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Report No. 1837

TITLE GENERAL REQUIREMENTS ON THE TELEVISION RECEIVER
(TELEVISION PRINCIPLES — CHAPTER 4)

DATE *June 30, 1938.*

MFR. *General.*

STROMBERG-CARLSON TEL. MFG. CO.

Approved W. A. MacDonald

GENERAL REQUIREMENTS ON THE TELEVISION RECEIVER
(TELEVISION PRINCIPLES - CHAPTER 4)

By C. E. Dean

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SPECIFICATIONS SELECTED FROM THIS CHAPTER

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Correction in Preceding Chapter

In Figure 7, page 51, change name of last tube from "Negative-Grid Limiter" to Positive-Grid Limiter, and insert grid resistor immediately at grid connection of tube.

On page 64 reference may be added to Hazeltine patents 2118,977 and 2052,183 relating to relaxation oscillators and the derivative-integral series of waveforms.

GENERAL REQUIREMENTS ON THE TELEVISION RECEIVER
(TELEVISION PRINCIPLES - CHAPTER 4)

INTRODUCTION

The preceding chapters describe the formation of the television signal in sufficient detail to give a general understanding of the electrical operations at the studio and the transmitter. We proceed now to the use of this signal by the receiver. Since data on the receiver are of special interest to most of the readers, these matters will be covered in considerably greater detail. The present and next chapters are devoted to a discussion of the general requirements imposed upon the receiver by the transmitted waveform and by the practical conditions prevailing. The next succeeding chapter will give a general description and discussion of the receiver, and succeeding chapters will treat individual parts of the receiver.

It is a well-known principle of radio engineering that where one transmitter is to supply signal for a number of receivers, it is economic to simplify the receivers at the expense of complication in the transmitter. This principle was one of the guiding factors in the choice of the complete television wave which was given on page 46 (Report 1822). The details of this wave are also given in the present chapter, page 76.

ASSIGNED TELEVISION CHANNELS

In Figure 1 we give the channels assigned for television use by the Federal Communications Commission, effective October 1, 1938. The channels will be seen to include seven located at intervals between 44 and 108 megacycles, and twelve additional channels at frequencies above 150 megacycles. At the present time, only the lower group of channels is of practical interest. On page 6 (Report 1776), we listed the stations which are at present licensed in the ultra-high-frequency region for powers of 1 kilowatt or more. For receiving more than one of these channels the tuned-radio-frequency design of receiver is ruled out, leaving the superheterodyne as the only practical means.

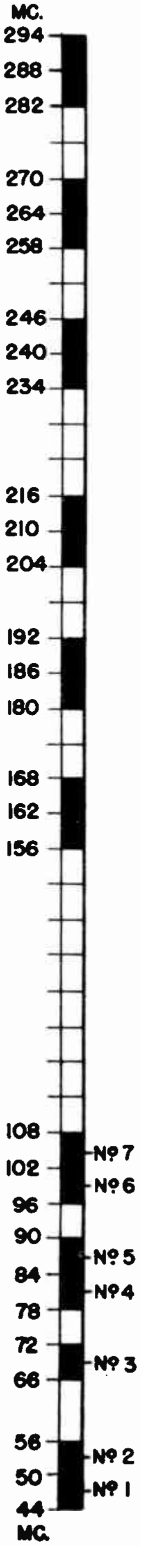


Fig. 1. Television Channels Assigned by Federal Communications Commission.

In Figure 2 we give the details of location of the carriers and the guard band of each television channel. The most striking characteristic in this figure is that there is an interval of 4.5 megacycles between the sound and picture carriers in each channel, while there is only an interval of 1.25 megacycles from the picture carrier to the lower limit of the band. This arrangement is made in order to accommodate an upper sideband of picture frequencies occupying most of the region between the two carriers while the lower sideband is partially suppressed so as to be accommodated in the narrower region provided. The sound transmission operates, of course, with both sidebands present in equal amounts, and requires only a very small relative frequency band.

Two other details related to standardization are the transmission of the average brightness, and the polarity of modulation. Some time ago the transmission of the average brightness by means of a direct-current component in the wave was adopted as standard by the Television Committee of the Radio Manufacturers Association. This method has replaced a former method of transmitting average brightness, in which no direct-current component was transmitted and the pedestal height was varied to supply this information. In regard to the polarity of modulation, it is expected that negative polarity will be standard in the United States. A further discussion of the average-brightness transmission and of modulation polarity is given below.

INTERVAL BETWEEN CARRIERS AND THE SESQUI-SIDEBAND METHOD

Single-Sideband and Sesqui-Sideband Methods

Probably all readers of the present chapter are acquainted with the conventional transmission of broadcast programs in which an unmodulated carrier component and upper and lower sidebands are radiated. It has probably also been observed that upon detuning a receiver, satisfactory reception is obtainable with the upper components of one sideband attenuated. This observation suggests that the essential information being transmitted does not require the double-frequency interval which is characteristic of the conventional method. This suggestion is really a fact which has been established by theoretical and practical work extending back for a number of years. As one case, the radiation of a single sideband without any unmodulated carrier component is used in trans-oceanic telephone practice to transmit the voice; a locally generated carrier is used at the receiver for detection. In this case the filtering operations, by which the single sideband is obtained, are possible because there is no necessity of accommodating lower audible and sub-audible frequencies.

For systems, such as television, in which modulation at very low frequencies must be transmitted, the use of a single sideband is impractical, but the sesqui-sideband method may be used. The meaning of sesqui-sideband is one and a half sidebands, and the significance is that one complete sideband is transmitted plus a fraction of the other sideband. Another name which has been used is "vestigial-sideband method". The carrier component is present in sesqui-sideband systems.

The lower modulation frequencies in a sesqui-sideband system are transmitted and reproduced by the conventional double-sideband method with the exception that the side frequencies on one side are less in amplitude than the corresponding frequencies on the other side. As higher modulation frequencies are considered, this condition becomes more pronounced, the weakened sideband contributing less and less and the normal sideband more and more to the detected signal. The point is reached in this way at which the contribution of the discriminated sideband is negligible, and all the detected signal delivered by the system is obtained from the normal sideband. In this way the

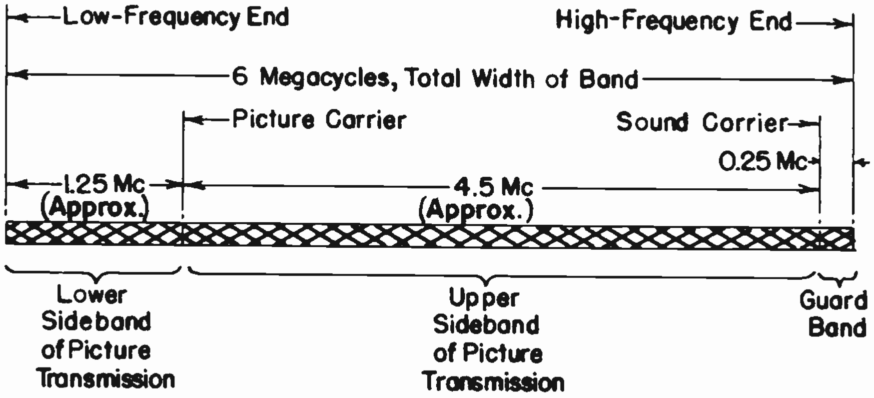


Fig. 2. Arrangement of Each Television Channel.

system operates in the conventional double-sideband manner for very low modulation frequencies and gradually passes thru a transition to where it operates with carrier and single-sideband for the higher modulation frequencies.

A more detailed analysis of the sesqui-sideband method leads to the conclusion that for uniform reproduction of the various modulation frequencies, the transmission curve of the entire system must be down 6 decibels for the carrier and must have complementary characteristics on the two sides of the carrier for the lower modulation frequencies. For example, if the lower sideband is attenuated so that a given side frequency has a transmission thru the system of only 25 percent, the corresponding upper side frequency must have a transmission of 75 percent; similarly a higher modulation frequency may be represented by a transmission of only 10 percent in the lower sideband and a transmission of 90 percent in the upper sideband.

A limitation in regard to detection prevails in the case of single-sideband operation. For high modulation with a signal having several frequency components, either a linear or a square law detector introduces objectionable distortion. For this reason the usefulness of the single-sideband method is limited to cases where the percentage of modulation is low, or can be made low by the introduction of a large local carrier. With sesqui-sideband operation, no difficulty is encountered if the modulation percentage is low for the higher signal components, which are transmitted single-sideband.

