NATIONAL BROADCASTING COMPANY

ENGINEERING DEPARTMENT
INFORMATION SERVICE

RECENT TELEVISION DEVELOPMENTS

KTBS

By

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National Broadcasting Company, New York, N. Y.

THE PHYSICAL SOCIETY
REPRINTED FROM
REPORTS ON PROGRESS IN PHYSICS, VOL. VIII, p. 135, 1942

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§ 1. HISTORICAL INTRODUCTION

ALTHOUGH this *Report* covers principally the most modern developments in the field of television, a brief historical outline of the inventions, discoveries and improvements which contributed most to its progress still serves a useful purpose. During the past several decades the technical advances in all branches of electrical communication—particularly radio—have been nothing short of phenomenal. It is therefore not altogether surprising that the development of electronic television is likely to be taken as a matter of course, and the fact that it had its humble beginnings often completely forgotten.

Probably the first practical discovery leading to the development of modern television was that which occurred in Valentia, Ireland, in 1873 (Larner, 1929), when a telegraph operator named May noticed that his instruments behaved erratically when the sun shone through the window on his selenium resistors. The photo-conductive properties of selenium, based on the observations of May, were reported to the Society of Telegraph Engineers by Willoughby-Smith in the same year. This discovery aroused considerable interest and stimulated inventors to propose, within the next few years, methods of picture transmission involving this principle. The next milestone in the development of modern television, although it was not recognized as such at the time, was the invention in 1878 of the Crookes tube by Sir William Crookes and the demonstration of the properties of cathode rays. However, it remained for Paul Nipkow to introduce the concept of scanning with his invention, in 1884, of a system involving a rotating disc, having apertures arranged in spiral fashion, a photo-sensitive element, and synchronized reproducing means. The sluggishness of selenium cells, although inventors apparently did not realize it at the time, rendered them impractical for any high definition television system, and the discovery of the photo-electric effect by Hertz in 1888, eventually leading to the development of vacuum photo-cells having negligible inertia, therefore ranks as the next important milestone.

In 1907, Boris Rosing in Russia and A. A. Campbell-Swinton in England separately and simultaneously published methods of electrical image reproduction using electromagnetic means for scanning. The first all-electronic television system, utilizing cathode-ray scanning at both transmitter and receiver, was later proposed by Campbell-Swinton in 1911 in an address before the Roentgen Society. In many respects this proposal visualized the present-day systems, but it lacked one important factor. That factor was storage of the electric charge between successive scannings—the principle that would give the all-electronic pickup device the sensitivity necessary to make it practical with high-definition scanning. Unfortunately, a practical demonstration of these early proposals was impossible at the time, chiefly because the epochal invention of the thermionic amplifier tube by De Forest in 1907 still needed further development to make practical video amplification available.

In the next 25 years or so, various improvements were suggested, but it seems that none of these proposals reached the demonstration stage until the early 1920's. In 1923, Mr. John Logie Baird in England and Mr. C. Francis Jenkins in the United States gave successful demonstrations of moving silhouetted figures. Both these inventors used electro-mechanical scanning methods. It was also in 1923 that V. K. Zworykin (1938) applied for patents on his iconoscope, a cathode-ray television camera tube having inherently greater sensitivity than any previously proposed, by virtue of its property of storage over relatively long periods of time of the electric charges resulting from photo-electric emission.

During the next 10 or 15 years, extending into the middle 1930's, electro-mechanical television methods reached the highest peak of their development, culminating in the use of the electron multiplier type high-vacuum photo-cells for maximum signal-to-noise ratio at the sending end.

In the early 1930's, P. T. Farnsworth (1934) with his dissector tube and V. K. Zworykin (1929, 38) with the iconoscope demonstrated television systems of fairly good definition, based exclusively on electronic scanning. By 1936, the all-electronic method, corresponding to the demand for television images of higher and higher definition, had so far outdistanced mechanical scanning methods that the prominent experimenters in the field discarded mechanical scanning entirely, except in a few instances for the televising of film. From 1936 to date, the demand has been for further refinements and higher definition, culminating in the 525 line 30 frame interlaced images being broadcast commercially in the United States to-day.*

Storage type cathode-ray camera tubes, because of their higher sensitivity, are now universally used for direct pickup purposes. Although the Farnsworth dissector tube, being of relatively low sensitivity, is no longer used for direct pickup, it has been found to have useful applications in the transmission of motion-picture film (Jensen, 1941). With one or two notable exceptions (Robinson, 1939; D. G. F., 1940), television equipment to-day is entirely electronic, involving no mechanical moving parts.

* In August 1936, high definition (405 line, 25 frame interlaced) television transmission was also initiated by the British Broadcasting Corporation (see Macnamara and Birkinshaw, 1938)—[Editor].

§ 2. PROBLEMS OF MODERN TELEVISION

(a) *Pickup*

Television programs for home entertainment are derived from three main sources—direct pickup from a studio, outside pickup from the scene of an event, and pickup from film. In order better to understand the development of the instrumentalities used in television broadcasting, it will be helpful to review briefly the requirements of each of these three types of pickup (Macnamara and Birkinshaw, 1938; Morris and Shelby, 1937; Protzman, 1940; Hanson, 1937; Lohr, 1940; Fink, 1940; Zworykin and Morton, 1940).

Studio. The requirements to be met in designing a direct-pickup television studio centre around the fundamental fact that a television program is continuous, as distinguished from motion-picture production. Once a television program has begun, the action must be continued without interruption to its end, except for brief intermissions in long productions. This is in contrast to the technique that may be employed in motion-picture production, where a single scene or a single sequence may be photographed after elaborate preparation, and any desired amount of time taken before filming the following sequence. This leads to the requirement that the television studio must be large enough to accommodate a minimum of two scenes and preferably several scenes. It would, of course, be possible to have successive scenes televised from different studios, but experience has shown that in most cases this is less desirable than the use of a single studio. The studio must be large enough to accommodate not only the sets of the scenes to be employed, but also the television cameras, microphone stands and booms, lighting equipment, and other auxiliary apparatus associated with the television operation. Usual practice calls for a control room immediately adjacent to the studio, where the programme producer and control operators can watch the studio action through a window and at the same time monitor the televised scenes on television screens (Hanson, 1937). In order to clear the floor of the studio of apparatus not absolutely necessary, and also to provide better lighting, most of the lighting fixtures are generally suspended from the ceiling. This requires a studio with a fairly high ceiling in order to get suitable spacing of the lighting fixtures from the scene to be illuminated and also to prevent the fixtures from showing in the televised scene. The high ceiling is also an aid in keeping the temperature of the air in the studio down to a satisfactory level.

The sound pickup which accompanies all television programs must be provided for, and certain problems arise in television operation which are not normally encountered in sound broadcasting. The sound-pickup technique in television operation is rather more like the sound-pickup technique in motion-picture production than in sound broadcasting, but again there is the important difference that action must be continuous. Because of the fact that it is usually desired that the television audience shall not see the microphone, it is often located farther from the performers than is the case in sound broadcasting.

This means that the acoustic properties of the studio take on added importance and must be somewhat different in television from what they are in sound broadcasting. Experience has shown that television studios should be designed to have a slightly shorter reverberation time than would be considered optimum for the same studio if used for sound broadcasting. This is due in part to the previously mentioned fact that the pickup microphone is, in the average case, farther from the performers than in sound broadcasting, and in part to the fact that the scenery, furniture and equipment in the television studio modify the acoustic properties in a way that tends to liven the pickup (Hanson, 1937).

In order to provide the best possible sound pickup and still keep the microphone out of the scene, television has adopted the same type of boom for the microphone as is used in sound-motion-picture operation. The boom consists of a multiple section telescoping arm, mounted on a movable stand with controls which permit an operator to follow the action in the television scene with the microphone on the end of the telescoping arm, always just above the scene but near enough to the performers to obtain satisfactory sound pickup.

Lighting presents one of the most difficult problems in television operation. The amount of light required for satisfactory results with the usual types of scene is dependent upon the sensitivity of the television pickup device and upon the light-gathering powers of the lens associated with it. As in photography, if the aperture of the lens is made too large, then the depth of focus is very limited and results are unsatisfactory. With television-pickup tubes of the iconoscope type, which is at present the most widely used type, satisfactory results are obtained if the lenses are operated with apertures which give speeds in the range from f/3·5 to f/5·6 and incident light on the scene ranges from 300 to 1500 foot-candles, depending upon the nature of the scene being televised. With recently developed pickup tubes of higher sensitivity, such as the orthicon, the above light requirements may be substantially lowered.

In lighting a scene, either for photography or television, the amount of light provided is only one of a number of requirements if pleasing results are to be obtained. The direction, diffusion and spectral quality of the light all have an important bearing upon the results obtained. At the present time, incandescent lamps are used more extensively for television lighting than other light sources, but the carbon arc provides very satisfactory lighting and many other types of light sources are being tested experimentally. All the knowledge and techniques developed in lighting for still photography and motion pictures find important application in television lighting, except that the television system is not yet able to reproduce the wide range of light shades possible in photography, and for this reason it is not possible to employ successfully certain of the dramatic lighting techniques which call for extremely harsh contrasts between highlights and shadows.

Television-lighting technique differs from that employed in stage lighting or in motion-picture production, and again the differences are due mainly to the requirement of continuous action. It is true that continuous action is also required in the theatre, but here the audience's viewpoint is fixed—that is, the physical relation of the audience to the scene remains the same throughout the play. In a motion picture, this relation may not remain fixed, but in this case the requirement of continuous action in photographing the show does not obtain. In television production, on the other hand, if more than one camera is used, or if a single camera is moved about, then the viewpoint of the audience is shifted and the lighting must be planned accordingly. It must not favour the pickup of one camera in one position to the detriment of the scene as viewed from other angles. As it is not feasible to provide instantaneous shifts in lighting when switching from one camera to another, the lighting of a given scene must represent a compromise between the requirements for all cameras, although some manipulation of the lighting is possible during the course of the program, if suitable flexibility is provided in the design of the lighting fixtures. A type of fixture for overhead use in television studios which allows adjustment of the direction of the light output from each fixture by means of remote control from a central point has been developed and described in the literature (Eddy, 1940).

The scenery used in television-studio productions must also meet certain special requirements, and here again the requirement for continuous action has its effect. The design of stage scenery is simplified by the fact that, roughly speaking, the scene is viewed from a single direction. This means that in many cases the scenery may be arranged in parallel rows facing the audience. Motion-picture technique, on the other hand, must provide a third dimension in most cases, since the viewpoint may be changed by moving the camera. This is also true in television, with the added requirement that, generally, " time out " may not be taken to rearrange the scenery for successive shots, as is the case in motion-picture production. These special requirements may be summed up by stating that the scenery must give the proper illusion when viewed from all camera positions. Obviously, compromises are necessary, since the perspective will be correct in a painted scene only when viewed from the proper angle. It might be thought that television would suffer a serious handicap because of this, but experience has shown that a clever scenic artist can produce completely satisfactory results for any reasonable scene with the co-operation of the producer in the matter of carefully planning the angles of the various camera shots.

It has been found helpful in the painting of television scenery to avoid the use of colour and to paint all scenery in various shades of grey. This minimizes the difficulties which might be encountered due to slight differences in spectral response of the pickup tubes in different cameras. Limited depth of focus, due to the relatively fast lens employed in the television camera, results in a slight defocusing of most of the scenery in the television set, if the performers are in sharp focus. Because of this it has been found helpful in the painting of scenery to employ somewhat sharper, harsher lines than would be used if the scenery were intended for direct viewing by eye. The softening effect of the slight defocusing then results in a scene which is not quite as blurred as would otherwise be the case.

An important requirement for television scenery is that it must be demountable quickly and silently, so that one scene in the studio may be rearranged while others are being televised, without objectionable noise being heard by the audience. The type of scenery most often used consists of cloth mounted on wooden frames and supported by fixtures of the type widely employed for theatrical scenery.

In addition to the ordinary painted scenery previously referred to, some use has been made in television of scenery projected upon a translucent screen behind the performers. This is a process which has been used widely both in still photography and motion-picture production. The somewhat higher light levels used in television call for a very bright projected picture, and this in turn limits the process at the present time to fairly small projected areas, unless extremely powerful light sources are employed. Another limitation is that the projected scene is of satisfactory brilliance only when viewed within a relatively narrow angle in front of the screen in the case of screens that are practical for this use (Protzman, 1940).

It was mentioned previously that the programme producer and technical control staff are generally located in a room separated from, but immediately adjacent to, the studio proper. This facilitates their work by allowing a view of the studio as well as of the television-monitoring screens, and at the same time permits them to talk freely with one another and by telephone to other points concerned with the television broadcast without interfering with the sound pickup in the studio. In order to afford an unobstructed view of the action, the control room is generally located somewhat above the studio floor level (Morris and Shelby, 1937).

In addition to the picture monitors in the control booth, the television amplifiers, scanning amplifiers, power supplies and control equipment associated with the studio cameras are usually located in the control booth (Morris and Shelby, 1937; Protzman, 1940). A monitoring loud-speaker and controls for regulating sound level and for fading between microphones are also located in the control room, and a sound-control engineer is provided in the booth to operate them. Controls for regulating picture brightness and contrast and for switching between cameras in the studio, as well as various other controls associated with the television equipment, are also located in the booth and are operated by control enginers. The camera operators and the operators of the microphone booms, as well as certain other operating personnel in the studio, all wear headphones, by means of which instructions may be received from the programme producer and engineers in the control booth (Morris and Shelby, 1937).

Outside pickup. Some of the most interesting television programmes consist of the televising of events as they occur outside the studio. This corresponds roughly to news-reel coverage in motion pictures, but it has the added appeal of immediacy—that is, the audience does not know the outcome of the event as it

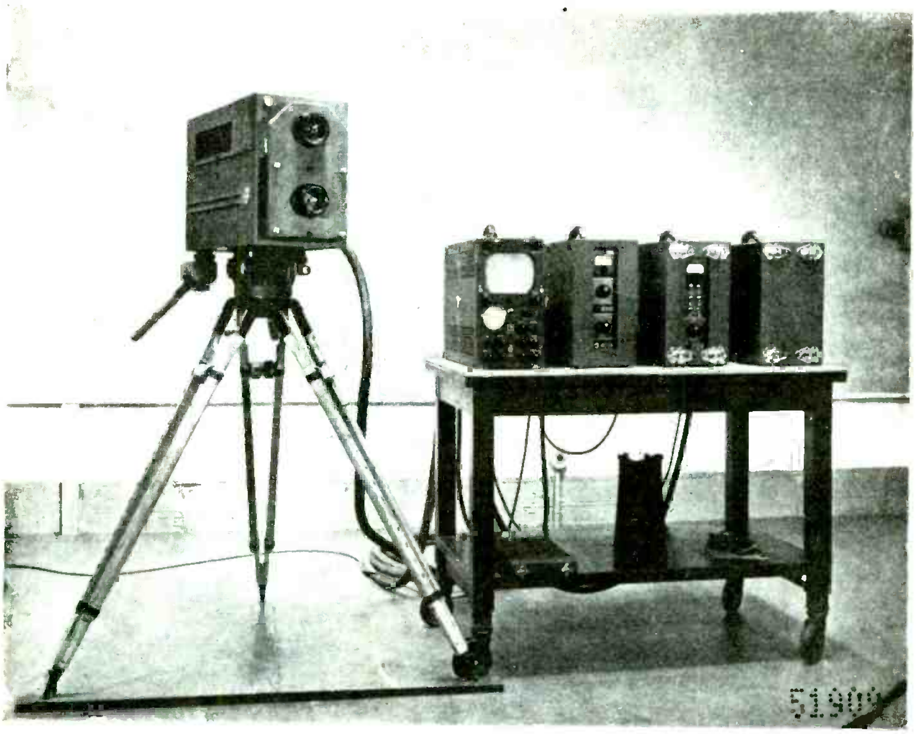

Figure 1.

