

where k is the optimum value of the coupling coefficient, Q_1 is the effective Q-factor of the primary circuit, including the effect due to damping by the anode slope-resistance of the previous valve, and Q_2 is the effective Q-factor of the secondary circuit, including the effect due to damping by the input resistance of the following valve.

Example. What is the optimum coupling coefficient if the working Q-factors of the primary and secondary circuits are 70 and 90 respectively?

$$k = \frac{1}{\sqrt{70 \times 90}} = 0{\cdot}0126.$$

NEGATIVE FEEDBACK

Gain of Amplifier with Voltage Negative Feedback.

$$A' = \frac{A}{1 + A\beta},$$

where A' is the gain of the amplifier with voltage feedback, A is the stage gain of the amplifier without feedback, and β is the feedback factor.

Example. The gain of an amplifier without feedback is 600. What must be the gain of the feedback loop to reduce this to 120? Rearranging the expression,

$$\beta = \frac{\mathrm{A} - \mathrm{A}'}{\mathrm{AA}'} = \frac{600 - 120}{600 \times 120} = \frac{480}{600 \times 120} = \frac{1}{150}.$$

Effective Slope-resistance of Valve with Voltage Negative Feedback.

$$r_a' = \frac{r_a}{1 + \mu A\beta},$$

where r_a' is the effective anode slope-resistance, in ohms, of the final valve in the amplifier, r_a is the anode slope-resistance, in ohms, in the absence of feedback, μ is the amplification factor of the final valve, A is the stage gain of the amplifier from the point of application of the feedback voltage to the grid of the final valve, and β is the feedback factor.

Example. Voltage negative feedback is applied over the final valve only of an amplifier. The anode slope-resistance is 50,000 ohms and the μ 400. Find the effective anode slope-resistance if $\beta = 1/150$.

$$r_a' = \frac{50{,}000}{1 + 400 \times 1 \times \frac{1}{150}} = \frac{50{,}000}{1 + 2{\cdot}667} = \frac{50{,}000}{3{\cdot}667} = 13{,}600 \text{ ohms}.$$

Gain of a Valve with Current Negative Feedback.

$$A' = \frac{g_m R_l}{1 + g_m R_k},$$

where A' is the gain of the valve with feedback, g_m is the working mutual conductance in amperes per volt, R_l is the anode-load resistance in ohms, R_k is the cathode resistance not by-passed in ohms. If $g_m R_k$ considerably exceeds unity, the gain becomes

$$A' \approx \frac{R_l}{R_k}$$

Example. A valve with a g_m of 2 mA/V, and an anode load of 100,000 ohms, is required to give a gain of 30. What must be the value of the cathode resistor? Rearranging the expression

$$R_k = \frac{g_m R_l - A'}{g_m A'} = \frac{2 \times 10^{-3} \times 10^{5} - 30}{30 \times 2 \times 10^{-3}} = \frac{200 - 30}{60 \times 10^{-3}} = \frac{170 \times 10^{3}}{60} = 2{,}800 \text{ ohms.}$$

Effective Slope-resistance of Valve with Current Negative Feedback.

$$r_a' = r_a + (\mu + 1)R_k,$$

where r_a' is the effective anode slope-resistance, in ohms, of the valve with feedback, r_a is its value, in ohms, without feedback, μ is the amplification factor of the valve, and R_k is the value, in ohms, of the resistance across which the feedback voltage is developed.

Example. If the r_a of the valve in the previous example is 1 MΩ, what is its effective value when the current feedback is applied?

$$\mu = g_m r_a = 2 \times 10^{-3} \times 10^{6} = 2{,}000;$$

$$r_a' = 1{,}000{,}000 + (2{,}000 + 1) \times 2{,}800 = 6{,}600{,}000 \text{ ohms.}$$

Stage Gain of a Cathode Follower.

$$A' = \frac{\mu R_l}{r_a + (\mu + 1)R_l},$$

where μ is the amplification factor of the valve, R_l is the value in ohms of the resistance in the cathode circuit, and r_a is the value in ohms of the anode slope-resistance of the valve.