We see therefore that the sesqui-sideband method of transmission has two important characteristics: (1) it makes possible an important saving in the high-frequency band; and (2) the fidelity is satisfactory if the larger signal components occur in the lower-frequency region so as to give a low percentage of modulation for the upper frequency components.

Use of Sesqui-Sideband Method in Television

The characteristics of sesqui-sideband transmission, given in the preceding section, make it the natural choice for television. Here a very wide band of signal frequencies is to be transmitted, and the energy is located chiefly in the lower-frequency portion of this band. It is necessary to conserve frequency space, both to accommodate a number of stations on the air and to relieve the bandwidth requirements of transmitting and receiving apparatus. In Figure 3, we show the details of a single television channel, such as given in Figure 2, with the addition in a dashed line of the transmission characteristic necessary if the lower-frequency sideband were to be used to the same extent as the upper sideband. On the upper side of the picture carrier the transmission may extend to the sound carrier; there must be substantial attenuation at this point to prevent the sound carrier and its side frequencies from interfering with the picture transmission and being reproduced as an interference pattern in the picture. On the lower side of the picture carrier a frequency band with a width of 1.25 megacycles is provided for the attenuated lower sideband.

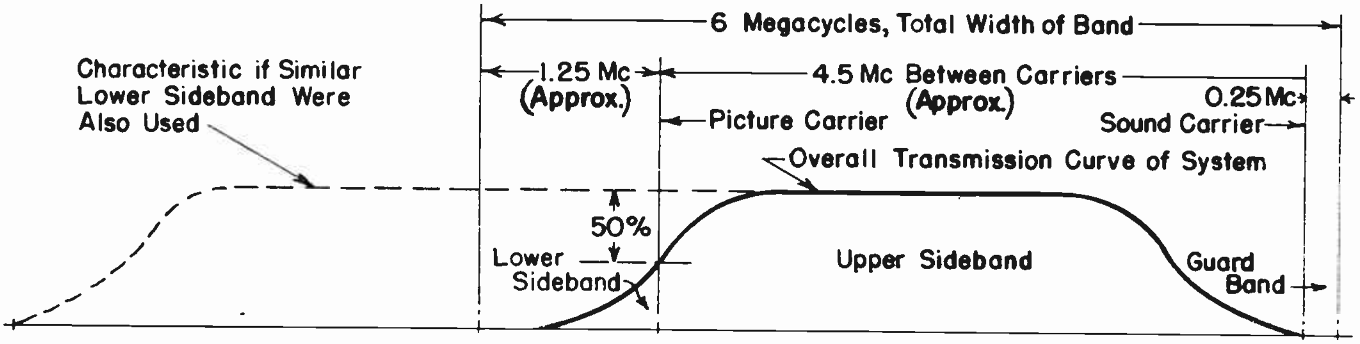


Fig. 3. Sesqui-Sideband Operation of Television Channel.

Beyond this point any transmitted frequency components would lie in the next channel and constitute interference; as a practical matter it is considered that an attenuation of 30 or 40 decibels should be provided at the transmitter against components thus falling in the next channel.

The predominance of the lower video frequencies, which permits the use of the sesqui-sideband method, occurs because the usual scene consists of relatively large, fairly uniform, areas in comparison with the size of the scanning spot. It will be realized that it is unusual for a scene to have very fine and contrasty detail over most of its area.

We mentioned above on page 69 that the overall transmission curve must indicate an attenuation of 6 decibels at the carrier frequency, in comparison with the medium-high modulation frequencies, if discrimination between modulation frequencies is to be avoided. This attenuation may be provided at the transmitter, or at the receiver, or part at each place. The signal-to-noise ratio is better on theoretical grounds if all of this attenuation is located in the transmitter. At this writing it cannot be said whether this will be found practicable; it may be necessary to provide some of this attenuation at the receiver.

Effect of Carrier Interval on Receiver Design

The general arrangements of the high-frequency circuits of the television receiver have been worked out so as to give single-dial tuning accommodating the picture and sound of a given station at the same time. In particular, the radio-frequency circuits are provided with sufficient width to accept both the picture and sound carriers of the desired station, and the oscillator is set at such a frequency as to convert both carriers in one converter tube to the desired intermediate frequencies. For example, the station operating in the first assigned television band has a picture carrier of 45.25 megacycles and a sound carrier of 49.75 megacycles. If a particular receiver had an oscillator frequency, when tuned to this station, of 55.25 megacycles, the intermediate frequency for the picture signal would be 10 megacycles, and the intermediate frequency for the sound would be 5.5 megacycles. With this arrangement it is seen that the oscillator frequency is located above both of the received carriers, with the result that the two intermediate frequencies have the same interval between them as the radio-frequency carriers, namely 4.5 megacycles. Also the picture intermediate frequency is higher than the sound intermediate frequency, which is a desirable relation. If the sound channel has a band width comparable with broadcast practice, the receiver must be tuned according to the sound reception. Enough additional width of sound channel should be provided to accommodate oscillator drift, and, in some cases, permit a slight adjustment of the picture tuning.

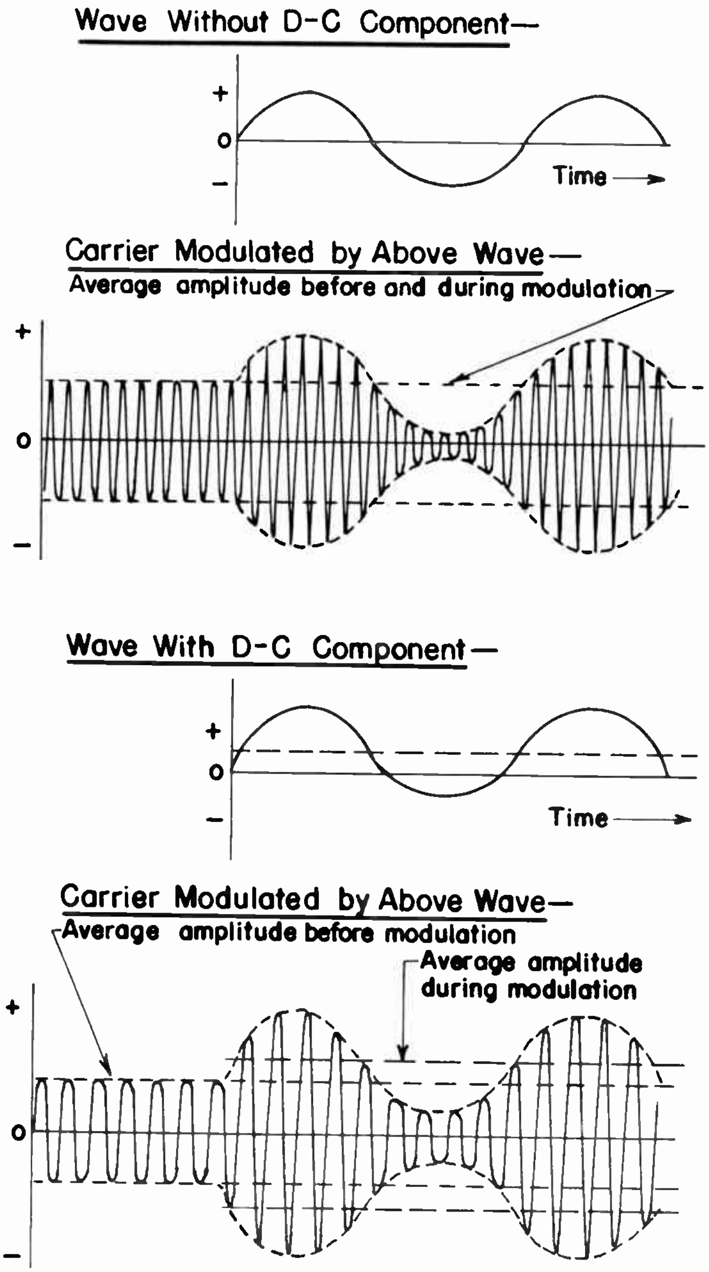
TRANSMISSION OF DIRECT-CURRENT COMPONENT

Nature of Direct-Current Component and Effect in Modulation

Communication engineers are well acquainted with alternating-current waves having direct-current components, for example the current thru a carbon microphone. In the Fourier analysis of the waveform the direct-current component is the first term, which is not multiplied by a trigonometric function. With such a composite wave, the ordinate equal to the direct-current component gives a horizontal line which is the alternating-current axis of the wave; this axis may be drawn by using the criterion that the area between the axis and the curve on the upper side of the axis must equal the corresponding area on the lower side of the axis. In Figure 4 an alternating-current wave without a direct-current component is shown at the top of the figure.