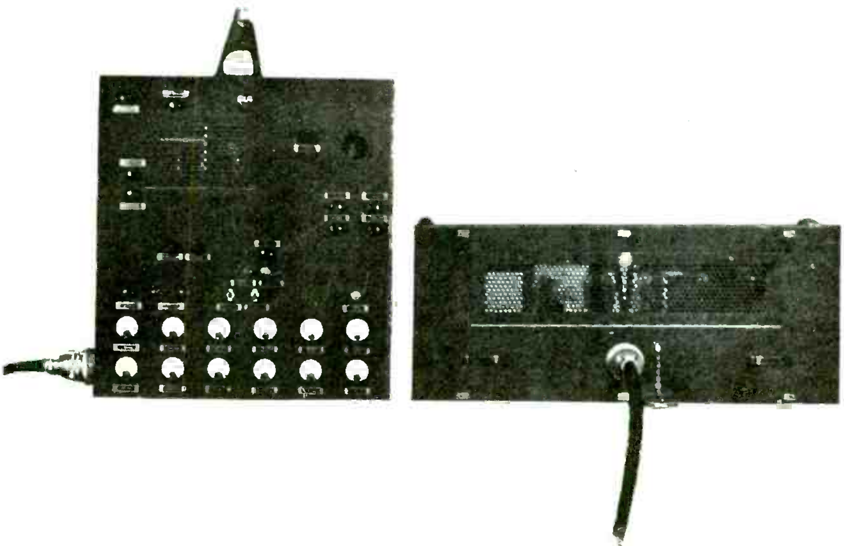

Figure 2.

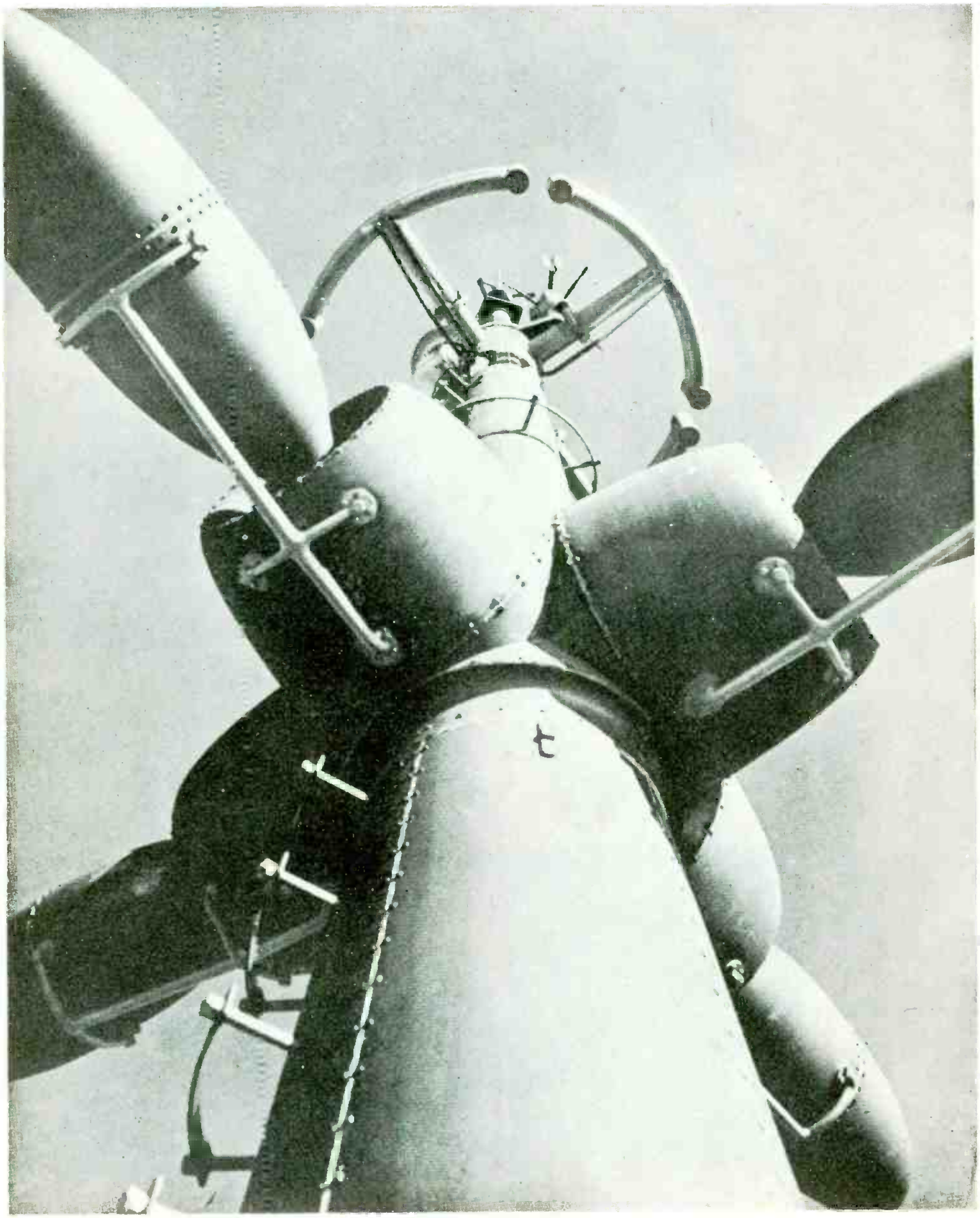

Figure 9.

watches it. Many people believe that television will find its most important application in this field. At any rate, it seems fairly certain that the extension of the television " eye " to points outside the studio is even more important to television than was the extension of the microphone to such outside pickup points in sound broadcasting (Hanson, 1941).

In order to provide on-the-scene remote television pickup, equipment must be provided which is the equivalent of a complete studio plant, plus some facility for relaying the signal back to the main plant or the broadcast transmitter. The problem is analogous to that of remote pickup work in sound broadcasting, but the equipment required is many times more complicated, and, in fact, must include complete facilities for sound pickup in addition to those for picture pickup. The most direct and complete solution to this problem has been the utilization of equipment similar to that employed in studio installations, mounted in trucks large enough to accommodate this relatively bulky and heavy equipment. Two such trucks have been employed by the N.B.C. for this purpose for several years past in the New York City area. One of these trucks houses the equipment associated with the cameras, the other a radio transmitter for relaying the signal back to the main point.

Another solution to the outside pickup problem has been provided in the form of equipment built in units small enough to be carried, which may be taken to the scene of the pickup by any suitable means of transportation and set up in the most advantageous position. In this case there has been some sacrifice in performance and operating flexibility for the sake of portability, but, nevertheless, such equipment is capable of providing high-quality television pictures and has the advantage of portability, which makes it possible to televise many scenes that might not be accessible to the equipment mounted permanently in large trucks (Beers, Schade and Shelby, 1940; Smith, 1940; Hanson, 1941).

The photograph of figure 1 illustrates typical portable television pickup equipment, and that of figure 2 shows a portable radio relay transmitter of complementary design.

The problem of relaying the television signal from the point of pickup to the main plant or broadcast station is an important one in remote television pickup work. In the case of sound broadcasting, it is possible to utilize wire lines which have been installed for telephone service and which are widely available. Circuits designed for the transmission of sound signals are, however, useless for the relaying of television signals on account of the wide band of frequencies associated with the latter. For transmission of television signals over short distances it has been found possible to obtain satisfactory results by special equalization of cable circuits originally installed for telephone service (Strieby and Weis, 1941). Such circuits have been used, for example, for the transmission of television signals from the Madison Square Garden area to the N.B.C. headquarters in Radio City in New York. Such transmission is limited to circuit lengths of approximately one mile between repeaters, and if the distance involved is more than a few miles, it would appear that other transmission means are more desirable. Since wide band circuits do not exist except in a very few special installations, most of the television-relay work has been done by means of radio circuits. In its television service in the New York area the N.B.C. has utilized mainly two radio transmitters for this purpose. One of these operates in the television channel 162 to 168 megacycles and is mounted in one of the trucks mentioned above. The distance over which it is possible to operate such a relay is dependent upon many variable factors, such as antenna height, interference at the receiving point, and terrain between the two points. Satisfactory programme transmissions have been achieved over a distance of 26 miles, utilizing the transmitter operating in the channel 162 to 168 megacycles. It is possible to extend this distance by multiple relays, and in this manner a television programme was successfully handled at a pickup point 68 miles from the main plant, utilizing three radio transmitters in a relay link service. As discussed elsewhere in this ***Report***, an extension of this principle makes possible television-network operation.

An outstanding example of a wire line facility for long-distance television transmission is the coaxial cable installation of the American Telephone and Telegraph Company between New York City and Philadelphia (Espenschied and Strieby, 1934). This has recently been used for a number of television demonstrations and experiments, including the outstanding series of programmes from the scene of the Republican Party National Convention in Philadelphia during June 1940 (Hanson, 1941). Scenes from the floor of the convention hall were televised by the Mobile Units of N.B.C., transmitted to New York via the coaxial cable and connecting facilities of the A.T. and T., and broadcast in New York City by the N.B.C. television transmitter. As its name implies, the coaxial cable consists of a central conductor surrounded by an outer conductor having, in this case, a diameter of approximately 5/8 inch and a characteristic impedance of approximately 72 ohms (Wentz, 1940). This cable has an attenuation of approximately 6 db. per mile at a frequency of one megacycle, and the installation between New York and Philadelphia, as it was used for the programme mentioned above, had repeater amplifiers approximately every five miles throughout its entire length in order to keep the signal sufficiently above the noise level on the circuit.

Film pickup. Any programme or scene which may be recorded on motion-picture film may be televised subsequently from the film with modern television facilities. This, of course, opens up tremendous programme possibilities for a television service. It is true that the overall resolution capabilities of even the best television system is not good enough to reproduce the finest resolution which is possible on the best motion-picture film. Experience has shown, however, that it is good enough to be acceptable in any case, and in most cases the loss in definition is not noticed by the average viewer, unless a direct comparison is made.

In addition to its importance as an independent source of programme material, television pickup from film is useful as an auxiliary service for direct pickup television. In many cases certain scenes in dramatic productions cannot be provided in a studio of reasonable size, or at the time the programme is televised. Such scenes may be photographed on motion-picture film and televised at the proper time in the programme to give the desired continuity. Another important application for film in television broadcasting is in the programming of important events which occur at a time when most of the potential audience is at work. Such programmes may be photographed on film in the afternoon, for example, the film processed and edited, and transmitted by television the same evening when the maximum audience is available.

Years of experience in the motion-picture industry have shown that the most satisfactory type of motion-picture projector for general use is the intermittent type. A special problem arises in the use of the intermittent projector in television because of the difference in standards between the motion-picture and television industries. In the case of motion pictures, the standard frame-repetition rate is 24 frames per second, while in television the frame-repetition rate is usually a sub-multiple of the power-supply frequency. Thus, for example, in the United States, the frame-repetition rate has been standardized at 30 frames per second, since the most widely used power-supply frequency is 60 cycles per second. In England, and on the Continent, the television standard is 25 frames per second, since the most widely used power-supply frequency is 50 cycles per second. In the latter case, if standard motion-picture films are projected at a speed of 25 frames per second, instead of 24 per second, the results are generally acceptable, although there is a slight distortion in sound reproduction which is noticeable on certain types of programmes. In the case of the U.S. standard, the operation of standard motion-picture film at 30 frames per second would produce intolerable distortion in the sound and serious distortion in the motion of objects in the reproduced scene. It would be technically possible to use only films which were taken at the 30 frame per second rate, but this would be a serious handicap, since the vast libraries of standard film could not be used. It is possible to utilize film in a continuous projector operating at the standard film rate in conjunction with a television system operating at 30 frames per second, provided the continuous projector gives sufficiently good performance, and this is done in some instances (Jensen, 1941).

A completely satisfactory solution to the problem created by the difference in standards between the motion-picture industry and the television industry has been found which permits the use of film projectors of the intermittent type. This method depends upon the storage properties of the iconoscope pickup tube. These storage properties enable the iconoscope to " remember " for an appreciable time a picture which is focused on its light-sensitive mosaic and then removed. When the light image is impressed upon the mosaic, electrical charges are built up on the mosaic corresponding to the light intensity at each point. This electrical charge will remain after the light image is removed until it is equalized by the scanning beam, provided the time interval is not long enough to allow the charge to leak off through imperfect insulation. This property of the iconoscope enables the usual film-projection cycle to be reversed —that is, instead of the shutter on the projector being closed for as short an interval as possible, during which time the film is pulled down from one frame to the next, the shutter is open only during the short interval when the scanning beam in the iconoscope is returning from the bottom to the top of the picture and the film pull-down occurs during the long interval when the shutter is closed and the mosaic is being scanned by the electron beam. In other words, the television picture is scanned with the iconoscope mosaic in darkness, the iconoscope " remembering " the picture which was projected on it during the preceding frame-blanking period.

Since interlaced scanning is standard and since, therefore, the scanning beam must be returned from the bottom to the top of the picture 60 times per second, it follows that the shutter is opened 60 times per second. The intermittent action in the projector is arranged so that alternate frames of the film remain in position in front of the aperture 50 % longer than the intervening frames. More specifically, one frame will remain in the aperture for two successive openings of the shutter, the third frame for two successive openings of the shutter, and so on. Since the shutter opens 60 times per second, it therefore follows that a complete operating cycle of the intermittent mechanism in the projector represents 2/60 plus 3/60, or 5/60 of a second. Thus one cycle covers the projection of two frames of the film. Therefore it is apparent that the average rate of travel through the projector is 24 frames per second, which is standard. This method of translation from a 24-frame per second rate for the film to a 30-frame per second rate for the interlaced television scanning is possible by virtue of the numerical relation of the two rates and the storage properties of the iconoscope pickup tube.

In a practical layout for television-programme operation it has been found desirable to have the film projectors located in one room and the television cameras and associated control equipment in an adjacent room (Hanson, 1937). When 35-millimetre film projectors are employed, the projection-room construction is usually required to meet certain rather stringent fire rules with regard to safety shutters, wall construction, exhaust vents, film-storage vaults, and so forth. These requirements are more readily met if the projectors are in a separate room from the other equipment. Another advantage of this arrangement is that the noise of the projectors does not interfere with monitoring in the control room. Usually two or more projectors are provided, so that continuous film operation is possible. This is further facilitated by the use of at least two television cameras. If the two cameras are movable, they may be used in conjunction with a number of projectors. In the N.B.C. film studio in Radio City, the two television cameras are mounted on tracks on the wall so that they may be moved in front of any one of several projection ports.

Television cameras employed for direct pickup have a lens system on the front of the camera for focusing an image of the scene to be televised upon the light-sensitive surface of the pickup tube. This arrangement is quite similar to that employed in cameras used for motion-picture and still photography. However, in the case of television cameras used with film projectors, it is customary to project the image upon the light-sensitive surface of the pickup tube by means of the objective lens mounted on the film-projection machine.