Example. A cathode-follower stage has a cathode resistance of 5,000 ohms; μ is 40 and r_a is 5,000 ohms. What is the stage gain?

$$A' = \frac{40 \times 5{,}000}{5{,}000 + 41 \times 5{,}000} = \frac{40}{42} = 0{\cdot}95.$$

Output Impedance of a Cathode Follower.

$$r_a' = \frac{r_a}{1 + \mu},$$

where r_a' is the effective generator resistance, in ohms, in the cathode circuit, r_a is the anode slope-resistance in ohms, and μ is the amplification factor of the valve.

Example. Find the output impedance of a cathode-follower stage having the values given in the previous example.

$$r_a' = \frac{5{,}000}{1 + 40} = \frac{5{,}000}{41} = 121{\cdot}96 \text{ ohms.}$$

OSCILLATORS

Condition for Maintenance of Oscillation in an LC Oscillator.

$$M \geqslant \frac{CR}{g_m},$$

where M is the mutual inductance in henrys necessary to sustain oscillation, g_m is the working mutual conductance of the valve in amperes per volt, C is the capacitance in the tuned circuit in farads, and R is the radio-frequency resistance of the inductor in ohms.

Example. A tuned circuit has a capacitance of 350 pF, and a radio-frequency resistance of 10 ohms. What is the smallest value of M which will cause oscillation if the valve used has a g_m of 1·5 mA/V?

$$M = \frac{350 \times 10^{-12} \times 10}{1\cdot5 \times 10^{-3}} = \frac{3\cdot5 \times 10^{-9}}{1\cdot5 \times 10^{-3}} = 2\cdot33\ \mu\text{H}.$$

Fundamental Frequency of Free-running Multivibrator.

$$f \approx \frac{1}{R_{g1}C_{g1} + R_{g2}C_{g2}},$$

where f is the frequency in cycles per second, R_{g1}, R_{g2} are the value of the two grid leaks in ohms, C_{g1}, C_{g2} are the values of the two coupling capacitors in farads. This expression is a very approximate one, and can be used only to indicate the order of oscillation frequency to be expected.

Example. A symmetrical multivibrator has grid leaks of 0·5 MΩ, and coupling capacitors of 0·01 μF. What is, very approximately, the fundamental frequency of oscillation?

$$f \approx \frac{1}{2R_gC_g} = \frac{1}{2 \times 0\cdot5 \times 10^{6} \times 0\cdot01 \times 10^{-6}} = 100\ \text{c/s}.$$

AERIALS AND FEEDERS

Length of a Half-wave Dipole.

$$l = \frac{143}{f},$$

where l is the length of the dipole in metres, and f is the frequency in Mc/s.

Example. What should be the overall length of a dipole to radiate or receive waves at a frequency of 9·5 Mc/s?

$$l = \frac{143}{f} = \frac{143}{9\cdot5} = 15\ \text{metres}.$$

Voltage Induced in a Receiving Aerial.

$$V = Xh,$$

where V is the voltage induced in the aerial in volts, X is the signal strength in volts per metre at the aerial site, and h is the effective height in metres of the receiving aerial.

Example. What must be the effective height of a receiving aerial in order to give an induced voltage of 5 millivolts from a wave of signal strength 700 μV/metre?

$$h = \frac{V}{X} = \frac{5 \times 10^{-3}}{700 \times 10^{-6}} = \frac{5{,}000}{700} = \frac{50}{7} = 7\cdot1\ \text{metres}.$$

Voltage Induced in a Loop-aerial.

$$V = \frac{2\pi XAN}{\lambda},$$

where V is the induced signal in volts, X is the signal strength in volts per metre, A is the area of the loop-aerial in square metres, N is the number of turns in the frame winding and λ is the wavelength of the transmission in metres.