When an alternating-current wave is used to modulate the carrier with the conventional type of modulation, the average carrier amplitude, averaged over the modulation cycle, remains the same. In other words the envelope of the modulated carrier on each side has as its alternating-current axis the peak value of the carrier before modulation. This is shown in the second diagram of Figure 4.

The presence of a direct-current component in the modulating wave is a



Wave Without D-C Component—

Carrier Modulated by Above Wave—

Wave With D-C Component—

Carrier Modulated by Above Wave—

Fig. 4. Effect of D.C. in Modulation.

condition not found in sound broadcasting. It causes a change in the average carrier amplitude when the modulation begins; this is indicated in the third and fourth diagrams of Figure 4. In the third diagram a waveform with a positive direct-current component is shown, and in the fourth diagram it may be seen that the application of this wave in modulation produces an increase in the average carrier amplitude. If the direct-current component of the modulating wave had been negative, there would have been a decrease in the average carrier amplitude.

In terms of antenna current we may note that in the absence of a direct-current component, the radio-frequency current peaks before modulation are 50 percent of the maximum current which the station can produce. The station is assumed to operate at maximum instantaneous power on the peaks of 100-percent modulation. Upon the application of an alternating-current wave as modulation, this 50-percent value is the mean line, or alternating-current axis, of the modulation envelope. Should a direct-current component be present, this value may be 40 percent, 60 percent, or any other proportion, of the maximum antenna current.

Stabilization of Video Levels

In Figure 1, page 46, of the preceding chapter (Report 1822) there are given the details of the complete video wave, and it may be seen that there is a range of potentials devoted to picture shades from white, thru gray, to black, and also a further range of potentials devoted to synchronizing signals. Electrically the synchronizing signals are therefore in a region which is "blacker-than-black", or "infra-black". In the receiver it is necessary to perform two functions related to these characteristics; these are: (1) the separation of the potentials in the synchronizing range from those in the picture range; and (2) the reproduction of each potential in the picture range with the proper brightness, including instances of sustained constant values, such as when the screen is dark for an appreciable length of time.

A receiver with direct-current couplings in its video amplifier will have an absolute brightness-voltage relationship throughout, and therefore can be designed to perform the two functions just listed. However, it is often desired to use alternating-current couplings in the receiving video amplifier, and then reinsert the direct-current component; this may be done in a manner similar to practices at the transmitter which are described in the preceding chapter under "Background Insertion" (pages 53-55 and Figure 12, Report 1822).

Direct-current reinsertion is a special case of an important process called "stabilization", which is an alteration of the axis of a wave in such a way that the peaks of the desired polarity are brought to a constant value. Stabilization may be used for various purposes, in carrier as well as video portions of a television system; the polarity and the time constant are chosen according to the nature of the particular case. We may say that stabilization lines up a wave by its peaks, or that stabilization brings the peaks into line, that is to a constant value. The type of stabilization of chief interest in receiver practice is direct-current reinsertion. This re-establishes the absolute relation between picture shade and the potentials at the particular point in the circuit.

A circuit called the "sync separator" in the receiver rejects the picture range of potentials and accepts the sync range of potentials. The input portion of this circuit, if it does not have a direct coupling, requires stabilization. The sync separator is designed to respond to all signals on one side of some critical potential level, and to have no response to signals on the other side of this level; the level should be somewhat blacker-than-black, to insure that no picture components pass thru into the synchronizing circuits under any conditions. If thru misadjustment this level should be at a dark gray, picture potentials would get into the synchronizing circuits and impair the scanning of the picture tube. Should the critical level be on the proper side of black, but be considerably removed from the black level, the amplitude of the sync pulses obtained from the complete signal might be insufficient - this condition is, however, seldom encountered.

Another point at which receivers may have an alternating-current coupling, and therefore require reinsertion of the direct-current component, that is, require stabilization of the signal, is in the grid circuit of the reproducing picture tube. An improper adjustment of the stabilization here will cause incorrect average brightness; also with one direction of the misadjustment, the scanning lines occurring during the field retrace will appear in the picture, as shown in Figure 22 of the preceding chapter (page 60, Report 1822).

From the discussion already given it will probably be realized that the video wave delivered to the grid of the picture tube must contain a direct-current component and that this component conveys the information as to the average brightness of the picture. In order to make certain that this point is clear, let us consider two special scenes. In case the scene is black, or almost black, the average video voltage must be, for proper operation, at or near the cutoff voltage for the particular tube. In case the scene is white, or almost white, the average video voltage must, of course, be near zero tube bias. In order to transmit one of these scenes and hold it fixed for any substantial length of time, it is obviously necessary to transmit the direct-current component of the picture.

We may summarize the preceding paragraphs by stating that: (1) the voltage wave finally used to actuate the picture tube of the receiver should contain the direct-current component, which represents the average brightness; (2) the operation of separating the sync signals from the picture signals requires the presence of the direct-current component; (3) after loss of the direct-current component in an alternating-current video coupling it may be regained by a stabilization process, generally using a diode; and (4) there is the obvious fact that the direct-current component is transmitted thru radio-frequency and intermediate-frequency circuits because the carrier-frequency amplitude represents it.

In Figure 1 of the last chapter (which is reproduced with some alterations and additions as Figure 8 of the present chapter) there is given the wave which stations are expected to transmit. This wave has the two related characteristics that: (1) a direct-current component is present; and (2) the top of the blanking pulses represents black. If this wave is transmitted thru an alternating-current coupling, the direct-current component is of course removed; this operation has the effect on the height of the blanking pulses, measured from the axis of the resulting wave, of making them represent the average brightness of the picture. The direct component can be regained by the usual reinserting process, which lines up the sync peaks as they were in the original wave; however we can say in terms of the height of the blanking pulses, that the information which they contained as to average brightness of the scene is employed in the reinserting process to regain the lost direct component.

A video wave generally similar to the one now of interest, but without the direct component, was used in the United States prior to the latter part of 1937 for transmitter modulation. The direct component was then necessarily inserted at the receiver in the same manner as necessary after an alternating-current coupling in the video amplifier of the receiver. Whether or not the direct component is present in the modulation of the radiated wave, and therefore thru a major part of the receiver, is an important matter. The use of a modulating wave having the direct-current component for representation of the average brightness has important advantages, and we proceed now to a discussion of these.

Reasons for Transmitting the Direct-Current Component

In Figure 5 we show the characteristic of a representative stage in a video-frequency portion of a television system, and indicate the action in the case of transmission with and without the direct-current component. The average bias of the curve in the center of Figure 5 is indicated by a dashed line and also the corresponding plate current. Similarly it will be seen that points P_1 and P_2 are designated on the curve, beyond which the curvature is considered to be too great for satisfactory use for picture signals; dashed lines for the corresponding input potentials and plate currents are also given. Considering first the alternating-current type of transmission, that is transmission without a direct-current component, we may note at the top of Figure 5 the maximum input waves for the two scenes which are represented; the upper one of these scenes has a white background with a vertical black bar in the center, and the second one of these scenes has a black background with a vertical white bar in the center. In each case the alternating-current wave necessarily locates itself about the operating bias in such a way that the area between the axis and the curve is equal in the positive and negative directions. At the left in the drawing the plate current for this maximum-level alternating-current operation is indicated.

With direct-current transmission the maximum input for the same scenes, in Figure 5, is the whole grid swing between P_1 and P_2, and this is indicated at the bottom of the drawing. The maximum output is correspondingly the entire swing of the plate current between these operating points.

In carrier-frequency stages the grid bias is of course the voltage axis of the carrier oscillations. On each side the envelope must be handled in a manner much like the video-frequency case we are considering, and similar conclusions as to direct-current and alternating-current transmissions apply.