(b) *Amplification and distribution*

The signal output from any of the known pickup devices, at the present time, represents only a minute amount of power—no more than a few thousandths of a microwatt—and a voltage level of the order of a few millivolts. Before this signal can be used to modulate a radio transmitter of even moderate power it must be amplified to a level of several hundred watts. Thus the power gain of the chain of amplifiers raising the signal level must be of the order of 10^{12}. In a simple laboratory set-up, employing standard tubes, this gain might be realized by approximately twenty stages. In elaborate television-broadcasting plant, two or three times this number may be used, because at many points in the system it is necessary to make up for attenuation losses in coaxial cables, losses incident in controlling and shaping the signal, and so forth (Zworykin and Morton, 1940).

Video amplifiers, like those employed for audio-amplification purposes, make use of thermionic vacuum tubes. However, because of the much more exacting requirements imposed by the amplification of the video signal, the means used to couple the tubes are somewhat different. Because the general amplifier problem has been so ably and completely discussed in numerous articles (Foster and Rankine, 1941; Wheeler, 1939 a, 39 b; Bedford and Fredenhall, 1939; Herold, 1938) and textbooks (Fink, 1940; Zworykin and Morton 1940), it is unnecessary to discuss the entire theory of the amplifier here. Instead, the differences in the requirements of audio and video amplifiers will be briefly outlined.

The principal differences which distinguish the video amplifiers from the audio amplifiers are:—

1. A constant frequency response over a band several megacycles wide (a minimum of approximately 30 cycles to 4·5 Mc. for present U.S. standards).
2. An essentially constant time delay over the usable frequency range.

The resistance-coupled amplifier most nearly satisfies the above requirements —although it is by no means ideal—and it is the type that is used almost universally for video amplification. With the tubes available at present, it is not feasible to design resistance-coupled amplifiers which meet the requirements specified without resorting to some circuit arrangement which equalizes the effect of unavoidable capacity across the coupling resistance. Even with a circuit design which reduces stray circuit capacity to a negligible quantity, the unavoidable inter-electrode capacities of the vacuum tubes still shunt the coupling resistance, and if this resistance is of a high enough value to provide a practical amount of voltage amplification, this combination resistance-capacitance network will have a frequency characteristic which falls off at the higher frequencies in the video range. A simple compensation for this effect is obtained by the addition of an inductance in series with the coupling resistor (see figure 3), the inductance being of such value that it will resonate with the capacity at a frequency somewhat above the highest frequency to be transmitted. In such a circuit, with capacity fixed, it is possible to choose inductance and resistance values such that the amplifier response will be essentially uniform over the video-frequency band (Herold, 1938).

This problem of providing uniform response over the video-frequency band may be considered as a low-pass filter network problem, and a very considerable

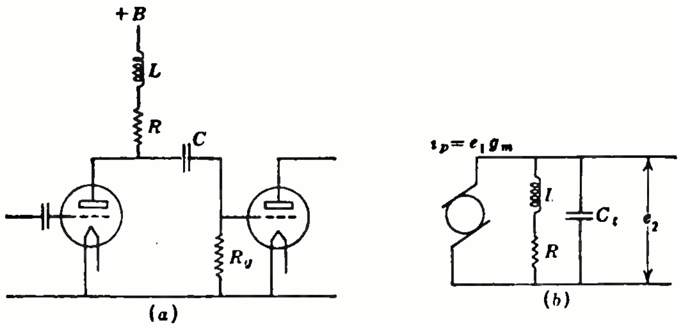

Figure 3.

amount of work has been done in applying classical filter theory to its solution (Wheeler, 1939 a, 39 b).

In addition to the problem at high frequencies in the video range, difficulty is encountered at the extremely low frequencies. Practical circuit considerations require the use of a blocking condenser between successive stages to isolate the different d.c. electrode potentials applied to the two tubes. At high frequencies this condenser will represent a negligible series impedance, even if it is of relatively low capacity, but at the extremely low frequencies its impedance becomes a problem. If it is made too large, its physical size may result in a capacitance to ground shunting the coupling impedance, which will affect the high-frequency response. Several practical expedients have been evolved to solve this problem. The diagram of figure 4 shows one such circuit arrangement. In this arrangement, an R.C. network is placed in series with the main coupling impedance in the plate circuit to give added response at low frequencies which will approximately compensate the loss at these frequencies caused by the coupling condenser and shunt grid resistor. Various other circuits have been proposed and are described in the literature.

The response of only a single stage of amplification has been considered so far. In practice, the complete amplifier consists of a great many cascaded stages, and the overall response is the important consideration (Bedford and Fredenhall, 1939). If the amplifier consists of identical stages and there is no incidental regeneration resulting from improper shielding, the overall gain will

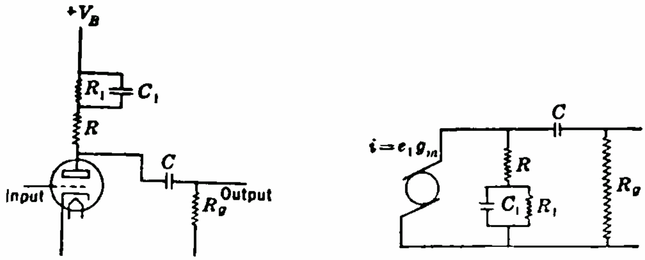

Figure 4.

be the gain of a single stage at each frequency raised to a power equal to the number of stages, while the time delay will be the product of the delay for each stage and the number of stages. The amplitude and delay curves for 16, 32 and 64 stages of amplification coupled as shown in figure 3, for two values of compensating inductance near the optimum value, are given in figure 5.

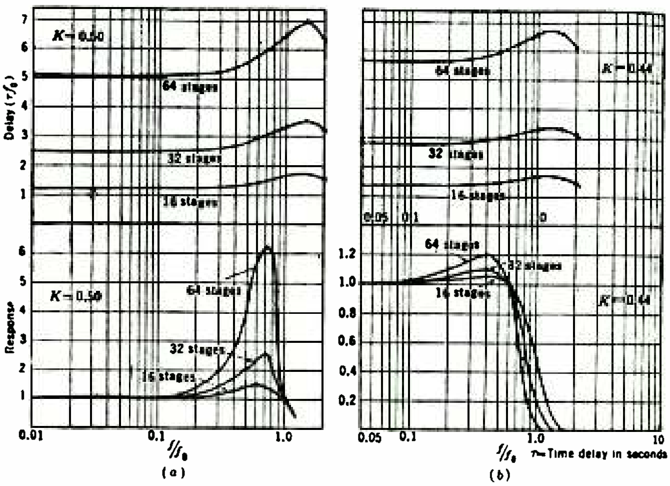

Figure 5.

It is often advantageous to employ amplifier stages which are not identical but which differ in such a way that they tend mutually to compensate their individual defects. Thus, a filter-coupled stage which has a flat response but a positive time delay error over part of the useful frequency band can be used with another constant-gain stage which has a negative delay error over the same portion of the band. If the characteristics of the individual stages differ, the overall gain is the product of the gains at each frequency, and the total delay error will be the algebraic sum of the individual errors.

In amplifiers having a great many stages, as at the pickup, monitoring and modulating units of a transmitter, it is ordinarily not practical to make use of the complex coupling circuits required for high-gain stages throughout. The reason for this is the extreme difficulty in maintaining constant delay and gain characteristics. It is general practice to use high-gain stages, with response corrections in later stages, for the first few stages—that is, until the signal level is well above the level of the noise generated by the amplifying tubes and coupling circuits. The remaining stages should be constructed to have a wide band at the expense of efficiency by using low-valued coupling resistors, and require only a small amount of response compensation. The deviation from constancy of gain and time delay of the whole amplifier can thus be made to fall within acceptable limits.

There is an important consideration which modifies the previously given requirement of uniform amplitude response in video amplifiers over the entire band of signal frequencies. All pickup devices at present in use in practical television systems give a response which is more or less dependent upon frequency. This is due in part to the electrical characteristics of the devices and in part to aperture effects. In order to obtain undistorted image reproduction it is necessary that the overall response be flat.

Scanning with a finite aperture always results in a decrease in signal at the higher frequencies (Mertz and Gray, 1934; Wheeler and Loughren, 1938). If the scanning aperture is very small, frequency distortion may be negligible over the working range of the video amplifier. However, in most practical pickup devices, including the iconoscope, aperture distortion cannot be neglected. Aperture distortion causes an attenuation which increases with frequency but produces no change in phase delay. The correction for this effect, therefore, should compensate for loss of amplitude at the higher frequencies, but should give no correction for phase delay. This may be accomplished by providing the correction first in a simple form which gives both amplitude and phase correction, followed by a phase-correcting network which does not affect the amplitude characteristic. Such phase-correcting networks are well known in the art of filter design.

The signal which is generated by the pickup device does not contain the complete information necessary for the reconstruction of the picture. In addition to voltage variations representing the light and shade in the picture, it is necessary to furnish the information required to insure synchronism between the scanning pattern at the transmitter and the receiver. This is supplied in the form of properly shaped pulses, timed so that they occur after the end of each scanning line and before the beginning of the next. Similarly a pulse or series of pulses is added between field repetitions to insure vertical synchronization (Bedford and Smith, 1940).

The synchronizing impulses are added to the picture signal in the amplifier chain. This operation is performed by rendering the amplifier inactive ahead of the point of injection for a period equal to or slightly in excess of that occupied by the actual synchronizing signal, and injecting the impulse during this interval. The purpose of this " blanking " process is to prevent any possible signal from the pickup device from interfering with the synchronizing signal. During the blanking period the voltage level in the amplifier is brought to a value which corresponds to maximum black of the picture, thus providing a reference point from which the average illumination in the picture is indicated. If the pickup device is essentially an a.c. device, indicating only the variation in light and dark over the picture but not giving information as to the average illumination, as, for example, an iconoscope, then a special photo-tube and d.c. amplifier may be necessary to establish this value. The various steps in the formation of the complete signal are indicated in figure 6. In some pickup devices, such as the

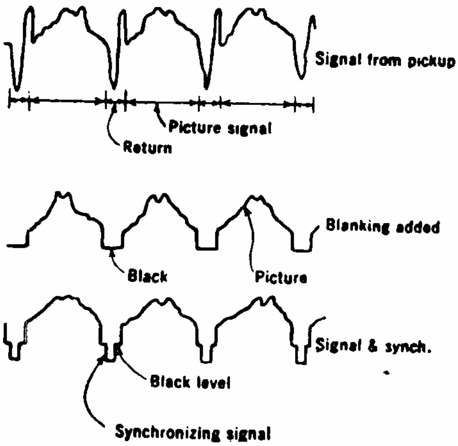

Figure 6.

orthicon (Rose and Iams, 1939 b) and image dissector (Farnsworth, 1934), the voltage level, when the scanning is blanked out during return time, bears a fixed relation to the voltage level corresponding to black level in the picture, and with such devices an auxiliary photo-tube is not required.

For convenience, the amplifying system at the sending end may be considered as consisting of three parts. At the pickup device there is a pre-amplifier which receives the very weak signal, usually of the order of a millivolt or at most a few millivolts, and raises it to a level of perhaps a tenth of a volt. This amplifier is made to have as low a noise level as possible, because the input at this point is not greatly in excess of the statistical fluctuations in the necessary coupling resistors and vacuum tubes. In order to obtain a maximum signal-to-noise ratio, it is necessary to make the gain of the first few stages as high as possible. This may be done even at the expense of loss of high frequencies in these early stages, which is made up by compensation in later stages.

The output of the pre-amplifier is arranged to drive a low-impedance cable (usually a low-loss coaxial) which connects it with a second amplifier chain, variously called the monitoring amplifier or the control amplifier. This unit raises the signal to a level of 1 to 10 volts. Also the gain, the d.c. level, etc., are controlled in this amplifier, and any special signals which may be necessary are added.

The output of this amplifier is fed to the line amplifier, which raises the signal level to that required by the modulator of the radio transmitter.

This subdivision of the amplifier chain into three, and only three, physical units is, of course, a simplification which does not exist in practice because the physical layout makes more than three units necessary. For example, in a typical television pickup and broadcast plant there are usually several studios, one of which is arranged to produce video signals from motion-picture film (Morris and Shelby, 1937; Hanson, 1937). Each studio will in general be equipped with two or more television cameras with their associated scanning wave generators, video amplifiers and monitoring equipment. Means must be provided for making rapid switches, or for fading from any one of these cameras to any other, without disturbing the synchronization of the television receiver. For this reason, the synchronizing signals are preferably inserted at a common monitoring point located somewhere between the video signal generating equipment and the modulator of the picture transmitter. The video signals reaching this common monitoring point already contain " blanking pedestals " at the end of each scanning line and at the end of each picture field, representing " picture black " reference level. The synchronizing signals can thus be combined with the picture signals by a simple addition process. The blanking signals, as well as the impulses for actuating the scanning amplifiers in each studio, are fed from one main synchronizing generator, delay networks being inserted in each circuit, so that when the video signals, containing the blanking pedestals, arrive at the common monitoring point from any camera or studio, they are delayed by the same amount and synchronizing signals can be added properly. Thus, any switching or fading between cameras or studios cannot upset the synchronizing signals or cause a loss of synchronism at the receiver. Therefore, the actual physical layout of the television plant is far more complicated than the idealized case of the three units already referred to, especially when provision is made to switch between studio subjects and remote pickups which are brought in to the common monitoring point via wire or radio links. Functionally, however, the three units can usually be easily identified.

(c) *Transmission and relay*

The design problem presented by the radio transmitter to be used for a television system is a formidable one (Blumlein, Brown, Davis, Green, 1938; Macnamara and Birkinshaw, 1938; Engstrom, 1939; D. G. F., 1939; Goldmark, 1939; McIlwain, 1939; Mertz, 1939; Sarnoff, 1939; Zworykin and Morton, 1940). This is because of the tremendous width of the band of frequencies which must be radiated if high picture definition is to be attained.

Like a sound transmitter, the transmitter in question may be made up of a carrier generator which produces a high-frequency oscillation of constant amplitude, and a modulator which varies the amplitude of this radio-frequency carrier in such a way that it is at every instant proportional to the signal applied to the modulator—in this case the video signal. The modulated radio frequency is then fed to the transmitting antenna, from which it is radiated. This is the general type of transmitter which has been most widely used in television work.

Recently proposals have been made for, and experiments conducted with, two other types of television transmitters. In one of these, the radio-carrier frequency is modulated instead of its amplitude, the frequency at any instant being governed by the voltage of the composite picture and synchronizing signal to be transmitted. This is a form of modulation which has received considerable attention recently in sound transmission and its fundamentals have been presented in the literature (Armstrong, 1936; Morris and Guy, 1940; Seeley, 1941). It is the type which has been standardized in the United States for the sound signal associated with the television programmes. It should be noted, however, that whereas " wide band " frequency modulation (i.e., the kind in which the complete signal spectrum occupies a frequency band several times the band width of the audio signal being transmitted) is generally favoured for such frequency modulation in sound operation, in the case of television the extremely wide band of video frequencies makes this inexpedient in present practical cases. Instead it has been found advisable to limit the frequency deviation, in frequency-modulated video transmission, to a small value so that the essential components of the signal spectrum are contained in a band not wider than would be required for the equivalent case of amplitude modulation. Frequency modulation has been applied successfully to the problem of relaying television signals from point to point where two or more stations may be necessary to cover the distances involved. In this application, the carrier frequencies employed have been somewhat higher than heretofore used, being in the vicinity of 500 Mc. (Kroger, Trevor and Smith, 1940). An arrangement for transmitting television signals by frequency modulation, in which receivers designed for amplitude modulation receptions are used without change, has been demonstrated recently. Field tests with this form of transmission and reception are now in progress, and it is yet too early to evaluate its merit.