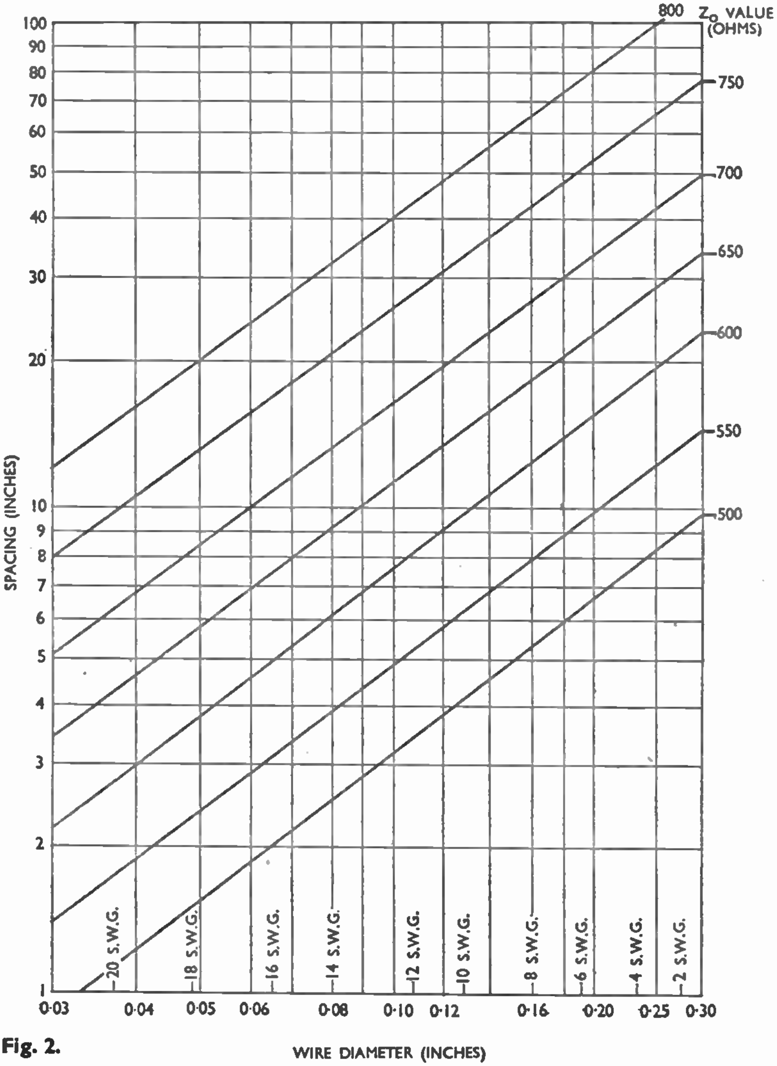


Fig. 2.

Example. A loop-aerial has an area of ¼ square metre and contains 25 turns. What voltage will it deliver from a signal on 300 metres with a signal strength of 3 mV/metre?

$$V = \frac{6{\cdot}284 \times 3 \times 10^{-3} \times 0{\cdot}25 \times 25}{300} = 0{\cdot}39 \text{ mV}.$$