From this consideration of Figure 5 we may conclude that: (1) with given

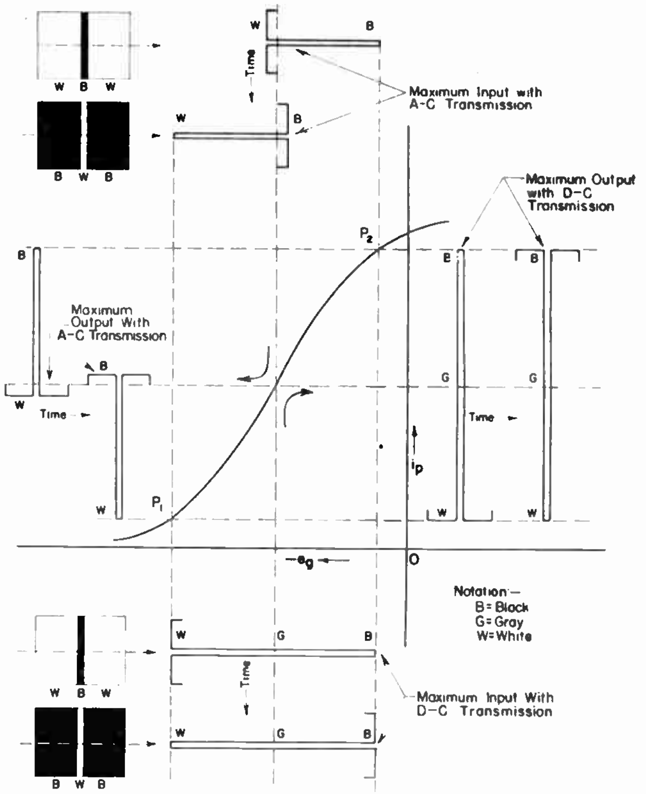


Fig. 5. Advantages of Transmission of Direct-Current Component.

distortion limits, the range of any stage is considerably greater with direct-current transmission than with alternating-current transmission; (2) with direct-current transmission there is an absolute brightness-electrical relationship applying to all scenes, (which is not the case with alternating-current transmission), with the result that with direct-current transmission the distortion introduced into the picture by curvature of characteristics remains always the same (and can be compensated) instead of changing position in the video range with the nature of the scene; and (3) sync signals in the case of direct-current transmission may be located beyond black in a region of considerable distortion which is useless for any other purpose.

Since the presence of a direct-current component is necessary for obtaining an absolute brightness-electrical relationship, the transmission of the direct-current component in the radiated wave is an American standard according to the action of the Television Committee of the Radio Manufacturers Association this spring, reading as follows: "It shall be standard in television transmission that black shall be represented by a definite carrier level independent of light and shade in the picture."

The stabilizing operations at the transmitter take place for the most part in stages where the blanking pulses are present but the sync pulses have not yet been added. At these stages the blanking pulses are the peak values in the black direction. The direct-current component can therefore be reinserted by detecting, or stabilizing on, this black level. At the receiver the sync signals are present, whence a peak detector operates upon them; however, a result equivalent to the use of the blanking pulses is easily obtained by employing a bias whose value is equal to the amplitude of the sync signals at the particular point in the system.

POLARITY OF TRANSMISSION

On page 62 (Report 1822), positive and negative polarities of transmission are defined, and are illustrated in the corresponding drawings, Figures 35 and 36; these drawings are reproduced in the present chapter as Figures 6 and 7.

The Television Committee of the Radio Manufacturers Association has given extended consideration to positive versus negative transmission. The subject involves automatic volume control, synchronization, the effect of noise with and without the use of limiters, and other matters. Negative transmission has been a tentative standard of the Radio Manufacturers Association for some time, and is now generally favored for the United States.

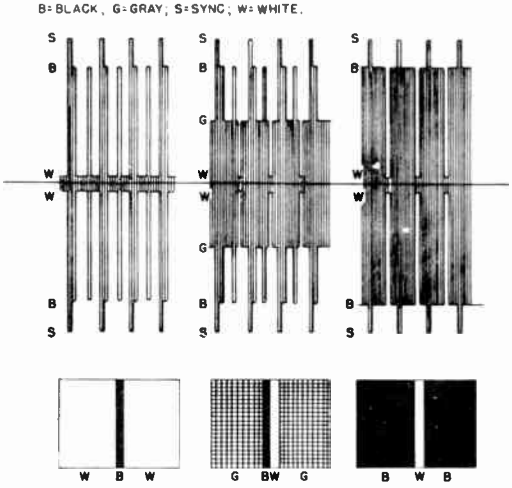


Fig. 6. Carrier Wave with Direct-Current Component and Negative Polarity of Transmission (Tentative Standard Practice).

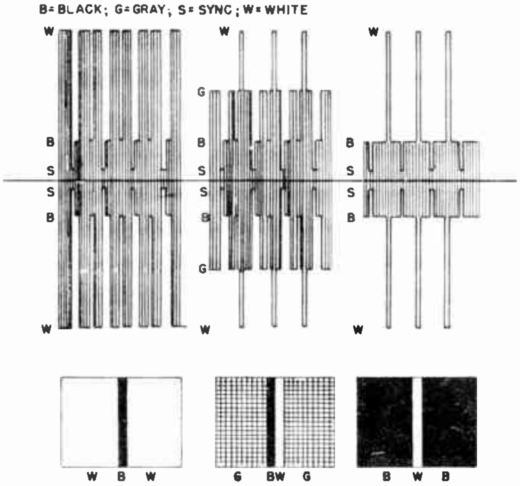


Fig. 7. Carrier Wave with Direct-Current Component and Positive Polarity of Transmission

Relation to Automatic Volume Control

The most striking difference between negative and positive transmission is in regard to automatic volume control. It may be seen in Figures 6 and 7 that the average carrier amplitude varies with picture content, and is therefore not suitable for detection for automatic volume control, such as in sound receivers. We have already seen in connection with direct-current transmission that such variation of the average carrier amplitude necessarily results when the direct-current component is transmitted. With negative transmission, which is shown in Figure 6, the synchronizing peaks can be seen to be the maximum level radiated. They occur regularly and are of sufficient duration to be used to operate a peak-detector circuit which will provide the bias for the automatic-volume-control system.

With positive transmission, shown in Figure 7, the synchronizing peaks lie at or near the zero axis; that is, there is little or no radiation during the synchronizing period. Such a low level cannot be used to provide the control bias. The average carrier amplitude we saw in the preceding paragraph to be useless for automatic volume control.

Another quantity in Figure 7, which may be considered as a possible carrier level for automatic volume control, is the peak voltage; however, this also depends on the picture content and therefore is not usable. With a black picture, the 20 percent of the total amplitude range reserved for the sync-to-black portion will be almost the peak value. On the other hand, with a very bright scene, the peak value will be almost the full maximum voltage. This illustrates why with positive polarity the peak voltage cannot be used to operate the automatic-volume-control system. One might take exception to this statement on the ground that some white could be expected in any picture and would give a peak for automatic volume control, but the arrangement would not work because there are times at the start of a program and during brief intermissions when the screen must be entirely dark. We come to the conclusion therefore that with positive polarity, the most suitable voltage level available for control bias is the black level. In a white picture this level appears for only a short interval following the line and field sync pulses. While this can be used for control purposes, many circuits using it require a timing feature to distinguish between this voltage and the larger gray or white voltages which may precede and follow it. Another limitation is that the voltage being detected is only about 20 percent of the maximum received voltage. Consequently, automatic volume control is often considerably more difficult with positive polarity of transmission than it is with negative.

Relation to Noise Effects

The effect of noise, as far as the more noticeable results are concerned, is to introduce large voltage peaks. We refer here to man-made noise, radiated chiefly by automobile ignition systems. With negative polarity, as shown in Figure 6, these noise peaks produce black patches in the picture and interfere with the synchronism. With positive polarity, as shown in Figure 7, the noise peaks produce bright flashes and the appearance of a snow-storm on the screen. These bright flashes may have considerably higher intensity than the normal maximum white reproduced by the picture tube, whence they are very objectionable. The black splotches in the picture obtained with negative transmission are objectionable, but not nearly as much so as the white splotches.

The choice of polarity of modulation, without the use of limiters, therefore hinges on the reliability of the synchronizing system with negative transmission. At earlier stages in the development of television, when the synchronizing systems were not reliable, positive transmission was markedly superior, and it was adopted in England. More recently, however, it has become possible to build receivers for negative transmission which synchronize so well that the additional advantage to be obtained from positive transmission is no longer important, or at least no more important than the disadvantage of the white flashes.