Another form of transmission, recently proposed, utilizes a combination of frequency modulation and amplitude modulation. In this system, the radiated carrier wave is amplitude modulated by those parts of the composite video signal corresponding to picture information, and is frequency modulated by the synchronizing pulse component. It is claimed that this type of transmission may be utilized by a receiver suitably designed for reception of single side-band, amplitude-modulated signals. This type of transmission is also undergoing field tests at this time, and its merits in practical operation are not yet fully known.

In order to accommodate the wide band of frequencies required in television transmission, and also to take advantage of desirable freedom from " sky-wave " transmission, television in recent years has resorted to the use of carrier frequencies above 40 Mc. As previously mentioned, carrier frequencies as high as 500 Mc. have come into use for television-relay purposes. In the United States eighteen channels, each 6 Mc. wide, have been set aside by the F.C.C. for allocation to television broadcasting stations. These channels are interspersed with other allocations in the region of the spectrum from 50 to 300 megacycles.

It is required that all signals for transmission of both video and audio intelligence fall within the 6 Mc. channel. Since all simple modulation processes for either frequency or amplitude modulation produce side-band components lying both above and below the unmodulated carrier in frequency, and since the minimum band-width of this double side-band spectrum, in any case, is equal

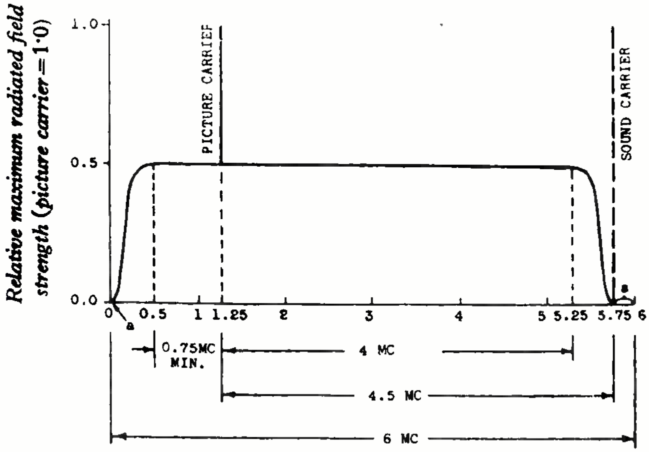

Figure 7. Idealized picture transmission amplitude characteristic.
a : Relative field strength of picture side band not to exceed 0·00005.
Drawing not to scale.

to twice the highest modulating frequency, it would seem that the 6 Mc. channel would not provide adequate transmission for television signals of the kind we have been considering, in which frequency components of 4 Mc. and more are present. Present practice in television broadcasting in the United States calls for the expedient of transmitting only one of the two side-bands generated for the higher video frequencies (Kallman and Spencer, 1940). It has been found that all of the information in the original signal may be reproduced at the receiver if only one side band is utilized (Poch and Epstein, 1937). In order to avoid distortions which occur with high percentages of modulation in single side-band transmission, present preferred practice calls for transmission of both side bands for the lower video frequencies, the attenuated side-band extending far enough to encompass those frequency components in the video signals which are of large amplitude in most cases. The standard amplitude characteristic of the signal in a 6 Mc. channel as specified by the F.C.C. is shown in figure 7. The amplitude characteristic of a receiver designed to give proper response to such transmitted signals is shown in figure 8. It will be noticed that this receiver characteristic has a uniform slope in the vicinity of the carrier frequency and goes down to a 50 % response at the carrier frequency. It is this sloping characteristic in the receiver which enables it to translate frequency-modulated signals into amplitude-modulated signals as mentioned above in connection with two recently proposed systems of television transmission involving frequency modulation.

Although a video transmitter has all the general components possessed by a sound transmitter, there are several problems which are peculiar to wide-band video transmission (Blumlein, Brown, Davis and Green, 1938; Macnamara and Birkinshaw, 1938; D. G. F., 1939). The generation, amplification and radiation of ultra-short waves is a recent development in the radio art, but has been accomplished for services other than television, and the solution to the various problems involved are now fairly well known. The complications that arise in the case of television-transmitter design will not be gone into in detail here, but they

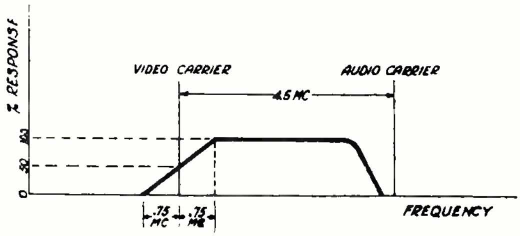

Figure 8.

include such matters as broad-band coupling circuits, special antenna (Lindenblad, 1939) and transmission-line design to provide uniform impedance and freedom from reflections over the broad band required, neutralization of high-power triode-amplifiers over a broad band, and design of suitable filters (Hollywood, 1939; Nergaard, 1939; Brown, G. H., 1941) for attenuating the unwanted side-band components without injuring the desired signal component.

The N.B.C. television antenna atop the Empire State Building in New York City is shown in figure 9.

The point-to-point transmission of video-signal intelligence has already been touched upon briefly. Because of the wide spectrum of the video signal there are very few facilities in existence which are capable of handling this type of signal. A nation-wide television service requires the distribution, to remote areas, of programme material originating in any one locality, as is now done by wire networks in sound broadcasting. When nation-wide sound broadcasting networks were desired, it was possible to utilize, in many instances, existing facilities which had been installed for the purposes of telephonic communication, It does not appear, however, that any existing facilities may be employed satisfactorily for television network purposes. Tests have been made, using both wire line (Strieby and Weis, 1941) and radio circuits (Kroger, Trevor and Smith, 1940), which have shown that either medium is capable of providing the network facilities desired. Relative costs of the two media are not yet accurately known, but it seems likely that radio relaying will be adopted first in most cases because the facilities can be installed more quickly.

In planning a radio-relay system for television it is necessary to consider the proper antenna heights, antenna gain, spacing between relay stations and power radiated to give the most economical result. The propagation characteristics of the frequencies employed will have an important bearing upon the optimum balance of these various factors for lowest cost. The particular terrain in question will be a factor in determining the final layout, since use may be made of elevated points with lower tower structures, or greater distances permitted between stations.

A television radio-relay system, operating in the 500 Mc. region of the spectrum and employing frequency modulation, has been set up and demonstrated in the United States by R.C.A. Communications, Inc. (Kroger, Trevor and Smith, 1940). In this instance the relay stations were approximately fifteen miles apart, the antennas were 100 feet high and the intervening terrain was such that line-of-sight transmission was possible. The relay transmitters delivered approximately two watts of power and provided an overall gain for each repeater station of approximately 80 db.

The results of the tests and demonstrations, using this experimental relay set-up, showed that a system consisting of radio relays would be technically adequate and feasible for the distribution of television-network programmes.

(d) *Reception*

Home receiver. The signal received by the antenna preferably is conveyed to the radio receiver by some form of balanced line. This line may merely be a twisted pair, if the location of the antenna is such that a relatively short line can be used, and if the signal strength is high. On the other hand, if the feed line is long, and particularly if the field strength at the antenna is small, it may be necessary to use a two-wire, air-insulated transmission line or even a pair of coaxial cables.

The receiving equipment itself provides for the conversion of the radio-frequency signal into a video signal and for sufficient amplification for it to be used to operate the viewing device. It also separates the synchronizing impulses from the picture signal, employing the former to control the scanning pattern of the viewing device (Engstrom and Holmes, 1938, 39).

As with the conventional sound radio receiver, several alternative types of television receivers for home use are possible. The two most frequently used employ superheterodyne and tuned radio-frequency circuits.

A tuned radio-frequency receiver has five or six tuned stages of ultra-high frequency amplification, a detector, and several stages of video amplification.

Because of the difficulty of accurately tuning the many radio-frequency stages, it is rarely used when reception from more than one transmitter is desired (Brown, W. J., 1939, 40).

The superheterodyne receiver is made up of a radio-frequency element, a first detector and oscillator, an intermediate amplifier, and a second detector followed by a video amplifier. The radio-frequency element may merely be a broadly tuned circuit whose chief function is to match the antenna feeder to the first detector circuit, or it may be more complicated, containing, for example, a stage of radio-frequency amplification (Tyson, 1940). The radio frequency leaving this first stage is mixed with the output from the local oscillator and rectified by the first detector, giving rise to the intermediate frequency. The mixing is merely an addition of the incoming modulated signal and the locally generated unmodulated signal in a non-linear tube circuit which produces a beat effect between these two waves (Herold, 1940). The intermediate carrier and its side band are amplified by the intermediate amplifier, the other frequencies

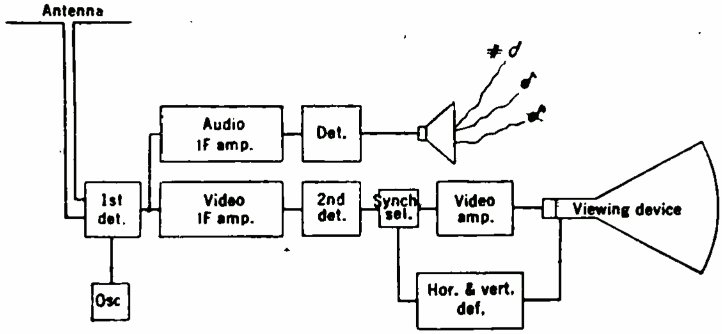

Figure 10.

present in the output of the detector being removed by the band-pass characteristics of the interstage coupling of this amplifier (Mountjoy, 1940). It has already been pointed out that the receiver-amplitude characteristic must have a sloping response in the vicinity of the carrier frequency if suitable reception of the transmitted signal, shown in figure 7, is to be had. This characteristic is obtained in the tuning of the intermediate, frequency-amplifier coupling circuits. Rectification of the mixed signals by a linear detector also leads to the intermediate carrier and side bands, but there are present, in addition, components resulting from the addition of various side-band frequencies. However, if the amplitude of the locally generated oscillation is large compared with the incoming signal, the amplitude of the unwanted combination of side-band frequencies will be small compared with those of the fundamentals. For practical reasons it is common to use a linear detector and a powerful local oscillator rather than a square-law detector.

After amplification, the intermediate carrier and side band are again rectified, this time by the second detector, which is also usually a linear detector. The output of this element is a signal which corresponds exactly to the video signal generated by the pickup device, together with synchronizing impulses and any correcting signals inserted at the monitoring amplifier. A superheterodyne receiver is illustrated by the block diagram given in figure 10. As shown in this figure, the combination audio and video receiver employs a common first detector for the two signals, but separate *if* amplifiers and second detectors.

The level of the video signal leaving the final detector is, in general, not sufficient to actuate the viewing device. In consequence, it must be amplified by one or more stages of video amplification before it can be used. These stages are similar to those between the pickup equipment and the transmitter, being resistance-coupled and compensated to increase the high-frequency response (Foster and Rankine, 1941). Because of the nature of the coupling, the amplifier will pass only the a.c. components of the video signal. Therefore, it is usually necessary to provide some arrangement to re-insert the d.c. component, in order to establish the average illumination of the picture being transmitted.

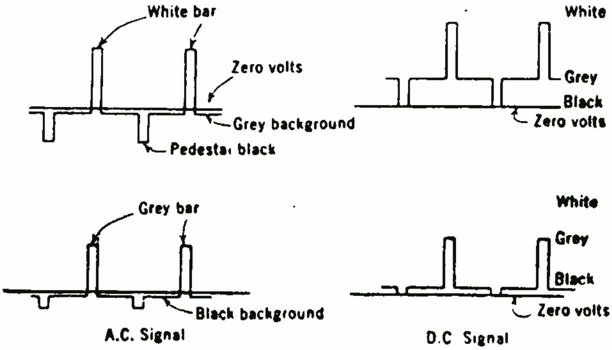

Figure 11.

By " d.c." signal is meant one for which the voltage relative to some fixed reference voltage corresponds to the absolute brightness of the point under the exploring spot at the transmitter. The diagrammatic oscillograms of figure 11 illustrate the distinction between the two types of signal. The d.c. level of the video signal can be re-inserted by making use of the pedestal or of the synchronizing impulse, because these bear a definite relation to either maximum dark or light of the picture.

A diode rectifier, or its equivalent, is employed for re-inserting the d.c. component to the signal at the terminals of the picture-reproducing device. This diode is similar in its action to a peak-reading vacuum-tube voltmeter, the d.c. voltage produced providing a bias for the picture reproducer which will maintain black level at the proper point on its characteristic (Foster and Rankine, 1941).

Some viewing device is necessary to convert the video signal into final visible reproduction, which is the ultimate objective of the system.

Two operations are necessary to perform the reconstruction of the image. The first consists of modulating a small but intense spot of light with the video signal; the second, of causing this spot to move in such a way that it sweeps out the scanning pattern on the viewing screen.

Broadly, there are two classes of viewing devices: electronic (Zworykin, 1929) and mechanical (Robinson, 1939). Of these, the former is the more widely used, particularly in home receivers. Very interesting results have been obtained with both systems as a means of producing large pictures for public viewing. The most widely used electronic reproducer is a modification of the cathode-ray oscilloscope tube known as the kinescope (Zworykin, 1929; Zworykin and Morton, 1940), the biggest change being the introduction of a control element to modulate the intensity of the cathode-ray beam. The kinescope consists essentially of an electron gun and a fluorescent screen enclosed in an evacuated container of suitable shape and size. The electron gun is a system of electrodes comprising an electron lens which drives a stream of sharply focused electrons against the fluorescent screen, producing a small luminous spot on the screen. The electron beam is deflected by either electric or magnetic fields in such a way that the spot is caused to move across the fluorescent surface in accordance with the scanning process in the camera where the television signal originates. At the same time, the intensity of the electron beam (and hence the brightness of the luminous spot produced by it on the screen) is controlled by applying the television signal to a control electrode of the electron gun. This modulation of the brightness of the luminous spot, in combination with its synchronous deflection across the screen, provides a reproduction of the original scene. An important requirement to be met in a kinescope is that modulation of the electron beam by variation of the potential on the control electrode must not result in appreciable variation of focus of the electron lens throughout the normal working range.

Home projection receiver. Very few of the television receivers now in use for home reception employ optical magnification of the received image. The cathode-ray screen is viewed either directly or by means of a mirror located in the lid of the receiver cabinet. Although a few types employ picture tubes having a 5-inch or 9-inch screen diameter, the most popular size is a 12- or 14-inch cathode-ray tube giving an image approximately 8 × 10 inches. A few receivers employing a 20-inch cathode-ray tube have been demonstrated (Goldsmith, 1940), but these very large cathode-ray tubes have not come into general use.

While the present receivers utilizing the 12-inch cathode-ray tube have given very satisfactory results from the standpoint of both picture resolution and brightness, there has been a general desire for larger television pictures, of the order of 18-inch to 24-inch in width, with increased contrast range, comparable to home motion pictures. It appears that the best engineering solution to the problem of providing such pictures is to produce a very intensely illuminated image on a small cathode-ray tube (Zworykin and Painter, 1937) and project it, optically magnified, on a larger viewing screen. Such an arrangement has many advantages, being more compact and economical than a very large cathode-ray tube directly viewed, and the indications are that some designs of projection receivers could be built in quantity to sell at a very reasonable price.