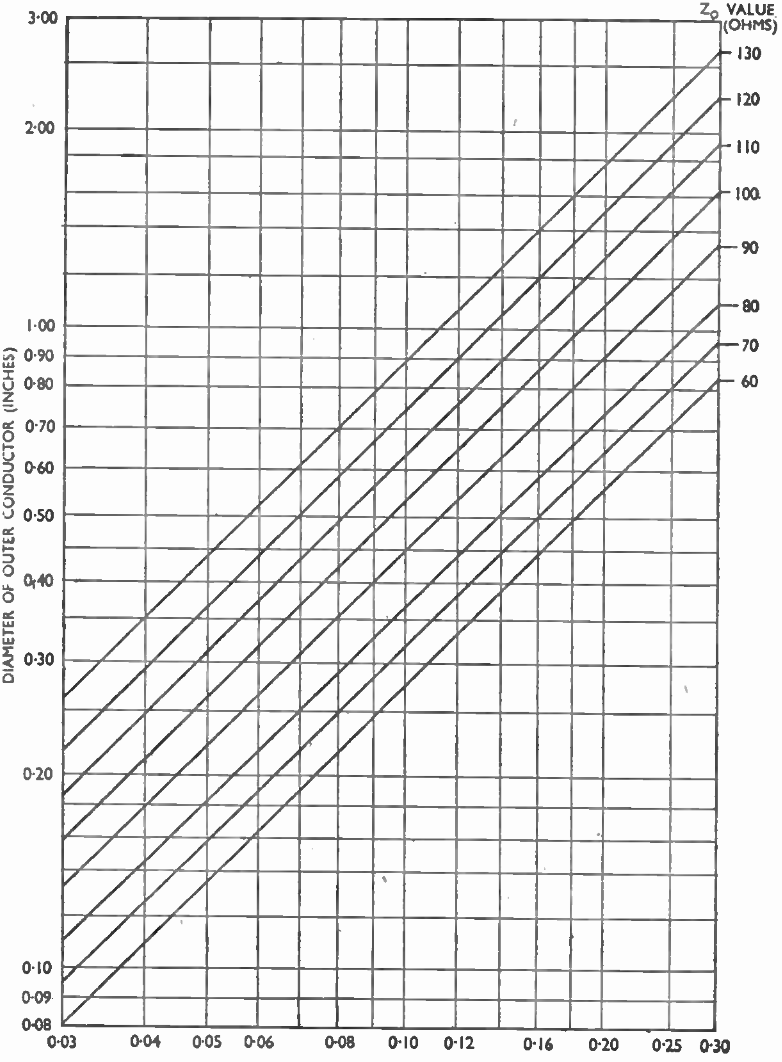


Fig. 3.

Characteristic Impedance of a Two-wire Transmission Line.

$$Z_o = 277 \log_{10} \frac{2D}{d},$$

where Z_o is the characteristic impedance in ohms, d is the diameter of each conductor in any units and D is the spacing between the conductors in the same units. To simplify calculations of characteristic impedance, Fig. 2 has been prepared. From it the impedance can be found for any wire diameter between 0·03 and 0·3 in., and for any spacing 1 — 100 in.

Example. What must be the spacing of two 12-S.W.G. conductors to give a characteristic impedance of 600 ohms? The ordinate through the 12-S.W.G. marking cuts the curve for Z_o = 600 ohms where the spacing is 8 in. This is therefore the spacing to be used.

Characteristic Impedance of a Concentric Line.

$$Z_o = 138 \log_{10} \frac{D}{d},$$

where Z_o is the characteristic impedance in ohms, D is the inner diameter of the outer conductor in any units, and d is the outer diameter of the inner conductor in the same units. Fig. 3 has been prepared to simplify calculations of characteristic impedance; from it the impedance can be found for any inner-conductor diameter between 0·03 and 0·3 in., and for any outer-conductor diameter between 0·08 and 3·00 in.

Example. What is the characteristic impedance of a co-axial cable in which the inner conductor is 0·08 in. in diameter and the outer conductor is 0·5 in. in diameter? The vertical line through 0·08 cuts the horizontal line through 0·5 where Z_o (the characteristic impedance) = 110 ohms.

Approximate Field Strength of a Sender.

The following two expressions are very approximate because they neglect energy losses due to soil conductivity and other factors.

(*a*) *When Aerial Current is known:* $X \approx \dfrac{377Ih}{\lambda d}$,

where X is the field strength in millivolts per metre, I is the aerial current in amperes, h is the effective height of the radiating aerial in metres. λ is the wavelength in metres, and d is the distance in kilometres.

Example. A sender on a wavelength of 500 metres has an aerial with an effective height of 75 metres and the aerial current is 50 amp. What is the field strength at a distance of 100 km.?

$$X \approx \frac{377 \times 50 \times 75}{500 \times 100} = 28{\cdot}3 \text{ mV/metre.}$$

(*b*) *When Radiated Power is known:* $X \approx \dfrac{300\sqrt{P}}{d}$,

where X is the field strength in volts per metre, P is the radiated power in kilowatts, and d is the distance in metres.

Example. At what distance from a sender radiating 100 kW is the field strength 1 mV/metre?

$$d \approx \frac{300\sqrt{P}}{X} = \frac{300 \times \sqrt{100}}{10^{-3}} = \frac{300 \times 10}{10^{-3}} \text{ metres} = 3{,}000 \text{ km.}$$