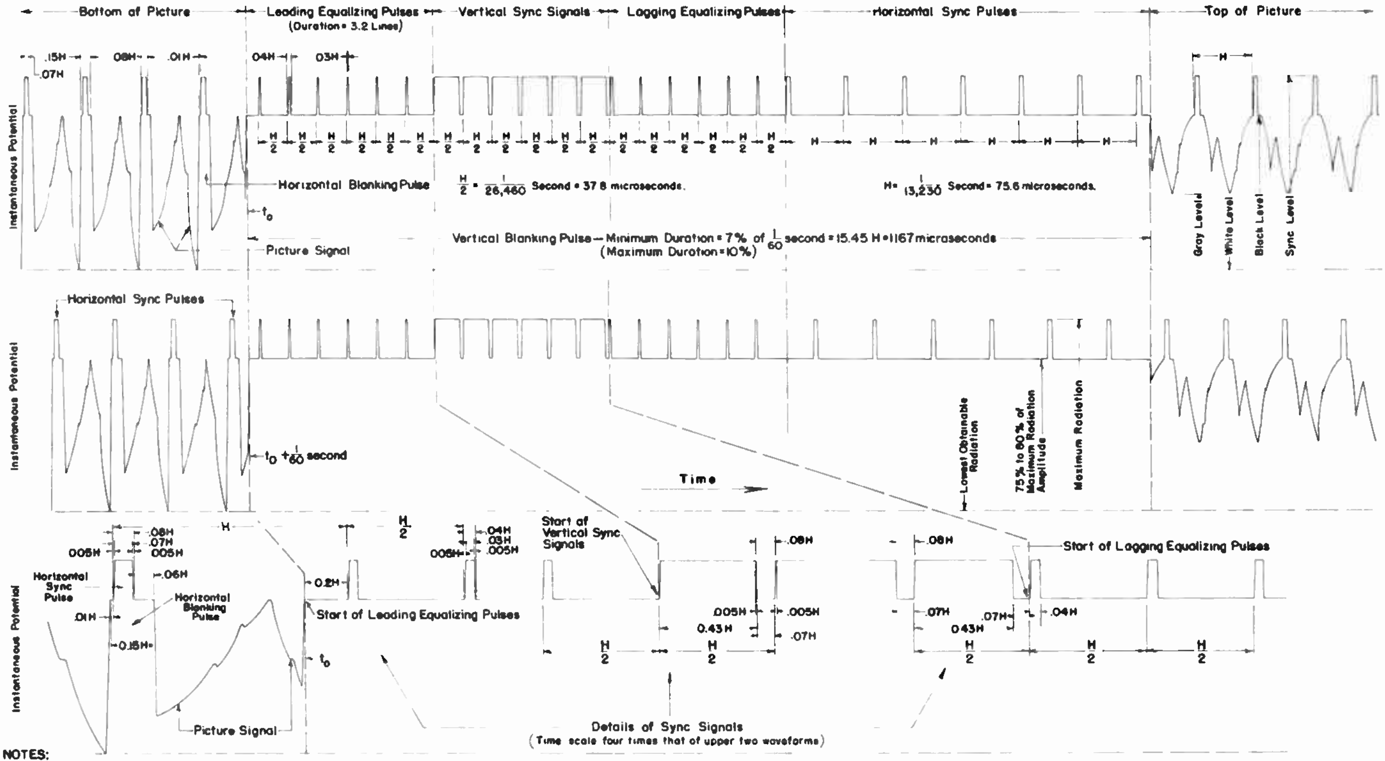
With either polarity of transmission the effects of noise may be alleviated by the use of a diode appropriately biased and poled to act as a limiter. This feature represents of course some added expense in the receiver.

AMPLITUDE DIVISION OF WAVE

In Figure 8 we give a drawing of the complete video wave from the preceding chapter, with the addition of sketches on a larger scale showing details of the sync pulses.

The black level radiated by a transmitter is specified at 75 to 80 percent of maximum radiation amplitude. The picture range extends from here to the lowest obtainable radiation, corresponding to white. If we assume black at 80 percent and white at zero, we have the largest proportion of station power in the picture signal. This condition is assumed in the following discussion of reasons for the particular amplitude choice. However, white may be appreciably removed from zero radiation.

In order to secure as large a ratio of signal to noise as possible, the picture should take up as much of the amplitude range as possible. The range taken by the synchronizing signal must be sufficient to secure reliable synchronism. It is obvious that if the picture fails to synchronize, it cannot be received at all, so that this is the first requirement. In areas where the signal is strong, the proportion devoted to picture



NOTES:
(1) Leading and lagging edges of all sync signals occupy a maximum time of 0.005H, and this value is assumed above — in case edges are steeper, duration at black level is same and duration at sync level is altered; (2) Horizontal and vertical blanking pulses are also called horizontal and vertical "pedestals", since they can be regarded as elevated bases for the sync signals.

Fig. 8. Complete Television Wave in Vicinity of Field Retraces

transmission is unimportant since a high signal-to-noise ratio is secured even though the picture amplitude is considerably less than 80 percent of the total. On the other hand, the percentage of the amplitude devoted to synchronizing is also unimportant in strong signal areas. The 20-percent sync amplitude was chosen on the basis of experiments in areas where the signal level was low; these tests showed that with the 20-percent value the picture was spoiled by noise effects somewhat before it was lost due to failure of synchronism.

The separation of the complete signal into two amplitude ranges makes it possible to separate the synchronizing information from the video signal after stabilization by means of amplitude discrimination, using limiters such as are described on pages 48-50 (Report 1822). The synchronizing information is prevented from appearing in the picture by means of the negative-grid limiting action which is inherent in the picture tube; that is, the sync signals are more negative than cutoff. The various potentials in the picture range of amplitudes which reach the picture tube correspond to various shades of white (minimum negative grid potential), gray (intermediate potentials), and black (cutoff potential). The maximum beam current in the tube occurs, of course, when the video signal is most positive, producing the least negative grid potential and the most intense spot on the screen. The signal here must have positive video polarity, that is, the brighter points must correspond to the more positive voltages. From this discussion we see that the sync signals, which are electrically "blacker-than-black", or "infra-black", have no effect on the beam current.

ASPECT RATIO AND TIME EFFICIENCY

The term "aspect ratio" is defined in standard M-9-116 of the Radio Manufacturers Association, which reads as follows: "The aspect ratio of a frame is the numerical ratio of the frame width to frame height." The particular value of the aspect ratio is tentatively standardized as 4/3 in accordance with the use of this value in motion-picture practice. In terms of the useful portions of the line and field scannings, we may say that the distance scanned horizontally during the active 85 percent of the total line period is 4/3 times the distance scanned vertically during the active 93 percent of the total field period. In English television practice the aspect ratio is called the "picture ratio" and has the value 5/4.

The time lost for vertical and horizontal retrace may be considered as a loss of picture area from the point-of-view that if the retrace were instantaneous so that no blanking was required, reproduction of an additional portion of the picture could start immediately after the instantaneous retrace. On this basis Figure 9 has been prepared. We may note that the 441 lines of each frame are indicated as the maximum vertical distance. The loss of 7 percent of these during field blanking leaves 410 lines which are used in the reproduction of the picture. As a measure of horizontal distances we may use the same unit, that is the center-to-center separation of lines; this leads to the concept of square picture elements, or points, with this unit length on each side. With a 4/3 aspect ratio, we obtain for 410 points vertically the figure of 547 points horizontally. The used portion of the total area therefore has dimensions of 547 x 410 points, and may be seen to be represented by the large white area in the center of the drawing.

The gray and black regions in Figure 9 are approximately what would be observed if normal blanking and instantaneous retraces are assumed, together with an alteration of the stabilization at the receiver so as to indicate the sync signals in black and the remainder of the blanking time in gray.

Considering first the field scanning, let us go down the picture corresponding to motion to the right in the portion "Bottom of Picture" at the upper left corner in Figure 8. At the moment t_0 the vertical blanking pulse begins and also the set of equalizing pulses which leads the vertical sync signals. These equalizing pulses are narrower than the normal line sync pulses and occur twice as frequently. At the bottom of Figure 9 they are represented as two black sections, one at the left and one at about the center. At the termination of this leading set of equalizing pulses, the first broad pulse of the vertical sync signal occurs. We assume that instantaneous field retrace then takes place, so that the broad pulses are represented at the top of Figure 9. These have sync amplitude for all except the short intervals which follow the pulses. The next occurrence is the beginning of the set of equalizing pulses which follows the field sync signals, and following this there are normal horizontal sync pulses lasting until the termination of the vertical blanking pulse, at which the reproduction of the picture begins again.

The horizontal scanning includes the gray edge at the right in Figure 9, which represents the interval of 0.01H, the very narrow shoulder on the horizontal blanking pulse before the occurrence of the horizontal sync signal. At the left are represented the horizontal blanking in the black and gray regions and the horizontal sync pulses in black. The narrower width of the equalizing pulses is also represented. With 547 points as the width of the used portion of the total area, there is obtained, upon dividing by 0.85, the result of 644 points as the total width of the diagram.