Early in 1941, one manufacturer demonstrated samples of a home-projection receiver having several novel features. This utilized a special 5-inch projection cathode-ray tube operated with a second anode voltage of about 27 kv. This voltage, as well as the first anode voltage, was generated by means of triode oscillators operating at a low radio frequency, the R.F. voltage being stepped up, by means of an auto-transformer arrangement tuned to resonate at the frequency of the oscillator, and rectified. Focusing was accomplished by tuning the oscillator supplying the first anode potential. It was pointed out that, although a power interlock system was provided to prevent the user from coming in contact with the high voltage, due to the smaller amount of energy stored in the R.F. high-voltage filter system, this power supply does not have the same lethal properties as many conventional power supplies of much lower voltage, but greater stored energy, as used in present direct-viewing television receivers.

The television image was projected via a suitable field flattener and a lens having a focal length of 5 inches and a rated aperture opening of f/2. The effective speed of the lens and the contrast range of the projected image were enhanced by coating the glass surfaces to prevent internal reflections. The television image was projected from the rear of a translucent viewing screen giving a picture 13·5 inches by 18 inches in size with a peak brightness of 10 foot-lamberts and a picture resolution of over 400 lines. The whole assembly was designed to fit into the same cabinet as a standard commercial 12-inch direct-viewing receiver.

Theatre projection. During the past several years, projection television equipment designed for theatre use has been demonstrated from time to time. Both the Baird system, using a projection cathode-ray tube operated at high voltages and a fast projection lens, and the Scophony system, utilizing a supersonic light valve in combination with mechanical scanning, have given very creditable results. The most recent development in this field is the newly designed theatre projection equipment (Zworykin and Painter, 1937; Maloff and Tolson, 1941; Law, 1937) demonstrated by the R.C.A. Manufacturing Company in a New York theatre early in 1941. The equipment utilizes a 7-inch white screen cathode-ray tube operated at an anode voltage of 70 kv. and producing a maximum luminous flux output of 1200 lumens. This light is collected by an optical system consisting of a spherical mirror and an aspherical lens or correction plate, which combine to form a projection system free from spherical aberration or coma. With a mirror 30 inches in diameter, the projection system has an efficiency of 25 %, delivering a luminous flux of 300 lumens to a viewing screen of full motion-picture size (15 × 20 feet). An idea of the increased efficiency of this special optical system can be gained from the fact that a conventional arrangement using a lens with an f/2 aperture would have an efficiency of only $3\frac{3}{4}$ %. The picture definition obtainable with the equipment was over 400 lines, when operated at the scanning rate of 441 lines, 60 fields, 30 frames per second. With a projection screen having a 2 : 1 directivity, the picture had an effective peak brightness of over 2 foot-lamberts, which is comparable to the range of 5 to 20 foot-lamberts peak brightness obtained with film projection on the same size screen in the better motion-picture theatres. A screen with a 5 : 1 directivity gave a peak brightness of 5 foot-lamberts with the projection television system.

§ 3. SPECIAL PROBLEMS.

(a) *Pickup tubes*

The Iconoscope. The basic limitation of mechanical scanning devices is so well known and so obvious that it will not be commented upon here. Practically all modern television pickup devices employ some type of electronic scanning. The one which has enjoyed most extensive use is the iconoscope (Zworykin, Morton and Flory, 1937; Janes and Hickok, 1939; McIlwain, 1939; Fink, 1940; Zworykin and Morton, 1940).

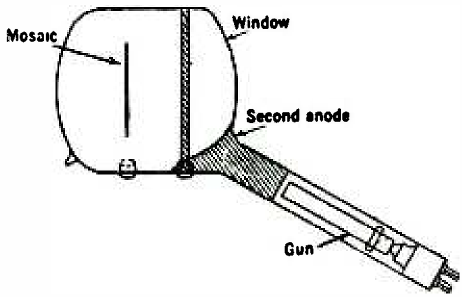

Figure 12.

The iconoscope consists of a photo-sensitive mosaic and an electron gun assembled in a highly evacuated glass envelope. The gun is an electron-optical system serving to produce a fine pencil of cathode rays which is made to scan the sensitized side of the mosaic by means of a suitable magnetic, or electrostatic, deflecting system. The mosaic in the normal iconoscope is a very thin mica sheet covered on one side with a vast number of minute silver globules, photo-sensitized and insulated from one another, and coated on the other with a metal film known as the signal plate. This metal film is coupled, on the one hand, to the silver elements by capacity through the mica and, on the other, to the video amplifier through a signal lead sealed into the bulb. The drawing of figure 12 shows a section through a typical iconoscope. It will be seen that the electron gun is not normal to the mosaic surface, but is displaced from normal by an angle of approximately 30° in order to provide clearance for the optical system employed to focus the light image upon the mosaic.

The optical image is projected on to the silver-coated side of the iconoscope mosaic. Each element, being photo-emissive, accumulates charge by emitting photo-electrons. Thus, the information contained in the optical image is stored on the mosaic in the form of a charge image. The scanning beam, sweeping across the mosaic in a series of parallel lines, releases the charge from each element in turn and brings it to equilibrium, ready to start charging again. The change in charge in each element induces a similar charge in the signal plate and, consequently, a current pulse in the signal lead. The train of electrical impulses so generated constitutes the picture signal. The iconoscope differs from all previously developed pickup devices in being able to store information for each element of the image during the entire scanning cycle, thus giving tremendous increases in sensitivity over non-storage devices.

The simple theory of operation of the iconoscope given above is complicated by the secondary emission of electrons which occur when the high-velocity scanning beam strikes the mosaic. Due to the fact of this secondary emission, the scanning beam, instead of merely replacing electrons emitted due to photo-emission, actually drives the scanned area to a more positive potential. In fact, the element under the scanning beam is the most positive on the entire mosaic. Under the combined action of photo-emission and bombardment by the scanning beam, the mosaic becomes positively charged to a potential very nearly the same as that of the collector electrode. There is a space charge in the region in front of the mosaic composed of electrons emitted by secondary emission and photo-emission. Electrons from this space charge settle more or less uniformly over all elements of the mosaic and also drift toward the collector electrode, depending upon the influence of a varying and rather complicated space distribution of the fields. On the average each element of the mosaic must regain the same number of electrons as it loses, due to photo-emission plus secondary emission. At the point of bombardment by the scanning beam, when the beam current is fairly high, the surface of the mosaic assumes a voltage between plus 2 and plus 3 volts with respect to the collector. The most negative area of the mosaic lies always just ahead of the scanning beam, and its potential is usually minus $1\frac{1}{2}$ volts. For lower beam currents the difference in potential between the most positive and most negative points on the mosaic is somewhat less.

The mechanism of the generation of the picture signal may now be considered on the basis of the above factors. Fundamentally, it is due to the fact that the potential of an illuminated element of area, just before being reached by the scanning beam, is more positive than one which has not been illuminated. Since the mosaic is driven to the same positive equilibrium regardless of its initial potential, charge will be released at a different rate when the beam is traversing the lighted region from that when scanning an unlighted area. The change in current reaching the collector constitutes the picture signal.

The Image Dissector Tube. The image dissector tube (Farnsworth, 1934; McIlwain, 1939) is an electronic television pickup device in which the light image is focused upon a photo-cathode surface and the electrons emitted therefrom in accordance with the light values at each point are brought to focus, by means of an electronic lens system, in the plane of a small aperture which is of picture element size. The electrons emitted from the photo-cathode are deflected both horizontally and vertically by means of deflecting coils, so that the electron image in the plane of the fixed scanning aperture is swept across the aperture in order that electrons from the various elementary areas on the photo-cathode may contribute their charge in proper turn to the collector inside the scanning aperture. An electron multiplier is associated with the collector inside the scanning aperture so that the minute currents collected may be intensified before being impressed upon the conventional video amplifier.

The important difference between the image dissector tube and the iconoscope is the lack of any storage of picture information in the former. As a result of this, its sensitivity is considerably lower. On the other hand, it is free from spurious signals which are produced by the complications arising from secondary emission in the iconoscope. In recent years the image dissector tube has found its most important application in the televising of film, where its relatively low sensitivity may be overcome by the use of bright light in projection and where its freedom from spurious signals is especially advantageous (Jensen, 1941).

The Image Iconoscope. The image iconoscope is a pickup device consisting essentially of the same elements as a standard iconoscope, but with the addition of an electronic image amplifier (Iams, Morton and Zworykin, 1939). In this tube the optical image is focused upon a semi-transparent photo-cathode surface. Electrons emitted from the other side of this surface are brought to focus, by means of an electronic lens system, upon a mosaic surface similar to that in a standard iconoscope. Because of their velocity, caused by a suitable acceleration potential, these electrons produce a charge upon the mosaic by secondary emission which corresponds to the original image, and this charge is then scanned and a video signal generated in the same manner as in the standard iconoscope. The addition of the electronic image amplifier gives this tube a greater sensitivity than the standard iconoscope. Its English counterpart, the super-emitron, came into use in some of the regular television operations of the B.B.C. during the last two years of service prior to the war.

The Orthicon. During the last two years of television programme operation in the United States a new type of iconoscope, known as the orthicon, has come into use in those applications where high sensitivity is of paramount importance (Rose and Iams, 1939 a, 39 b). This tube also makes use of the storage principle, and may be said to differ fundamentally from a standard iconoscope in the employment of a low-velocity cathode-ray scanning beam. The importance of this difference lies in the fact that the low-velocity electrons do not produce any secondary emission upon striking the mosaic, and hence do not produce the space-charge effects and attendant spurious signals which are present in the standard iconoscope and image iconoscope. This tube makes use of a mosaic similar to that employed in the iconoscope except that the signal plate is semi-transparent and the optical image is focused upon the mosaic by transmission through the signal plate. Although this arrangement results in a reduction of sensitivity due to imperfect light transmission through the signal plate, it allows the light optical system and electron optical system to be on opposite sides of the mosaic, and the axis of the electron gun, therefore, can be at right angles to the mosaic, whereas in the iconoscope it must be off the normal by approximately 30° in order to avoid physical interference with the light optical system.

The low-velocity scanning beam employed in the orthicon creates special problems in deflection and in focusing. In the type most commonly used, focusing of the scanning beam is by means of an axial magnetic field, and vertical deflection is electro-magnetic. Horizontal deflection is provided by means of an electrostatic field operating in conjunction with the magnetic focusing field, the electrostatic plates in this case being horizontal, or parallel to the direction of deflection.

In its present state of development the orthicon tube is not capable of as high resolution as the best standard iconoscope, due to imperfect focusing of the low-velocity electrons in the scanning beam at the surface of the mosaic. On the other hand, its greater sensitivity, due to a combination of better storage and freedom from spurious signals, has opened new possibilities in television programme operation, and its resolution is adequate for many purposes.

Future developments. Although the pickup tubes available at present for television operation have sufficient sensitivity to give good pictures with reasonable light levels, it would, nevertheless, be desirable to increase the sensitivity. The orthicon tube represents an improvement over the standard type of iconoscope in this respect, and also in its freedom from dark-spot signal. Even the orthicon, however, does not give the television camera the sensitivity necessary to equal the performance possible in photographic work when using the recently developed super-sensitive film emulsions. Many schemes have been suggested for improving the sensitivity of the television pickup devices and a considerable amount of experimental work has been done and is still in progress on some of these schemes. No attempt will be made here to cover the entire field, but some mention might be made of two of the most promising proposals.

The principle of the electron multiplier, which has made possible such substantial improvements in the sensitivity of photo-electric tubes, has also been applied to television pickup tubes. The image iconoscope, previously described, embodies one stage of electron multiplication. Experimental tubes have also been made in which a portion of the electrons emitted from the iconoscope mosaic under the impact of the scanning beam is led into a series of electron multiplier stages. A several-fold increase in sensitivity, compared with standard iconoscopes, has been obtained by this method, but some difficulty has been experienced in obtaining uniform pickup by this method of the electrons from all parts of the mosaic. A more promising application of this principle is the use of electron-multiplier stages in conjunction with the low-velocity scanning-beam type of tube (orthicon). In this tube those electrons from the scanning beam which are not absorbed in equalizing the charge on the mosaic produced by photo-emission are turned away from the mosaic and are collected in an electron multiplier. In this case there are no complicating factors due to secondary emission (until the electron-multiplier stages are reached), and this tube shows considerable promise of a several-fold increase in sensitivity over the standard type of orthicon, which is itself several times more sensitive than the standard iconoscope. Tubes have been built in accordance with this principle and operated in the laboratory, but the design is not yet ready for tests in the field.

Since spurious dark-spot signal inherent in the standard type of iconoscope tube is eliminated by use of a low-velocity scanning beam, it now appears likely that future developments in the field of pickup tubes will all utilize the low-velocity scanning beam. Another interesting development in this field is that of a tube in which an image multiplier stage is employed ahead of the mosaic just as in the case of the image iconoscope, but with a low-velocity scanning beam for the mosaic.

(b) *Colour television*

A study of the history of the motion-picture industry reveals that experimenters and inventors began to attempt to add colour to the monochrome reproductions almost as soon as the first crude pictures were produced. The reproduction of scenes in natural colour in most cases adds a desirable quality and, provided there are no serious sacrifices in other picture characteristics, it is decidedly worth while. It is only within recent years, however, that colour-motion pictures have achieved the technical perfection which makes possible their wide-scale acceptance, and even to-day many important feature films are made in monochrome.

In television, also, the desire to add natural colour to the reproduced television picture has stimulated the minds of inventors and experimenters almost from the beginning of the television art. It was not until the 1920's that colour experiments were demonstrated that seem worthy of mention. The literature of that decade describes several different systems for colour television, prominent among which are reports on the work of the Bell Telephone Laboratories (Ives and Johnsrud, 1930; Ives, 1931) in the U.S., and J. L. Baird (Tiltman, 1928) in England. In 1925 a proposal for an all-electronic colour television system was made by V. K. Zworykin (1928).

During the past ten years a number of systems for the transmission of television images in natural colours have been described in the literature. Some of these, while theoretically sound, have for practical reasons never advanced beyond the proposal stage, but others have actually been demonstrated with varying degrees of success. The same general principles of colour analysis and synthesis, long used in colour photography (Luckeish, 1927), have been utilized. According to these principles, the colours in the original image are split up into relatively narrow spectral bands corresponding to the three primary colours, and these are transmitted separately. At the receiving end, the three video signals so generated actuate light sources of the corresponding colours to reproduce the proper shade of colour for each elementary picture area. While such a procedure would seem to involve a compromise in colour reproduction, inasmuch as a continuous spectrum cannot be transmitted accurately, it is a well-known fact—repeatedly demonstrated by three-colour printing and three-colour photographic processes—that as far as the eye is concerned a highly satisfactory result can be obtained. The reason for this is two-fold: the inability of the eye to analyse colours accurately, and the fact that monochromatic colours occur only very rarely in nature or in the scenes to be reproduced.

As in photography, a three-colour system for television may use either the additive method, with red, green and blue as the primary colours; or the subtractive method, in which the primaries are yellow, blue-green and magenta. An example of a system using the subtractive method is a recent proposal involving the use of special cathode-ray tubes which operate as light valves for picture reproduction (Rosenthal, 1940 a, 40 b). The cathode-ray target in these tubes consists of a crystal which is normally transparent, but which will absorb light in a narrow wave-band when bombarded by electrons, the effect persisting for a fraction of a second after cessation of bombardment. In a reproducing system for a three-colour subtractive process, the light would pass through three such tubes in tandem, each one providing absorption of a different primary colour component from the original white light in accordance with signal modulation of its electron scanning beam. While this proposal is novel and interesting, there is no report of any such system having been set up and tested.