LOGARITHMS OF NUMBERS

	0	1	2	3	4	5	6	7	8	9	Mean Differences.								
											1	2	3	4	5	6	7	8	9
10	0000	0043	0086	0128	0170	0212	0253	0294	0334	0374	4	8	12	17	21	25	29	33	37
11	0414	0453	0492	0531	0569	0607	0645	0682	0719	0755	4	8	11	15	19	23	26	30	34
12	0792	0828	0864	0899	0934	0969	1004	1038	1072	1106	3	7	10	14	17	21	24	28	31
13	1139	1173	1206	1239	1271	1303	1335	1367	1399	1430	3	6	10	13	16	19	23	26	29
14	1461	1492	1523	1553	1584	1614	1644	1673	1703	1732	3	6	9	12	15	18	21	24	27
15	1761	1790	1818	1847	1875	1903	1931	1959	1987	2014	3	6	8	11	14	17	20	22	25
16	2041	2068	2095	2122	2148	2175	2201	2227	2253	2279	3	5	8	11	13	16	18	21	24
17	2304	2330	2355	2380	2405	2430	2455	2480	2504	2529	2	5	7	10	12	15	17	20	22
18	2553	2577	2601	2625	2648	2672	2695	2718	2742	2765	2	5	7	9	12	14	16	19	21
19	2788	2810	2833	2856	2878	2900	2923	2945	2967	2989	2	4	7	9	11	13	16	18	20
20	3010	3032	3054	3075	3096	3118	3139	3160	3181	3201	2	4	6	8	11	13	15	17	19
21	3222	3243	3263	3284	3304	3324	3345	3365	3385	3404	2	4	6	8	10	12	14	16	18
22	3424	3444	3464	3483	3502	3522	3541	3560	3579	3598	2	4	6	8	10	12	14	15	17
23	3617	3636	3655	3674	3692	3711	3729	3747	3766	3784	2	4	6	7	9	11	13	15	17
24	3802	3820	3838	3856	3874	3892	3909	3927	3945	3962	2	4	5	7	9	11	12	14	16
25	3979	3997	4014	4031	4048	4065	4082	4099	4116	4133	2	3	5	7	9	10	12	14	15
26	4150	4166	4183	4200	4216	4232	4249	4265	4281	4298	2	3	5	7	8	10	11	13	15
27	4314	4330	4346	4362	4378	4393	4409	4425	4440	4456	2	3	5	6	8	9	11	13	14
28	4472	4487	4502	4518	4533	4548	4564	4579	4594	4609	2	3	5	6	8	9	11	12	14
29	4624	4639	4654	4669	4683	4698	4713	4728	4742	4757	1	3	4	6	7	9	10	12	13
30	4771	4786	4800	4814	4829	4843	4857	4871	4886	4900	1	3	4	6	7	9	10	11	13
31	4914	4928	4942	4955	4969	4983	4997	5011	5024	5038	1	3	4	6	7	8	10	11	12
32	5051	5065	5079	5092	5105	5119	5132	5145	5159	5172	1	3	4	5	7	8	9	11	12
33	5185	5198	5211	5224	5237	5250	5263	5276	5289	5302	1	3	4	5	6	8	9	10	12
34	5315	5328	5340	5353	5366	5378	5391	5403	5416	5428	1	3	4	5	6	8	9	10	11
35	5441	5453	5465	5478	5490	5502	5514	5527	5539	5551	1	2	4	5	6	7	9	10	11
36	5563	5575	5587	5599	5611	5623	5635	5647	5658	5670	1	2	4	5	6	7	8	10	11
37	5682	5694	5705	5717	5729	5740	5752	5763	5775	5786	1	2	3	5	6	7	8	9	10
38	5798	5809	5821	5832	5843	5855	5866	5877	5888	5899	1	2	3	5	6	7	8	9	10
39	5911	5922	5933	5944	5955	5966	5977	5988	5999	6010	1	2	3	4	5	7	8	9	10
40	6021	6031	6042	6053	6064	6075	6085	6096	6107	6117	1	2	3	4	5	6	8	9	10
41	6128	6138	6149	6160	6170	6180	6191	6201	6212	6222	1	2	3	4	5	6	7	8	9
42	6232	6243	6253	6263	6274	6284	6294	6304	6314	6325	1	2	3	4	5	6	7	8	9
43	6335	6345	6355	6365	6375	6385	6395	6405	6415	6425	1	2	3	4	5	6	7	8	9
44	6435	6444	6454	6464	6474	6484	6493	6503	6513	6522	1	2	3	4	5	6	7	8	9
45	6532	6542	6551	6561	6571	6580	6590	6599	6609	6618	1	2	3	4	5	6	7	8	9
46	6628	6637	6646	6656	6665	6675	6684	6693	6702	6712	1	2	3	4	5	6	7	7	8
47	6721	6730	6739	6749	6758	6767	6776	6785	6794	6803	1	2	3	4	5	5	6	7	8
48	6812	6821	6830	6839	6848	6857	6866	6875	6884	6893	1	2	3	4	4	5	6	7	8
49	6902	6911	6920	6928	6937	6946	6955	6964	6972	6981	1	2	3	4	4	5	6	7	8
50	6990	6998	7007	7016	7024	7033	7042	7050	7059	7067	1	2	3	3	4	5	6	7	8
51	7076	7084	7093	7101	7110	7118	7126	7135	7143	7152	1	2	3	3	4	5	6	7	8
52	7160	7168	7177	7185	7193	7202	7210	7218	7226	7235	1	2	2	3	4	5	6	7	7
53	7243	7251	7259	7267	7275	7284	7292	7300	7308	7316	1	2	2	3	4	5	6	6	7
54	7324	7332	7340	7348	7356	7364	7372	7380	7388	7396	1	2	2	3	4	5	6	6	7
55	7404	7412	7419	7427	7435	7443	7451	7459	7466	7474	1	2	2	3	4	5	5	6	7