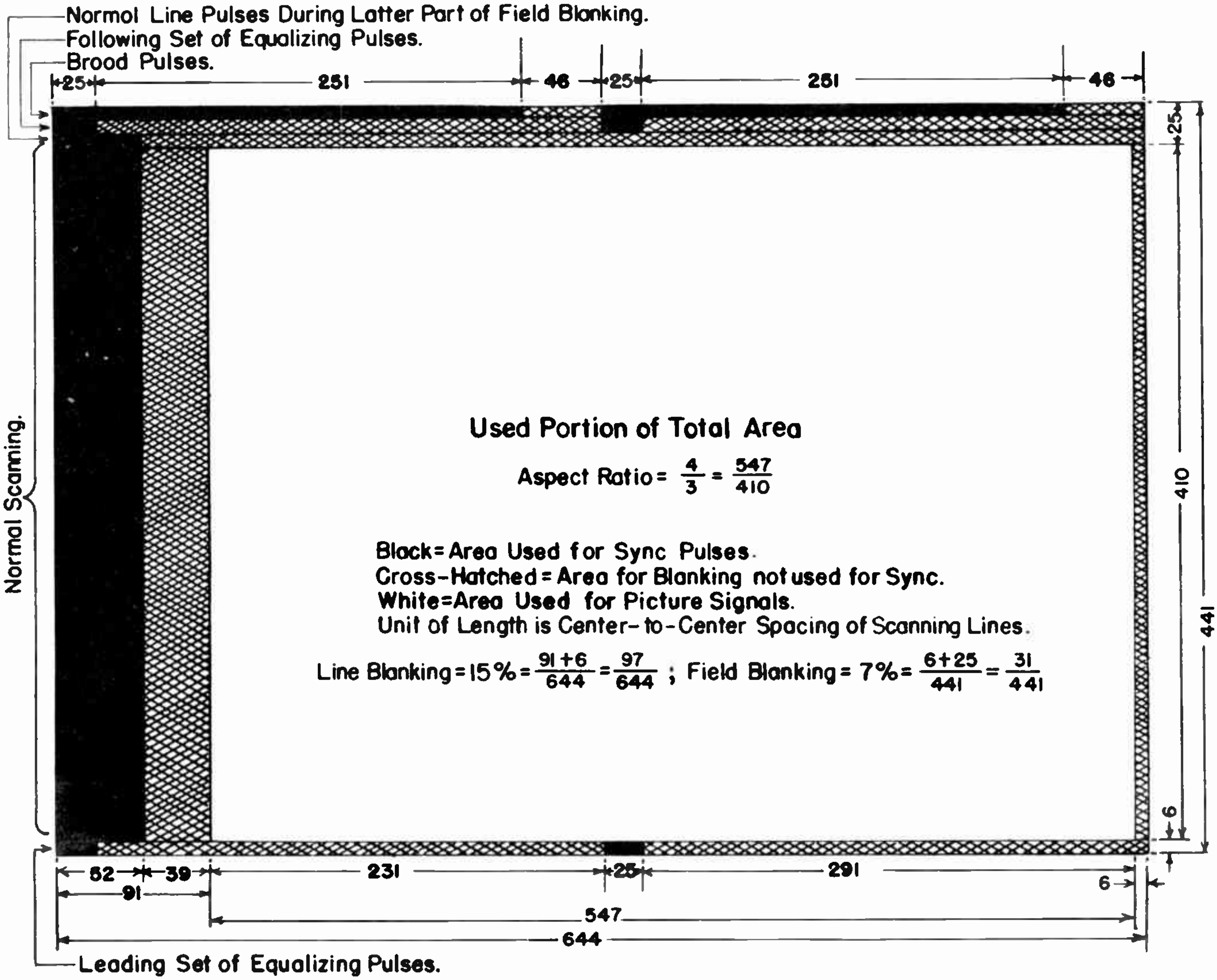


Fig. 9. Location of Blanking and Synchronizing Pulses With Respect to Picture Area, Assuming Instantaneous Retraces

Figure 9 is drawn on the basis of 7-percent field blanking. This is the minimum specified, the maximum being 10 percent. In receiver design the 7-percent figure can, and should be, accommodated. On a basis of 10-percent field blanking, the number of vertical lines for picture reproduction, with 441 lines per frame, is 397 lines.

The time efficiency of a television system is the proportion of the total elapsed time which is used for actual reproduction of the picture. The appearance of a picture screen when only the scanning lines are seen, that is when no picture is being transmitted but conditions are otherwise normal, is called the "raster", a term of German origin. For example it may be said that a close inspection of the raster generally reveals the individual scanning lines. The term is also used in the phrase "raster efficiency", which has the same meaning as time efficiency. With 15-percent line blanking and 7-percent field blanking, the time efficiency, or raster efficiency, is 0.85 x 0.93 = 0.79; this is the ratio of the white area to the total area in Figure 9. In case the field blanking is 10 percent, while the line blanking remains at 15 percent, the time efficiency is 0.85 x 0.90 = 0.77.

INTERLACING

A brief description of interlacing is given on page 10 (Report 1776), including standard definitions of the Radio Manufacturers Association. In Figure 10 of the present chapter we show the essential principle of odd-line interlacing, which is the type in general use. In this figure the lines of the first field of the frame are shown solid, while the lines of the second field of the frame are shown dashed. The arrows on the various lines and the letters, beginning with A, indicate how in the scanning process first one set of lines, those of one field, are scanned, and then the other set of lines of the next field. On pages 15-18 (Report 1776) there is given a discussion of flicker and its prevention in television, without an increase of frequency band, by means of interlacing.

There are various ways in which a television system can be interlaced. In particular, there are rhythmic and non-rhythmic types of interlacing, the difference being that in the rhythmic types the successive line and field scannings occur at perfectly regular intervals, while with non-rhythmic types this is not the case. As an example of non-rhythmic interlacing we may mention even-line interlacing in which there are an even number of lines per frame, these lines occurring at regular intervals, but in which the field scanning consists of two sets of saw-tooth waves occurring in alternative order, one set being displaced with respect to the other so as to make the otherwise coincident lines of successive fields have an interlaced relation.

Odd-Line Interlacing

The odd-line type of interlace, which is in general use here and abroad, is an example of the rhythmic type. In the United States there are 60 identical field scans per second and 13,230 identical line scans per second. The ratio of these two numbers gives 220.5 lines per field; it should be particularly noted that this number ends in five-tenths. This means that the line oscillator must operate at exactly 220.5 times the frequency of the field oscillator. An explanation of timing circuits which will maintain this ratio exactly is given on page 47 (Report 1822). The terms even-line and odd-line interlacing refer to the number of lines per frame. A 441-line interlaced system is therefore an odd-line system. In Figure 10 the principle of odd-line interlacing is shown with fifteen lines per frame. With an odd number of lines

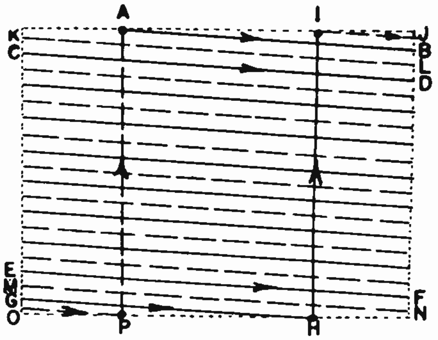


Fig. 10. Principle of Odd-Line Interlace

per frame, the number of lines per field is an integer plus one-half; in the 441-line system this is 220.5, and in the simple representation of Figure 10 it is half of 15, or 7.5.

It may be a little difficult to visualize the fact that the existence of a number of lines ending with one-half, such as 220.5, in each field will produce interlacing. The essential feature is that each sixtieth of a second the vertical scanning starts downward from the top of the picture for the reproduction of the particular field, but that the scanning spot is not at the same point horizontally at the beginning of the two vertical scans. In particular, the scanning spot is displaced just such an amount that, in conjunction with the downward vertical scanning, the lines of one field lie between those of the other field.