Inasmuch as most of the colour-television systems which have been set up for experiment and demonstration have employed the additive process, the subtractive process will not here be dealt with further.

Various two-colour systems using blue-green and orange-red filters for analysis and synthesis have been proposed, and one of these has been demonstrated recently (Bartlett and Caldwell, 1941). The fidelity of colour reproduction obtainable is in general inferior to that with three-colour systems, but the process has some merit since, in comparison with three-colour processes, it results in simplification of equipment and permits the transmission of more detail within a frequency band of fixed width.

In addition to the two-colour and three-colour additive and subtractive classifications already referred to, colour-television systems may be subdivided further under the general heading of *cyclic systems* and *simultaneous systems*, according to the manner in which the electrical signals corresponding to the primary colours are transmitted and received.

A cyclic system is one in which the video signals corresponding to the three primary colours are transmitted and received on a time-division basis over a single communication channel. An example of a cyclic system is one in which complete scanning fields of the primary colours are transmitted according to a pre-determined sequence. Since three fields are required to complete the red, blue, green colour cycle, it is evident that with this system the avoidance of flicker requires that the vertical deflection rate be substantially increased above that normally used for monochrome of comparable definition.

A typical simultaneous system employs three pickup tubes, one for each of the primary colours, continuously focused on the scene, three separate transmission channels for the electrical signals, and optical means for recombining the light from three reproducer tubes into a single image at the receiving end. In such a system the proper colour-selecting filters are placed in front of each pickup device and in front of its corresponding reproducer at the receiving end (or each reproducing kinescope may have a screen phosphor which produces, directly, light of the proper primary colours). Parallax can be avoided by using a single lens at the sending end with a suitable optical arrangement for focusing three identical images on the three pickup tubes with their colour-separation filters. Such optical combinations are extensively used in cameras for three-colour photography and will not be described in detail here. The simultaneous system has several advantages: (i) The vertical deflection rate need not be greater than in a comparable monochrome system to avoid flicker; (ii) the apparent brightness of the received image will generally be greater than with a cyclic system, since the receiver screen is continuously illuminated with all three primary colours; and (iii) there are no mechanical moving parts.

The main practical disadvantage encountered in applying this method is the difficulty in obtaining sufficiently accurate deflection of the cathode-ray beams at both sending and receiving ends, so that satisfactory registration of the three images may be obtained. It is interesting to note here the striking similarity to the problem that existed for some years in the field of colour cinematography with respect to accurate registration of the coloured images transferred from the several " taking " films to a single coloured film for projection. It is hoped that the problem of registration in three-colour simultaneous television may be solved by the same type of painstaking work that finally produced satisfactory colour-motion picture films.

In passing, it might be mentioned that a three-channel simultaneous system does not necessarily involve the use of three separate transmitters and receivers. It is possible to modulate a single carrier by three subcarriers to produce a signal capable of being sent out by a single transmitter. The resulting single carrier and side bands can be demodulated in a suitably designed receiver to separate the signal into the three original channels.

There are numerous possible variations of the simultaneous and cyclic systems as outlined here, and no attempt will be made to survey all of the many systems that have been proposed.

Recently there has been a revival of interest in a cyclic method of colour television which bears some similarity to a cyclic film system (Kinemacolour) that enjoyed favour for a brief span in the early days of colour-motion pictures (Luckeish, 1927). The arrangement in this type of system provides for the use of electronic pickup and reproducing devices in connection with colour filters moved synchronously by mechanical means in front of the camera and receiver tubes. While it might seem to many that it is a backward step to incorporate mechanical rotating machinery in a television system which is otherwise completely electronic, the method is attractive from the standpoint that it produces better results than any other immediately available. Experiments, using semi-mechanical cyclic systems, are now in progress at several laboratories and, although the histories of both colour-motion pictures and television itself tell us that such systems will not survive the advent of a practical all-electronic colour television system, it is undoubtedly true that much is being learned through these experiments which will be useful and valuable in the future art, no matter what system may be the prevailing one ultimately.

During the latter part of 1940, considerable interest was shown in the results obtained in demonstrations by the Columbia Broadcasting System of a cyclic system (D. G. F., 1940; Goldmark, 1940) using 60 frames per second, 343 lines interlaced 2 to 1. Electronic pickup and cathode-ray reproducing tubes were used in connection with mechanically rotated filter wheels fitted with red, green and blue filters. Complete colour fields of the primary colours were transmitted at the rate of 120 per second, making the colour-flicker rate 40 per second and giving a colour-scanning coincidence rate of 20 per second. (The colour-scanning coincidence rate is the rate at which each scanning line goes through the complete cycle of three colours.) The colour-scanning coincidence rate was one-half the colour-flicker rate by virtue of the 2-to-1 interlace used. With these standards, and with a given communication channel, a loss in total resolution of approximately two to one, compared to conventional monochrome systems, is accepted to allow for the addition of colour. Also, visible flicker is present in the reproduced picture under some conditions.

A three-phase amplifier section with separate gain control on each of the phases permitted independent variation of the signal corresponding to each of the three primary colours, thus permitting convenient adjustment of colour balance in the reproduced picture.

While the recent tests and demonstrations by C.B.S. and others have served to show that excellent colour reproduction can be obtained with such a cyclic system, there is considerable doubt whether the sacrifice in resolution will be acceptable except in certain types of scenes. When attempting to add colour to an existing monochrome system with a fixed communication channel, it must be realized that some compromise is necessary. This follows when it is understood that the addition of colour requires the transmission of a greater amount of information in a given time than for an equivalent monochrome picture. In monochrome transmission it is necessary only to convey information as to the position and illumination intensity of each picture element, but when colour is added, we must not only transmit information about the position of each picture element, but also the individual intensities of the red, green and blue components which combine to reproduce its colour.

Since a compromise must be made with respect to resolution and/or flicker rate when applying the cyclic method to a system applicable to the video band width available at present, it is of interest to consider the possible choices. Some of them are:

(*a*) The present scanning rates of 525 lines per frame, 30 frames per second can be retained and colour added by transmitting sequential colour fields. Under these conditions, the colour-flicker rate will be 20 per second, and the colour-scanning coincidence rate will be 10 per second. Although this combination produces the same horizontal and vertical picture resolution as for monochrome conditions, actual tests show that the flicker produced is intolerable, as would be expected.

(*b*) Keeping the same number of horizontal scanning lines per frame, and the same 2 to 1 interlace ratio, the field rate can be doubled to 120 per second. In order to obtain the same horizontal resolution as before, however, the video band width must be doubled. If we keep the same band width (4·25 Mc.), the horizontal resolution will be halved, but the flicker will be greatly reduced.

(*c*) We may keep the same number of lines per frame, 525, the same number of frames per second, 30, but increase the field frequency and the interlace ratio. This arrangement gives full horizontal and vertical resolution, and cuts down field flicker. However, experience has shown that any interlace ratio greater than 2 to 1 is unsatisfactory because the eye can partially resolve the individual scanning lines and an objectionable " creeping " effect of the lines is seen in the picture.

(*d*) An alternative to (*b*) above would be to use double the vertical scanning frequency and double the frame rate, but reduce the number of horizontal picture scanning lines until horizontal and vertical picture resolution are approximately equal.

Total resolution would, however, still be limited as in (*b*). It has recently been reported (Baldwin, 1940) that the distribution of definition, between the horizontal and vertical dimensions, is not critical for a given overall resolution.

The present 6·0 Mc. channels allocated in the United States for broadcasting television and associated sound make available an effective video-frequency band width of approximately 4·25 Mc. at most. With some types of scene, the lower image definition obtainable when applying the three-colour cyclic system to this limited band width in place of the standard monochrome system is compensated for by the colour resolution obtained. However, since in general there are various psychological and other complex factors involved, comprehensive field tests will be required to determine the usefulness of such a colour system in the limited band width.

A comprehensive field test of colour television was started in March 1941 by the National Broadcasting Company and is still in progress as this *Report* is written. The system tested has used 441 and 343 lines per frame, and 120 fields, 60 frames per second, interlaced 2 to 1. Consecutive scanning fields are transmitted in the primary colours in a red, blue, green sequence. The colour television signals, comprising both film and direct pickup subjects, originating in the N.B.C. studios have been broadcast over Station W2XBS, the television transmitter normally used for monochrome broadcasts in New York. These signals have been observed at various points in the Metropolitan area, and at distances up to 50 miles, by means of colour receivers especially prepared for the field test.

An orthicon (Rose and Iams, 1939 b) camera equipped with a specially designed colour wheel and fitted with standard Wratten no. 25, no. 58 and no. 47 red, green and blue filter transparencies has been used at the sending end for both film and direct pickup subjects. Approximate colour balance was obtained by using either high-intensity carbon arcs or fluorescent lamps having a colour temperature of 4000–5000° K. for illuminating the scene, and by adjusting the effective transmission of the sending-end colour filters. The camera tubes used have essentially uniform response for the three primary colours, so that the remaining small colour un-balance can be readily corrected by means of individual electrical colour-gain controls operating in a three-phase amplifier provided for that purpose.

The receivers utilize kinescopes having a short-persistence white sulphide screen-material, giving substantially uniform colour response over the visible spectrum when viewed through a rotating wheel containing no. 25, no. 58 and no. 47 Wratten tricolour filters. Most of the receivers used so far are of the standard 9-inch viewing type, modified to accommodate the colour wheels and driving motor. Additional power-supply filtering had to be added because of the difficulty in obtaining good interlace when operating at 120-cycle field frequency, which is double the a.c. power-supply frequency. A projection type colour receiver giving an image 18 × 13 inches and ½ inch in size was also tested.

This field test is still in progress, but the following tentative results have been obtained:—

(*a*) Those who have viewed the transmissions have been well pleased with the fidelity of colour rendition, and some expressed the opinion that the colours reproduced were equal to the best in coloured motion-picture films.

(*b*) Many observers have been disappointed by the low value of resolution possible with the system. This is not objectionable in close-up scenes, but is very apparent in average scenes.

(*c*) The obtaining of good interlace on the receivers operating at 120 fields turned out to be a major problem, inasmuch as a very small amount of residual 60-cycle hum in the deflection, video or high-voltage supply circuits completely destroys interlace. If present in the horizontal deflection circuit, 60-cycle hum cuts down picture resolution. Similar problems were encountered in the pickup equipment associated with the camera.

(*d*) In the field tests, some flicker was observed, mostly on white high-lights in the picture. Another effect directly related to the vertical deflection rate, and therefore to the colour-repetition rate, is that of " colour break-up ". This takes place when objects move rapidly in the picture field. A white handkerchief moved rapidly will appear as a number of red, green and blue blotches. Also an observer watching a coloured image, on suddenly turning away from the picture, or upon blinking his eyes, will momentarily see a completely red, blue or green screen, depending on the timing of his movements. On ordinary gestures no serious colour break-up was observed.

Pickup tube problems in colour television. The cyclic method of colour-television transmission places additional burdens upon the television-pickup tube employed in the camera. The most obvious of the new problems relates to the colour response of the tube. The spectral response of the pickup tube will, of course, have a direct effect upon the fidelity of the reproduced colour. While it is true that the overall colour fidelity is also affected by other characteristics of the system, including the spectrum of the light used to illuminate the scene being televised, and while these variables might be manipulated to compensate for variations in the colour response of the pickup tube, experience so far indicates that the most desirable colour-response characteristic for the pickup device is essentially a uniform one over the entire visible spectrum. A good approximation to such a response is possible in pickup tubes of the orthicon or iconoscope type, but suitable uniformity in all tubes on a production basis is not easy to achieve at the present time.

The effective sensitivity of a pickup camera in the three-colour cyclic process is substantially less with the same lens than the same camera would have with black and white operation. The exact ratio between these two sensitivities is not easy to calculate or measure, but it is in the order of four or five to one in favour of black and white operation. There is a three to one loss in sensitivity inherent in the cyclic process and some additional loss due to imperfect transmission through the three-colour filters. This loss in sensitivity means that in the televising of a given scene by the cyclic-colour method, a greater amount of light must be used on the scene, a faster lens employed on the camera, or a more sensitive pickup tube used, than when televising the same scene in black and white. (We have ignored the difference in sensitivity between colour and black and white, which is due to the difference in scanning standards usually employed, since it is believed to be smaller than the other factors mentioned.)

It has already been shown that modern high-definition television is possible only with electronic pickup devices employing the storage principle. Because of the added sensitivity required in the cyclic colour process, the importance of these storage devices for direct pickup is still further emphasized. However, with the interlaced scanning and colour sequence cycle proposed for colour television, the storage property in the pickup tube results in one undesirable effect. When light from the scene being televised passes through any one of the three filters in the optical system, the light image corresponding to that colour is focused upon the entire mosaic in the pickup tube. This creates an electrical charge on all elements of the mosaic corresponding to the light intensity of this colour component of the image at each point. Since, with the interlaced scanning generally favoured, only alternate lines in the picture will be scanned before the colour filter is replaced by one of a different colour, it follows that the unscanned lines on the mosaic will retain an electrical charge corresponding to the preceding colour image, upon which the electrical charge of the new colour image will be superimposed. This results in colour mixture and impaired colour fidelity in the reproduced image. Actually, with present pickup tubes the colour mixture is not as serious as might at first be supposed because of imperfect focusing of the electron beam which scans the mosaic. Since some of the electrons in the beam fall outside the nominal scanning-spot area, the effective width of the scanning spot is greater than one scanning line, and a partial equalization of the charge on the unscanned lines results. This imperfection in present-day pickup tubes has made possible the relatively good colour fidelity demonstrated in three-colour cyclic television transmissions, but it causes a corresponding reduction in resolution.

Several schemes have been proposed to eliminate this difficulty caused by the charge remaining on the unscanned lines at the end of each field scanning. One of these proposals (D. G. F., 1940; Goldmark, 1940) involves the shifting (vertically) of the optical image by a distance equal to the height of one scanning line at the end of each field scanning and a corresponding scanning control which causes the electron beams always to scan the same lines on every field. In this way the charge on the unscanned lines presumably would be ignored. Other proposals for solving this problem include various means of equalizing the electrical charge on the unscanned lines by auxiliary sources of electrons or by causing the main electron beam to sweep across these lines upon its return during the horizontal or vertical blanking interval. There has been no report of a demonstration of any of these in operation.

Either the iconoscope or the orthicon type of pickup tube may be used in cyclic colour television, and both have been used. However, the orthicon type of tube is preferred for two reasons. First of all it is substantially more sensitive than the iconoscope type and, as previously emphasized, sensitivity is quite important. In the second place, the iconoscope tube has a spurious output (dark spot signal) which is even more troublesome with colour than in black and white operation. Since the dark spot signal is not constant, but varies with the amount of light and type of scene, it follows that the dark spot signal is not always the same for the three colours in a cyclic colour system. It is possible to provide separate compensation for the dark spot signal for each of the three colours, but this is rather complicated and, therefore, undesirable. Another advantage of the orthicon tube for colour work is its linear characteristic as regards signal output versus light input.

It has been found experimentally that colour mixture is substantially reduced in the orthicon type of tube by increasing the thickness of the dielectric between the mosaic and signal plate. Special orthicon tubes having this lower capacitance between mosaic and signal plate were employed in the recent colour-television field tests and demonstrations previously reported.