The above tables of common logarithms can be used also to determine antilogarithms. This can best be shown by taking an example: find the value of X_L from the formula $X_L = 2\pi f L$, when f = 1,250 c/s and L = 2·4 henrys; 2π may be taken as 6·283. By taking the logarithms of these numbers and adding, we have $\log_{10} X_L = 0{\cdot}7982 + 3{\cdot}0969 + 0{\cdot}3802$

LOGARITHMS OF NUMBERS (continued)

	0	1	2	3	4	5	6	7	8	9	Mean Differences.								
											1	2	3	4	5	6	7	8	9
55	7404	7412	7419	7427	7435	7443	7451	7459	7466	7474	1	2	2	3	4	5	5	6	7
56	7482	7490	7497	7505	7513	7520	7528	7536	7543	7551	1	2	2	3	4	5	5	6	7
57	7559	7566	7574	7582	7589	7597	7604	7612	7619	7627	1	2	2	3	4	5	5	6	7
58	7634	7642	7649	7657	7664	7672	7679	7686	7694	7701	1	1	2	3	4	4	5	6	7
59	7709	7716	7723	7731	7738	7745	7752	7760	7767	7774	1	1	2	3	4	4	5	6	7
60	7782	7789	7796	7803	7810	7818	7825	7832	7839	7846	1	1	2	3	4	4	5	6	6
61	7853	7860	7868	7875	7882	7889	7896	7903	7910	7917	1	1	2	3	4	4	5	6	6
62	7924	7931	7938	7945	7952	7959	7966	7973	7980	7987	1	1	2	3	3	4	5	6	6
63	7993	8000	8007	8014	8021	8028	8035	8041	8048	8055	1	1	2	3	3	4	5	5	6
64	8062	8069	8075	8082	8089	8096	8102	8109	8116	8122	1	1	2	3	3	4	5	5	6
65	8129	8136	8142	8149	8156	8162	8169	8176	8182	8189	1	1	2	3	3	4	5	5	6
66	8195	8202	8209	8215	8222	8228	8235	8241	8248	8254	1	1	2	3	3	4	5	5	6
67	8261	8267	8274	8280	8287	8293	8299	8306	8312	8319	1	1	2	3	3	4	5	5	6
68	8325	8331	8338	8344	8351	8357	8363	8370	8376	8382	1	1	2	3	3	4	4	5	6
69	8388	8395	8401	8407	8414	8420	8426	8432	8439	8445	1	1	2	2	3	4	4	5	6
70	8451	8457	8463	8470	8476	8482	8488	8494	8500	8506	1	1	2	2	3	4	4	5	6
71	8513	8519	8525	8531	8537	8543	8549	8555	8561	8567	1	1	2	2	3	4	4	5	5
72	8573	8579	8585	8591	8597	8603	8609	8615	8621	8627	1	1	2	2	3	4	4	5	5
73	8633	8639	8645	8651	8657	8663	8669	8675	8681	8686	1	1	2	2	3	4	4	5	5
74	8692	8698	8704	8710	8716	8722	8727	8733	8739	8745	1	1	2	2	3	4	4	5	5
75	8751	8756	8762	8768	8774	8779	8785	8791	8797	8802	1	1	2	2	3	3	4	5	5
76	8808	8814	8820	8825	8831	8837	8842	8848	8854	8859	1	1	2	2	3	3	4	5	5