In Figure 10 an instantaneous field retrace is assumed and is represented by the vertical retrace lines HI and PA. It is of course not necessary to have instantaneous retraces in order to secure correct interlace, else it could not be obtained in practice. Proper interlace is secured if successive field scannings are identical and start at accurate intervals of one-sixtieth second, and if the line frequency is maintained accurately at 220.5 times the field frequency. On page 47 (Report 1822) under "Timing Circuits", and particularly in Figure 3 on that page, it is shown that the timing or sync pulse initiates the retrace of the oscillator. Assuming that these retraces occur at accurate intervals of one-sixtieth of a second, and that the duration of the retrace is the same for successive cycles, we see that the start of successive field scans will be at accurately timed intervals, so that this requirement for satisfactory interlace is met. This dependence on accurate initiation of retrace and on constant duration of retrace is representative of practical conditions in television apparatus.

We may summarize the odd-line method of interlacing in a formal statement as follows: In odd-line interlacing, such as with 441 lines per frame, the number of lines per field is an integer plus one-half, such as 220.5, and the existence of this relation has the result that successive fields start at two points along the top of the scene which are separated in time by half a line period; interlacing is secured by this time difference in conjunction with the uniform downward motion of the vertical scanning.

The following tabulation gives several television systems with odd-line interlacing which are, or have been, used in various countries:

No. of Fields per Sec.	No. of Frames per Sec.	No. of Lines per Frame	No. of Lines per Sec.	Remarks
60	30	441	13,230	United States
50	25	405	10,125	England
50	25	441	11,250	Germany
50	25	455	11,375	France
60	30	343	10,290	Former U.S.

It may be noted that the number of lines per frame is independent of the field and frame frequencies. It is the ratio of line frequency to frame frequency.

Pairing of Interlaced Lines

A certain type of fault in the field scanning will cause an interlaced raster to have "pairing" as shown in Figure 11. Close examination of this figure will show definitely the occurrence of the lines in pairs, rather than with uniform spacing. This fault impairs the detail, and in the limit halves the effective number of scanning lines; for example a 441-line picture becomes a 220-line picture upon total failure of the interlace, that is upon complete pairing. The cause

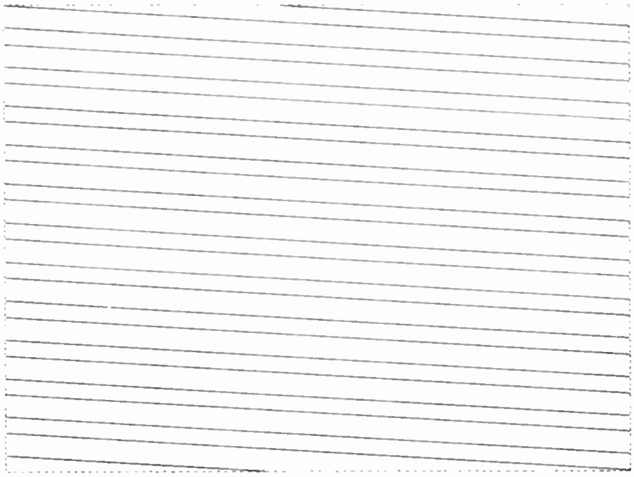


Fig. 11. Illustration of Imperfect Interlace, or Pairing.

of pairing is an incorrect relation on the screen between the sets of lines of the two fields. If one field is regarded as occurring first, the pairing can be considered to be due to each line of the second field occurring with a slight vertical displacement from its proper position; each such second line lies too close to the adjacent line of the first field on one side, and too far from the adjacent line of the first field on the other side. This causes the complete interlaced pattern, or raster, to show the appearance of lines in pairs. In Figure 11 the lines of both fields are drawn solid in order to give an impression similar to that observed in laboratory experience. The degree of pairing shown here is taken as the maximum allowable in setting a criterion for accuracy of field-oscillator timing in the section on field synchronization below.

REASONS FOR EQUAL AND RECTANGULAR SYNC PULSES

In Figure 8, page 76, which gives the complete video wave, it may be seen that the sync pulses for the line and field synchronizations have the same height, and also that both are practically rectangular in shape. These characteristics have been chosen with due consideration, and in the present section we give the reasons for the choice.

Equal Height of Line and Field Sync Pulses

Before the adoption of the wave of Figure 8, consideration was given to the use of sync pulses of different height for field and line synchronization, and particularly to the possibility of having the field sync pulses of greater height than the line sync pulses. Such an arrangement can be made to afford sharp field timing and also separation between the field and line sync pulses by amplitude discrimination. However the arrangement has the characteristics of: (1) assigning a portion of the power range of the transmitter to the sole function of field synchronization; and (2) incurring the risk of loss of the amplitude difference in an overloaded receiver. Since it is possible to obtain satisfactory results without these features, the choice of equal height for the two types of pulses was made.

Rectangular Shape of Sync Pulses

In Figure 8 the specification is included that the leading and lagging edges of all sync signals shall occupy not more time than 0.005H, where H is the line period of 1/13,230 second. This specification is essentially a statement of the small permissible amount by which the sync pulses may depart from a perfectly rectangular shape. In Figure 8, the duration of line and equalizing pulses is shown at both base and tip in terms of the maximum transition time of 0.005H. For a shorter transition time, the duration at the base remains the same, and the duration at the tip is correspondingly greater. The duration of the broad field-sync pulses is discussed below under "Broad Pulses as Field Sync Signal".

The most important advantage of the rectangular shape of a synchronizing pulse is that the timing, which is represented by an edge of the pulse, is preserved despite great "abuse" in the way of distortion in transmission. As an example of this we show in Figure 12 the action of a negative-grid limiter which cuts

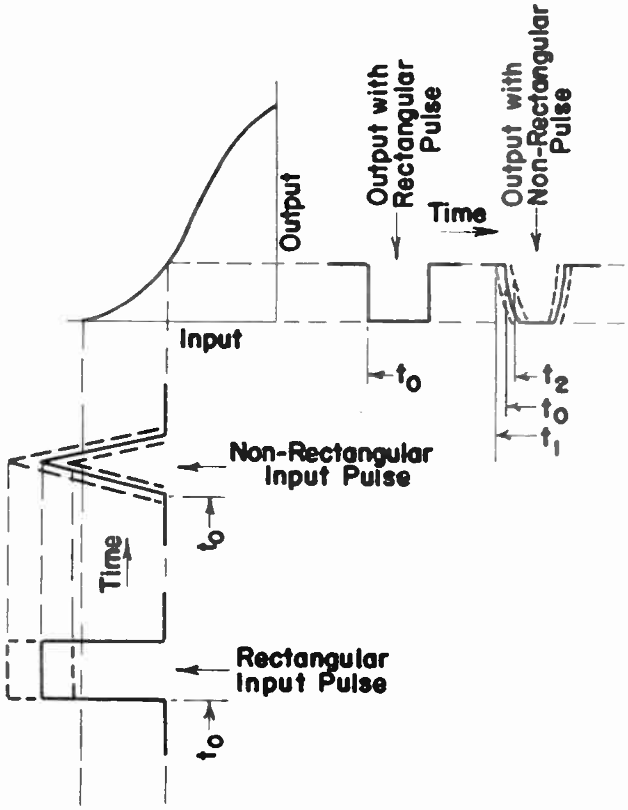


Fig. 12. Preservation of Timing by Use of Rectangular Pulses

off the applied pulses beyond a certain point. It will be seen in this figure that with the rectangular shape, variation of the input level, as shown in dashed lines, does not affect the timing t_0, established by the leading edge of the pulse. However, with a non-rectangular shape, this is not in general the case. To illustrate this there is shown in Figure 12 the operation with a triangular wave, and it can be seen that erroneous times t_1 and t_2 characterize the base of the output pulse with change of input level.

The operation of cutting, or limiting, is characterized essentially by the complete removal of part of the amplitude range. In another type of distortion to which sync signals are exposed, namely crushing or compression, all parts of the amplitude range are retained in amount sufficient for restoration, but are altered in their relative proportions. After a compression, rectangular pulses can be restored to their original height by either expansion or amplification; there is no need of matching the characteristic of the compressor with a complementary characteristic in an expander.

It is seen therefore that with the rectangular shape, amplitude distortion does not have to be corrected - it is only necessary to obtain the final required height of pulse. This fact makes it possible to use the non-linear portions of tube characteristics, both in the transmitter and the receiver, for handling the sync signals.

HORIZONTAL BLANKING AND SYNC

Duration of Line Blanking

The duration of the line blanking pulse must be sufficient to allow the line scanning system to return the spot to the left-hand side of the picture and also to permit resumption of the normal velocity of the spot in the trace direction. We have seen in Figure 8 that 0.15H is allotted for the line blanking pulse; this is 15 percent of 75.6 microseconds, or about 11 microseconds. This length of time for the line blanking is about as short as can be used economically. It is of course desirable to have this interval short in order to use as much time as possible for actual picture transmission; for this reason it has been set at about as short a value as is usable under practical conditions.