Present status and future development of colour television. In recognition of the present interest in colour television, the Federal Communications Commission in the United States recently announced preferred values for standards for experimental colour transmissions. These tentative preferred standards fix a field frequency of 120, a frame frequency of 60, and 375 lines per frame interlaced 2 to 1. The preferred colour sequence was given as red-blue-green. The Commission has asked that television station licencees carry out tests of colour-television systems.

(c) *Scanning and synchronizing*

Consideration of number of lines. The problem of the transmission of a picture of finite detail and discontinuous or limited motion has no unique solution (Zworykin and Morton, 1940). Of the several possible methods, that involving the process of scanning has been chosen as the most practical for use in all important systems providing a service or undergoing experimental development at the present time. This scanning process consists of moving an exploring element or spot over the image to be transmitted in a periodically repeated path covering the image area. The exploring element is so arranged that it will generate a signal which indicates the average brightness of its instantaneous position. This signal is transmitted over the communication channel to the reproducing spot, the brightness of which is controlled by the signal. The reproducing spot is caused to move over the viewing screen in a path similar to, and synchronous with, the path of the exploring element. Thus the reproducing spot reconstructs at the viewing screen, both in magnitude and distribution, the brightness of the image area.

A variety of configurations has been proposed for the scanning path covering the image area and the viewing screen. These include spiral scanning, sinusoidal scanning, and so forth. In what follows, we will confine our discussion to straight-line scanning, since that has been generally adopted as the most desirable form.

In order to reproduce exactly the scene being televised, there must be exact synchronism of the scanning patterns in the pickup and reproducing devices. and there must be a one-to-one correspondence between the brightness of the reproducing spot and the brightness of the scene at the point corresponding to the position of the exploring element.*

In order to maintain the illusion of continuous motion, the separate pictures showing the different steps of the motion must follow one another rapidly. The motion-picture industry has adopted twenty-four frames per second as a standard, partly to allow for better sound fidelity in the usual sound-on-film arrangements than could be had at a lower frame-repetition rate. This rate, higher than absolutely necessary, insures smooth motion for most types of pictures. In television it has been found desirable that the frame-repetition rate bear a simple relation to the frequency of the commercial a.c. power supply (Zworykin and Morton, 1940). This minimizes undesirable effects of residual hum from rectifiers and stray fields, and is also helpful in practical use of motion-picture-film projectors with the television system which are of the intermittent type. Thus the frame-repetition rate chosen for use in the United States is thirty per second, the power-supply frequency most widely used being 60 cycles per second, while in England and on the European continent the frame-repetition rate most widely used is 25 per second, due to the prevalence of 50-cycle a.c. power supply. Actually, the rates of 25 or 30 frames per second, while fulfilling most requirements of continuity of motion, are not high enough to avoid flicker effects. To meet this situation, interlaced scanning has, in recent years, been almost universally adopted for television. In this special form of straight-line scanning, the spot, instead of moving across the horizontal lines in simple sequence, scans the odd-numbered lines first, then the even-numbered lines. It thus covers the field from top to bottom twice in order to scan completely all portions of the picture and, therefore, the field frequency is twice the frame frequency.

It is apparent that this form of scanning is not restricted to the simple interlacing mentioned. The scanning may be interlaced in accordance with much more complicated schedules, requiring three or more field excursions completely to scan the picture. The simple two-to-one interlace process has, however, been most widely adopted, since experience has shown that with this arrangement the flicker rate for most types of scenes is equal to the field-repetition rate, while for the more complex forms of interlacing, troublesome effects such as interline flicker, and an appearance of crawling or weaving, begin to show up.

One of the most controversial subjects in the field of television in recent years relates to the obtaining of optimum resolution with a given arbitrary limitation on the band width available in the communication channel (Wheeler and Loughren, 1938; Kell, Bedford and Fredenhall, 1940; Goldmark and Dyer, 1940; Baldwin, 1940). It has been generally assumed that the reproduced

* In actual practice such a linear relationship in brightness may not be possible or even desirable. In many scenes which it might be of interest to transmit, the range of brightness is far beyond the capabilities of many of the reproducing systems. As in photographic practice, it has been found both expedient and desirable to utilize non-linear relationships in this characteristic, the preferred relationships being governed by many of the same considerations as apply in photographic technique (Maloff, 1939; Fink, 1941).

picture should have approximately equal horizontal and vertical definition. Recent study (Baldwin, 1940) of the problem, however, by means of simulated television images has shown that the optimum distribution between horizontal and vertical resolution with a given fixed amount of total definition is not at all critical. It was, in fact, found that to produce a definitely discernible deterioration in overall quality a change of approximately two to one in the distribution between horizontal and vertical definition was necessary when the total definition remained constant. This means thatin a television system having a communication channel of fixed-frequency band width the optimum number of scanning lines is not critical within a two-to-one range. Other factors, of course, such as appearance of the scanning-line pattern, enter into a determination of a preferred number of scanning lines. In England the public television service in operation prior to the outbreak of the war employed a 405-line standard (Blumlein, Brown, Davis and Green, 1938), and in Germany 441 lines was the preferred value in 1939. In the United States, the standards recently set by the Government for commercial television operation call for 525 lines.

Vertical resolution in a television picture is governed primarily by the number of scanning lines. Although vertical resolution may be increased with a fixed number of scanning lines by the use of very small scanning apertures at the transmitter and reproducer, these will not give optimum resolution because of spurious images due to line structure (Mertz and Gray, 1934; Wheeler and Loughren, 1938; Kell, Bedford and Fredenhall, 1940). The effect is particularly objectionable if the spot size is smaller than the line separation. For example, if the exploring spot at the transmitter is less than the width of the vertical line separation, the reproduction of a bright line nearly parallel to the scanning lines will be a row of separated bright beads, visible even at distances for which the line structure cannot be resolved. This and other spurious effects due to line structure can be minimized by making the distribution of the spot such that the response and brightness at the transmitting and receiving ends, respectively, are uniform over the entire field. A field, meeting this requirement, will be termed a " flat field ". Rectangular spots having a uniform distribution, whose height is equal to the line separation, will give a flat field.

In most cathode-ray systems the spot has radial symmetry, and a distribution such that the brightness or response is a maximum in the centre. To obtain a flat field in this case it is necessary to overlap the lines. The actual distribution across a scanning line may be represented by a cosine-squared distribution with a fair degree of accuracy. The minimum size of a spot having this distribution which will give a flat field requires 50 % overlap.

Band width. Resolution in the horizontal direction (along the scanning lines) is determined primarily by the frequency band width available in the communication channel. Signal frequencies generated in scanning a given image are determined by the rate at which the scanning spot moves across the image, and this, in turn, is dependent upon the number of scanning lines and the picture-repetition rate. Thus it is at once apparent that an increase in the number of scanning lines in order to improve vertical resolution is accompanied by a corresponding decrease in horizontal resolution if the band width is fixed. Likewise an increase in picture-repetition rate, in order to reduce flicker, results in reduction in horizontal resolution. It is for this reason that interlaced scanning is used, since it gives a two-to-one increase in effective flicker frequency without the corresponding reduction in horizontal resolution.

Synchronizing signal. As was pointed out previously, the geometric fidelity of the picture reproduction depends upon the exact correspondence in position of the scanning spot at the transmitter and receiver. This correspondence requires that the periodicity and phasing of the horizontal and vertical scanning motions at the two termini be alike. It has not been found practicable to attempt

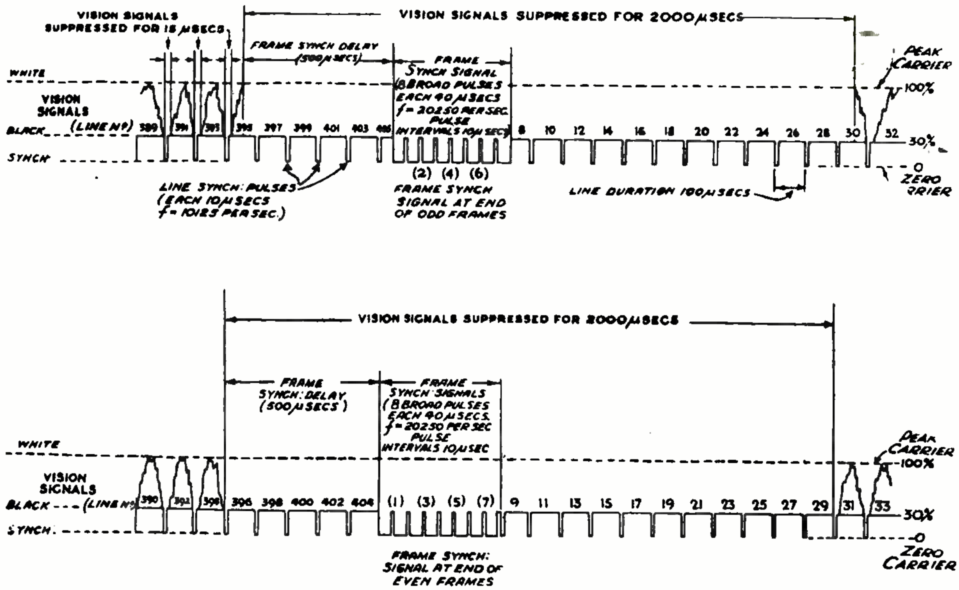

Figure 13.

to maintain this condition with independent control of the scanning pattern at the pickup and viewing device. Instead, suitable signals are transmitted which indicate the beginning of each frame (or field repetition in the case of interlaced scanning) and the beginning of each line (Bedford and Smith, 1940). These synchronizing signals are part of the complete video signal, and occur during time not utilized by the picture signal itself, that is, during the interval in which the scanning spot is returning to its original position, after completing a line or field traversal. In terms of the frequency spectrum of the picture signal (discussed above) the frequency components of the synchronizing signal are multiples of line and frame frequency, their phase and amplitude being such that they have no effect on the picture except around the edges, where

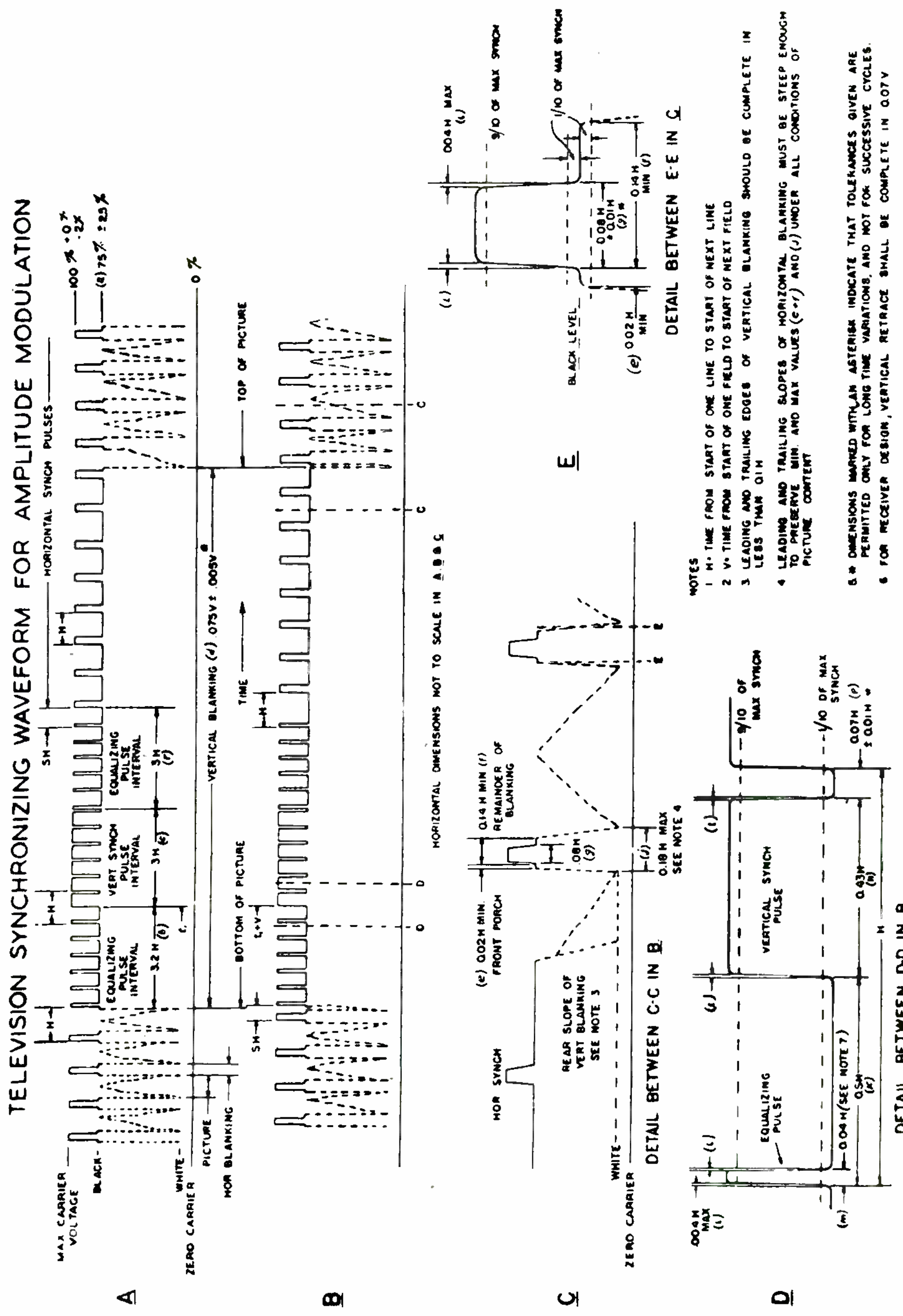
TELEVISION SYNCHRONIZING WAVEFORM FOR AMPLITUDE MODULATION
A
B
C
D
E
MAX CARRIER VOLTAGE
BLACK
WHITE
ZERO CARRIER
PICTURE
HOR BLANKING
HORIZONTAL SYNCH PULSES
EQUALIZING PULSE INTERVAL
VERT SYNCH PULSE INTERVAL
EQUALIZING PULSE INTERVAL
VERTICAL BLANKING (d) 0.75V ± 0.05V
BOTTOM OF PICTURE
TOP OF PICTURE
TIME
HORIZONTAL DIMENSIONS NOT TO SCALE IN A B & C
DETAIL BETWEEN C-C IN B
HOR SYNCH
REAR SLOPE OF VERT BLANKING SEE NOTE 3
(e) 0.02 H MIN. FRONT PORCH
0.14 H MIN (f) REMAINDER OF BLANKING
0.18 H MAX SEE NOTE 4
DETAIL BETWEEN D-D IN B
EQUALIZING PULSE
VERTICAL SYNCH PULSE
9/10 OF MAX SYNCH
1/10 OF MAX SYNCH
DETAIL BETWEEN E-E IN C
BLACK LEVEL
NOTES
1 H = TIME FROM START OF ONE LINE TO START OF NEXT LINE
2 V = TIME FROM START OF ONE FIELD TO START OF NEXT FIELD
3 LEADING AND TRAILING EDGES OF VERTICAL BLANKING SHOULD BE COMPLETE IN LESS THAN 0.1 H
4 LEADING AND TRAILING SLOPES OF HORIZONTAL BLANKING MUST BE STEEP ENOUGH TO PRESERVE MIN. AND MAX VALUES (e+i) AND (j) UNDER ALL CONDITIONS OF PICTURE CONTENT
5 * DIMENSIONS MARKED WITH AN ASTERISK INDICATE THAT TOLERANCES GIVEN ARE PERMITTED ONLY FOR LONG TIME VARIATIONS, AND NOT FOR SUCCESSIVE CYCLES.
6 FOR RECEIVER DESIGN, VERTICAL RETRACE SHALL BE COMPLETE IN 0.07 V
7 EQUALIZING PULSE AREA SHALL BE BETWEEN 0.45 AND 0.5 OF THE AREA OF A HORIZONTAL SYNCH PULSE.