77	8865	8871	8876	8882	8887	8893	8899	8904	8910	8915	1	1	2	2	3	3	4	4	5
78	8921	8927	8932	8938	8943	8949	8954	8960	8965	8971	1	1	2	2	3	3	4	4	5
79	8976	8982	8987	8993	8998	9004	9009	9015	9020	9025	1	1	2	2	3	3	4	4	5
80	9031	9036	9042	9047	9053	9058	9063	9069	9074	9079	1	1	2	2	3	3	4	4	5
81	9085	9090	9096	9101	9106	9112	9117	9122	9128	9133	1	1	2	2	3	3	4	4	5
82	9138	9143	9149	9154	9159	9165	9170	9175	9180	9186	1	1	2	2	3	3	4	4	5
83	9191	9196	9201	9206	9212	9217	9222	9227	9232	9238	1	1	2	2	3	3	4	4	5
84	9243	9248	9253	9258	9263	9269	9274	9279	9284	9289	1	1	2	2	3	3	4	4	5
85	9294	9299	9304	9309	9315	9320	9325	9330	9335	9340	1	1	2	2	3	3	4	4	5
86	9345	9350	9355	9360	9365	9370	9375	9380	9385	9390	1	1	2	2	3	3	4	4	5
87	9395	9400	9405	9410	9415	9420	9425	9430	9435	9440	0	1	1	2	2	3	3	4	4
88	9445	9450	9455	9460	9465	9469	9474	9479	9484	9489	0	1	1	2	2	3	3	4	4
89	9494	9499	9504	9509	9513	9518	9523	9528	9533	9538	0	1	1	2	2	3	3	4	4
90	9542	9547	9552	9557	9562	9566	9571	9576	9581	9586	0	1	1	2	2	3	3	4	4
91	9590	9595	9600	9605	9609	9614	9619	9624	9628	9633	0	1	1	2	2	3	3	4	4
92	9638	9643	9647	9652	9657	9661	9666	9671	9675	9680	0	1	1	2	2	3	3	4	4
93	9685	9689	9694	9699	9703	9708	9713	9717	9722	9727	0	1	1	2	2	3	3	4	4
94	9731	9736	9741	9745	9750	9754	9759	9763	9768	9773	0	1	1	2	2	3	3	4	4
95	9777	9782	9786	9791	9795	9800	9805	9809	9814	9818	0	1	1	2	2	3	3	4	4
96	9823	9827	9832	9836	9841	9845	9850	9854	9859	9863	0	1	1	2	2	3	3	4	4
97	9868	9872	9877	9881	9886	9890	9894	9899	9903	9908	0	1	1	2	2	3	3	4	4
98	9912	9917	9921	9926	9930	9934	9939	9943	9948	9952	0	1	1	2	2	3	3	4	4
99	9956	9961	9965	9969	9974	9978	9983	9987	9991	9996	0	1	1	2	2	3	3	3	4

= 4·2753. From the tables it will be seen that the nearest figure to 2753 is 2742, which appears along the 18 line under 8; this gives the first three figures as 188. In the mean-difference columns 12 is the nearest difference given, and this appears under 5. From this we are able to say that the antilogarithm required is 1885, and, therefore, that X_L = 18,850.

COPPER-WIRE DATA

S.W.G. No.	BARE COPPER						
	Diameter in in.	*Section Area in sq. in.*	*Working Current at sq.-in. densities of 1,000 amp.*	*Length per ohm (yd.)*	*Resistance in ohms per yard at 60 deg. F.*	*Weight in lb. per 1,000 yd.*	*Yards per lb.*
16	0·064	0·00322	3·217	134·0	0·0074	37·20	26·86
17	0·056	0·00246	2·463	103·0	0·0097	28·48	35·00
18	0·048	0·00181	1·810	75·3	0·0132	20·92	47·66
19	0·040	0·00126	1·257	52·2	0·0191	14·53	68·66
20	0·036	0·00102	1·018	42·4	0·0236	11·77	85·00
21	0·032	0·000804	0·804	33·2	0·0299	9·301	107·6
22	0·028	0·000616	0·616	25·6	0·0390	7·120	140·6
23	0·024	0·000452	0·452	18·8	0·0531	5·231	191·6
24	0·022	0·000380	0·380	15·8	0·0632	4·395	228·3
25	0·020	0·000314	0·314	13·1	0·0765	3·632	275·3
26	0·018	0·000254	0·254	10·6	0·0944	2·942	340·0
27	0·0164	0·000211	0·211	8·8	0·1138	2·442	410·0
28	0·0148	0·000172	0·172	7·18	0·1398	1·989	503·0
29	0·0136	0·000145	0·145	5·97	0·1655	1·680	596·6
30	0·0124	0·000121	0·120	5·03	0·1991	1·396	716·6
31	0·0116	0·000106	0·105	4·41	0·2275	1·222	820·0
32	0·0108	0·0000916	0·091	3·82	0·2625	1·059	943·3
33	0·0100	0·0000785	0·078	3·27	0·3061	0·908	1100
34	0·0092	0·0000665	0·066	2·77	0·3617	0·768	1300
35	0·0084	0·0000554	0·055	2·31	0·4338	0·640	1556
36	0·0076	0·0000454	0·045	1·89	0·5300	0·525	1903
38	0·0060	0·0000283	0·028	1·18	0·8640	0·327	3058
40	0·0048	0·0000181	0·018	0·755	1·3500	0·209	4776
42	0·0040	0·0000126	0·013	0·513	1·9500	0·145	6880

S.W.G. No.	ENAMEL COVERING		DOUBLE SILK COVERING		SINGLE SILK COVERING		DOUBLE COTTON COVERING	
	Turns per inch	*Turns per sq. in.*	*Turns per inch*	*Turns per sq. in.*	*Turns per inch*	*Turns per sq. in.*	*Turns per inch*	*Turns per sq. in.*
16	14·81	219·4	14·71	216·3	14·93	223·0	13·16	173·1
17	16·95	287·3	16·67	277·8	16·95	287·3	14·71	216·3
18	19·72	388·9	19·61	384·7	20·00	400·0	16·95	287·3
19	23·47	550·8	23·26	541·0	23·81	567·0	19·61	384·7
20	25·97	674·4	25·64	657·3	26·32	692·8	21·28	452·7
21	29·15	849·5	28·57	816·1	29·41	864·5	23·26	541·0
22	33·33	1111	32·26	1041	33·33	1111	25·64	657·3
23	38·91	1514	37·04	1372	38·46	1479	29·41	864·5
24	42·37	1794	40·00	1600	42·55	1810	31·25	976·8
25	46·51	2163	43·48	1891	46·51	2163	33·33	1111
26	51·55	2655	48·78	2379	51·81	2684	35·71	1275
27	56·50	3191	52·91	2800	56·50	3191	37·88	1435
28	62·50	3906	57·80	3341	62·11	3858	40·32	1625
29	67·57	4566	62·11	3858	67·11	4504	42·37	1794
30	74·63	5569	67·11	4504	72·99	5326	44·64	1992
31	79·37	6301	70·92	5028	77·52	6008	46·30	2144
32	85·47	7308	75·19	5652	82·64	6830	48·08	2311
33	91·74	8417	80·00	6400	88·50	7830	50·00	2500
34	100·0	10000	85·47	7308	95·24	9070	52·08	2712
35	109·9	12080	91·74	8418	103·1	10630	57·47	3312
36	120·5	14520	99·01	9800	112·4	12630	60·24	3629
38	151·5	22950	117·6	13830	137·0	18770	66·67	4446
40	188·7	35620	137·0	18770	163·9	25870	72·46	5250
42	227·3	51670	161·3	26010	192·3	36980	—	—