Figure 14.

they form a narrow border which cannot be used for the image, and which, in cathode-ray terminal tubes, has no real existence. Instead of this multiplicity of frequencies, it might seem possible to use, for purposes of synchronization, a single frequency, falling, for example, in one of the vacant regions of the picture spectrum. However, while no picture component of this frequency appears in the spectrum, the presence of the signal would be reproduced in the form of a spurious moving shading.

In a simple Nipkow disk mechanical system the rotation of a single element only needs to be governed, and, for this, one kind of impulse alone is necessary. The usual procedure is to drive the disk with two motors: one a variable-speed motor which supplies most of the power and is adjusted to run at nearly the required speed, the other a synchronous motor driven by the synchronizing impulse itself, which serves to lock the disk into the correct speed and phase.

More often two types of synchronizing impulses are needed: one to control the horizontal spot displacement, the other the vertical motion. Mechanical film scanning requires synchronization of the vertical scanning produced by the motion of the film, and of the disk or drum giving line scanning. Similarly, where two mirror drums are used for picture reproduction, one for each direction of scanning, both frame and line synchronization are necessary.

Scanning in the case of electronic terminal tubes is produced by deflecting an electron stream periodically in two mutually perpendicular directions by means of suitably varying magnetic or electrostatic fields. The current or voltage producing these fields is supplied from two deflection generators, one operating at line frequency, the other at frame (or field) frequency. Each generator is controlled by its own synchronizing impulse; therefore the complete signal must include two types, which can be distinguished from one another by some form of selector circuit. It is general practice to make the generator (Bedford and Smith, 1940), producing the synchronizing impulses at the transmitter, the fundamental timing unit of the entire system. Thus the synchronizing signal governs not only the scanning pattern at the reproducer, but also that at the pickup as well. When possible, the synchronizing signal generator is itself tied in with the public electric power supply serving the area over which the transmitter is being used, in order to minimize the effect of interference between the picture and the 60-cycle power supply.

Three different synchronizing wave forms are shown in figures 13, 14 and 15. That of figure 13 is the wave form which was used by the B.B.C. Television Service which was in operation prior to the outbreak of the war (Blumlein, Brown, Davis and Green, 1938; Macnamara and Birkinshaw, 1938). That of figure 14 is the wave form recommended in the United States by the National Television System Committee, and that of figure 15 is an alternative wave form which is undergoing comparison tests with that of figure 14 in the United States.

Experience has prompted the almost universal adoption of synchronizing impulses which are " blacker than black ". That is, the blanking level corresponds to black in the video signal, and the impulses extend below this level in the direction of black.

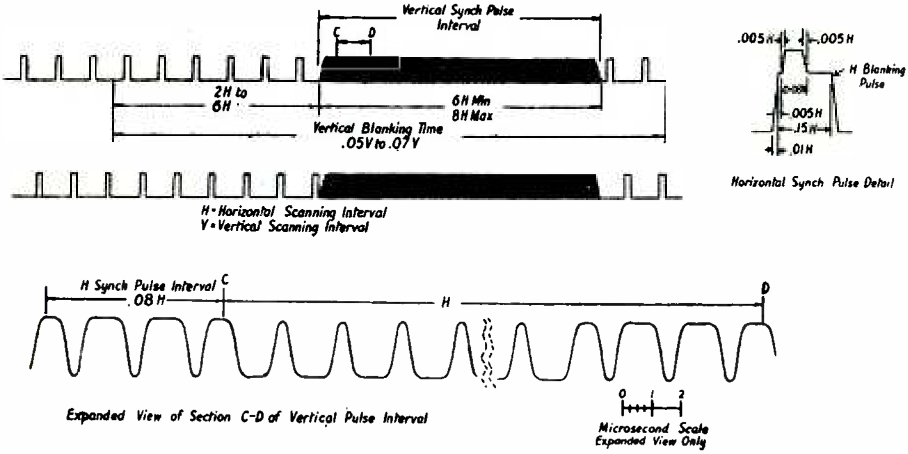

Figure 15.

Some of the conditions which must be satisfied by the synchronizing signal are:—

(i) The wave shape of the pulse must be such as to permit accurate control of the scanning pattern.

(ii) The pulse must not interfere with the picture.

(iii) The signal must be of such shape and amplitude that synchronization is not easily interrupted by interference.

(iv) The line and frame pulses must be easily separable.

(v) Where possible, the signals should aid in some other picture operation, such as extinguishing the beam in the cathode-ray viewing tube or providing automatic gain control.

(d) *Projection tube and projection optics*

The desirability and importance of a projected television image at the reproducer has already been referred to. Although cathode-ray tubes having screen diameters of 20 inches (Goldsmith, 1940) are available, and experimental tubes with screen diameters as large as 36 inches have been constructed, it is generally felt that the largest practical diameter is approximately 12 inches. Since it is very desirable to have pictures larger than this available for de-luxe type receivers in the home, and essential for theatre television, the use of optical magnification is the obvious expedient. Considerable work has been done on this problem, and satisfactory lenses have been found for both home-television receivers and theatre television.

In order to obtain adequate brightness in the projected image, it is necessary that the brightness on the screen of the projection tube employed be great enough not only to offset the loss in brightness per unit area due to magnification, but also to compensate for losses due to the inefficiency of the optical arrangement employed for projection (Maloff and Tolson, 1941). Because of the diffused radiation of light from the surface of the kinescope, only a small part of the total is picked up and transmitted by the optical system employed for magnification. It follows from the above considerations that the brightness of the picture on the projection kinescope must be at least several times greater than on kinescopes which are viewed directly. Considerations of physical size and cost in the design of the optical system dictate that the projection kinescope be somewhat smaller in size than the 12-inch tube which is considered to be more or less standard for direct viewing. The presently preferred size for the home-type projection receiver has a 5-inch screen and that employed in the latest type of theatre projection equipment has a screen 7 inches in diameter. The smaller diameter screen, however, aggravates the problem of focusing the electron-scanning beam, which has already been made more difficult by the larger current values that are required to give increased screen brightness (Zworykin and Painter, 1937; Law, 1937).

An important problem in the development of projection-type kinescopes has been the performance of the fluorescent material, under the increased current and higher velocity conditions called for in this tube. Depending upon the secondary emissive properties of the screen material and other factors tied up with its chemical content, a point is reached where voltage saturation of the screen sets in and an increase in voltage beyond this point yields no appreciable increase in light output. Another important factor is the deterioration of the fluorescent material under bombardment by the high-intensity cathode-ray beam. Considerable progress has been made within the past few years on the problem of suitable screens for use in projection kinescopes, and it is to be expected that work now in progress will yield still further improvements (Zworykin and Painter, 1937; Zworykin and Morton, 1940).

It will be readily understood from the foregoing considerations that the optimum physical size of the projection kinescope represents a compromise between spot resolution, total light output from the fluorescent screen, and the physical size and cost of the optical system used for projecting the image. As further advances are made in electron-gun design (Law, 1937) and in improved efficiency of fluorescent materials it is to be expected that the diameter of the projection kinescope may be decreased, with a corresponding decrease in cost of the optical system, or that the projected images may be made still brighter.

At the present time projection receivers for home use employ potentials up to approximately 30,000 volts on the projection kinescope while, in television systems for theatre projection, voltages up to approximately 70,000 volts are utilized. At 70,000 volts the projection kinescope employed in the theatre-projection system is capable of delivering about 1200 lumens of useful light. With an overall optical efficiency of about 25 %, and with a screen having a directional gain of two to one, a high-light brightness of slightly more than two foot-lamberts was obtained on a screen 15 × 20 feet (Maloff and Tolson, 1941).

Two general types of optical system are in use for projection of kinescope images: the reflection type of lens system, sometimes referred to as the Schmidt optical system, and the transmission lens system, of the type commonly employed for motion-picture projection. Each system has its advantages. Although it is somewhat larger in physical dimensions, the Schmidt optical system is capable of gathering a greater percentage of the total light output from the kinescope and thus can be made to provide a higher optical efficiency than is feasible or economical with the transmission type of optical system. It is for this reason that it is employed in the most recently developed equipment for theatre-television projection (Maloff and Tolson, 1941). This system is physically rather large and will give optimum performance at only one projection distance. The transmission type of optical system, on the other hand, is fairly flexible in this latter respect, is not very large physically, but cannot be made economically to have the high-light efficiency which is possible with the reflector-type optical system.

§ 8. CONCLUSIONS

(a) *F.C.C. findings*

On May 3, 1941, the U.S. Federal Communications Commission issued Orders, Rules and Regulations covering television broadcasting in the United States. These provided for the issue of commercial licences for television-broadcast stations, effective July 1, 1941. Standards covering the type of signal to be permitted in such operation were set up, so that the design, manufacture and sale of television receivers to the public might go ahead, with assurance that such receivers would not become obsolete in a short time. The standards were based upon recommendations made to the F.C.C. by the National Television Systems Committee, a special group set up in 1940 under the joint sponsorship of the Radio Manufacturers Association and the F.C.C. for the purpose of studying all known television systems and recommending standards believed to be capable of permitting the best possible operation (D. G. F., 1941).

The standards call for a 6 Mc. channel in which both the sound and picture signal must be transmitted, the spacing between the two unmodulated carriers being 4·5 Mc. and the sound carrier being located 0·25 Mc. below the upper extremity of the channel. Frequency modulation with a deviation of plus or minus 75 kc. is specified for the audio signal, and vestigial side-band operation for the video signal. The scanning standards call for 525 lines, with 2 to 1 interlacing, a field frequency of 60 per second and a frame frequency of 30 per second. Negative polarity is standard for the radiated picture signal (i.e., a decrease in initial light intensity causes an increase in radiated power). It is specified that the synchronizing signals and picture signals are to be radiated on the same carrier, and the synchronizing wave form is restricted to types which will adequately operate a receiver responsive to the synchronizing wave form shown in figure 19. Horizontal polarization is made standard for both audio and video radiations (Brown, G. H., 1940). Other standards are given which are either necessary or desirable for a public television service (D. G. F., 1941).

In setting up the television broadcasting service, the F.C.C. made available 18 channels, each of 6 Mc. width. These channels do not comprise a continuous band, but are interspersed with other services in the radio spectrum between 50 Mc. and 294 Mc. To date, assignments for broadcasting have been made only in the lower eight channels, since presently available transmitting and receiving equipment performs most efficiently at the lower frequencies. Some of the upper channels are available for television-relay purposes under experimental licences in conjunction with the operation of commercial television-broadcast stations.

(b) *Present status of television broadcasting*

As this ***Report*** is written (August 1941), the United States is the only country, so far as we know, in which, as a result of the war, there is any activity in television broadcasting as a public service. In this country one station (the N.B.C. station in New York City) is broadcasting television programmes on a commercial basis; several other stations are operating on a regular schedule, and some of these have announced their intention of beginning commercial operation within a few weeks. At the time of issuing the F.C.C. " Rules and Regulations governing Television Broadcasting Stations ", in May 1941, the F.C.C. also issued two lists of potential commercial stations: one list of five existing experimental television stations which would be eligible for commercial television-broadcast operation upon the filing and approval of an application for a construction permit, and a second list of sixteen experimental television stations which would be eligible for commercial operation upon the filing and approval of an application for a modification of construction permit. Thus it is seen that a fairly large number of potential commercial television stations were available in the United States on July 1, 1941.

The manufacturers of television receivers are now modifying sets which were sold to the public prior to the announcement of the present commercial standards, so that these receivers will operate in accordance with the new standards. A reawakening of public interest in television is beginning to manifest itself, and it is expected that the demand for television receivers will go up sharply as the television programme service is expanded. There is, however, considerable doubt, on account of the existing national emergency, as to whether the manufacturers of receivers will be able to provide receivers in large quantities. The war emergency has produced both a shortage in certain materials required in the manufacture of receivers and a shortage in the type of skilled personnel required to build the receivers. This situation will also seriously affect the manufacture of new equipment for television broadcasting stations. Although it seems certain that these circumstances will have a retarding effect upon the expansion of television braodcasting in the United States, there is no indication at present that it will be necessary to suspend this service completely, as was done in England at the outbreak of the war.

(c) *Future (immediate) trends of television broadcasting*

As was previously indicated, the immediate future of television broadcasting is made somewhat uncertain by present war conditions, but it is the belief of the overwhelming majority of those persons who have had an opportunity to become familiar with the present and future possibilities in this new form of mass communication that it is destined to become the most important medium of home entertainment and education. There is no longer any question about the ability of television to render a service which will be welcome in the home, and for which people will be willing to buy receivers. Under normal conditions, it would be possible to predict with some certainty the rate at which this home service would be built up, but present world conditions make it difficult to determine exactly when such a service will be free to develop on a large scale. However, a television service comparable in extent to the present-day sound broadcasting service seems inevitable in the not too distant future.

It is possible that the intensive research and development work in radio for military purposes now going on all over the world will help provide new tools which will permit of an improved television service in future years. High power at higher carrier frequencies, with broader channels permitting greater picture definition and pictures in natural colour with adequate definition, are the benefits which it is reasonable to expect from this work. Networks of radio-relay stations connecting television-braodcast stations spread over large areas should be available within a relatively short time when the men and material can be made available for their planning and construction.

The projection-type receiver already developed is a clue to what the home television receivers of the near future will be like. This receiver will provide a bright picture of high definition and of sufficient size to be viewed at any comfortable viewing distance in the home. The same receiver cabinet in the future may provide for a facsimile reproducer and, as at present, will probably provide reception for standard and short-wave sound broadcasting bands, including the high-fidelity F.M. band. In the not too far distant future it is probable that the same television receiver will provide for reception in natural colour as well as in black and white, but our experience to date indicates that satisfactory colour will come only in channels substantially wider than the present standard 6 Mc. channels. It is still too early to predict with certainty whether the colour system of the future will be a simultaneous three-colour process or a cyclic system.

The successful demonstration of theatre television indicates a bright future for this branch of the art. It does not seem too rash to predict that within a matter of a few years most local theatres, at least in the large metropolitan areas, will be equipped with television projection equipment and serviced by special television programmes over wire networks connecting to centralized distribution points. Theatres relying solely upon television may come into existence, but it seems more likely that television will be supplementary to the film projectors in existing theatres. The possibility of televising important events as they occur and distributing the television pictures to audiences in many theatres at remote points seems very attractive. Technically, the means for accomplishing this have been developed. Progress toward realization of such a service would seem to depend entirely upon the availability of equipment for doing the job, and this also is tied up with the present war conditions.

ACKNOWLEDGMENTS

Figures 3, 4, 5, 6, 10, 11, and 12 and portions of the text in the sections on *amplification and distribution*, *home receivers*, *the iconoscope*, and *scanning and synchronization*, are reprinted, by permission, from the book *Television*, by Zworykin and Morton, published by John Wiley and Sons, Inc., New York, N.Y.

The authors also wish to acknowledge the helpful assistance of Mr. F. J. Somers in connection with the preparation of the bibliography and of the section on *colour television*.

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