Uniform Line Timing in the Field Blanking Interval

The scanning circuits of a television receiver are usually designed on the basis that the normal line scanning will be maintained during the field retrace. That is, the line scanning coils at the picture tube operate continuously, whether or not the electron beam is present. As a matter of fact, during both field and line retraces, the electron beam is cut off by the control grid under the influence of the blanking pulses. This does not however prevent the scanning currents and the resultant magnetic fields from being in operation.

To permit the maintenance of line scanning during the field retrace, there are provided, as shown in Figure 8, suitable pulses throughout the field blanking interval. Before considering these pulses in detail, let us note two relevant facts: (1) the excursion of the complete video wave from the black level to the sync level is the essential line timing operation - this synchronizes the line oscillator in the receiver in the manner shown in Figures 2 and 3 of the preceding chapter (page 47, Report 1822); and (2) the line oscillator is insensitive to pulses occurring a substantial time in advance, for example pulses occurring in the middle of the scanning of a line.

We may now note that in Figure 8 of the present chapter there are represented at the upper left corner the last few lines of normal scanning which occur at the bottom of the picture being transmitted. Here the horizontal sync pulses may be seen, and note may be taken of the left side of each, which determines the timing of the line oscillator at the receiver. An interval of time designated as H, equal to the line period of 1/13,230 second, elapses between each of these synchronizing strokes. This timing is maintained during the insertion of the equalizing pulses because these include a pulse with a leading edge occurring at each interval of H; the equalizing pulses have been made narrower than the regular line pulses by advancing their lagging edges - the leading edges are unaltered in position. It will be seen that there are also equalizing pulses located just half-way between those we have been considering; the function of the equalizing pulses is described below in connection with the field sync signals. At the present point it is sufficient to note that these additional pulses do not introduce any difficulties in the line scanning.

At the end of the period of insertion of the equalizing pulses, the first broad pulse of the vertical sync signals occurs with its leading edge at one of these intervals of H or H/2. Each broad pulse terminates soon enough to accommodate, at the next H/2 instant of synchronization, an upward stroke of the curve, from the black level to the synchronizing level, as required for the line synchronizing operation.

At the termination of the vertical sync signals in Figure 8, there is a group of three vertical strokes, of which the central one is the only one going in the necessary direction for synchronization; this one is properly timed for this purpose. The equalizing pulses following the vertical sync signals are timed in the same manner as the equalizing pulses occurring before the vertical sync signals.

We may conclude this treatment of the uniform line timing during the field blanking interval by stating the essential result that vertical strokes of the wave in the direction toward sync level occur regularly at line frequency (which includes double line frequency), permitting the maintenance of normal operation of the line oscillator.

For the other field of the frame, represented by the second curve in Figure 8, the same remarks apply as above in regard to line timing by the upward strokes. In this case also there is the additional set of upward strokes during the period of both sets of equalizing pulses and during the vertical sync pulses. We may note that for this field the line oscillator is tripped by the second, fourth, etc., equalizing pulses, in comparison with the first, third, etc., for the first field.

Width of Line Sync Pulses

The line sync pulses, that is the horizontal sync pulses, are shown in Figure 8 as having a width of 0.08H at the base, and maximum transition times at the leading and lagging edges of 0.005H; therefore the width at the tip lies between the values of 0.07H and 0.08H. For satisfactory operation of the receiver the width or duration of these line sync pulses must be sufficient to provide the necessary charge per peak for effective stabilization of the signal. We have noted above on page 71 that such stabilization is used for the separation of the picture and synchronizing components, and for reinserting the direct-current component after an alternating-current coupling.

In Figure 13 we show a circuit for the reinsertion of the direct-current component, and give diagrams showing unsatisfactory operation with too narrow pulses, and proper operation with pulses of sufficient width. The circuit at the top is conventional, and is similar to the diode reinserters shown in the preceding chapter (Figure 12, page 56, Report 1822). The condenser C is charged during the short time that the diode is conducting,

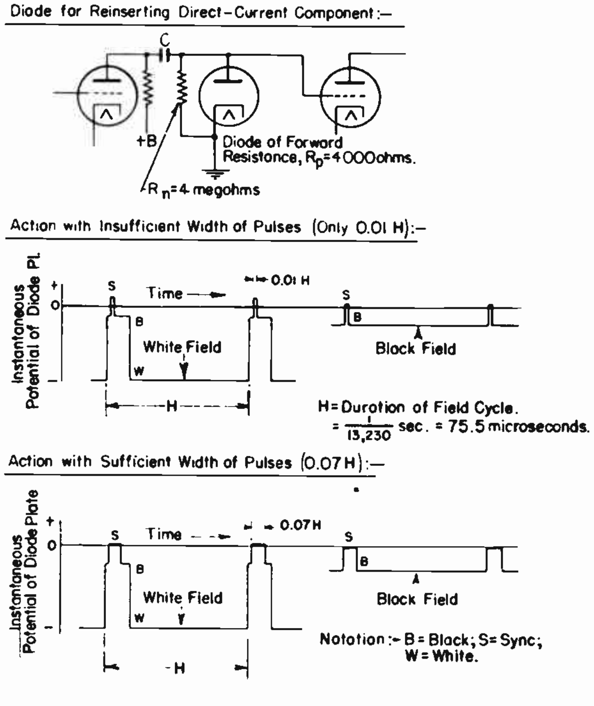


Fig. 13. Necessary Width of Line Sync Pulses for Peak Detection

and discharges continuously. Since there can be no indefinite increase of potential, the charge and discharge per cycle must be equal. The charge in either case is the product of current multiplied by time, and we may express current as the ratio of voltage to resistance. The values of resistance are different for charge and discharge. Taking the side of the condenser which is connected to the diode plate as the reference point, the condenser is charged positively while the diode is conducting, whence the forward diode resistance is designated R_p. It is indicated as having the representative value of 4000 ohms, which includes the plate resistor of the preceding tube. The resistance thru which the condenser discharges is the four-megohm leak R_n.

Equating expressions for the charge and discharge of condenser C in Figure 13, and then substituting the known resistances and solving for the voltage ratio, we obtain the relation e_p/e_n = 0.001 T/t, which gives the relative excursion of the sync peak in the positive direction for any width of sync peak. For example, with a narrow sync peak having a duration of only 0.01H, the value of T/t is 100, whence for the ratio e_p/e_n the result 0.1 is obtained. This means that with an all-white picture, the position of the axis, as illustrated in Figure 13, divides the complete video signal range into 9 percent above the axis and 91 percent below the axis. Of the 20-percent height of the sync peaks, 9 percent is above the axis and 11 percent is below. With a black field the voltage which produces discharge of the condenser is much less, and the circuit comes much nearer having the sync peaks on the axis. It is seen that reinsertion of the direct-current component with sync pulses only 0.01H in duration is unsatisfactory; the exact duration required depends on the resistance values.

Upon increasing the width of the line sync pulses to 0.07H, satisfactory reinsertion is obtained, as shown by the lower sketch of Figure 13.

The requirement as to the width of the line sync pulses is essentially that they have sufficient duration for the necessary charge to pass at low voltage; the desired result is very low voltage. In other words, peak detection is wanted; diode reinserters are special cases of peak detectors.

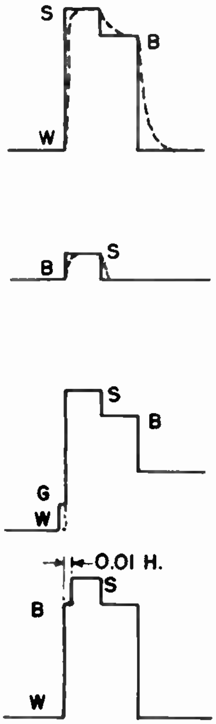
These considerations point to the selection of as broad a line synchronizing pulse as can be used. However, in some other circuits, particularly in the transmitter, it is desirable to make use of the remaining black-level portion of the field blanking pulse, or pedestal. For such circuits it is desirable to have the black portion of the blanking pulse as wide as possible. The wave of Figure 8 is a compromise between these two conflicting requirements, and has approximately half the width of the total blanking pulse occupied by the synchronizing pulse.

Location of Line Sync Pulse in the Blanking Interval

On account of the very limited amount of time available for the line retrace, it is obviously desirable to locate the leading edge of the line sync pulse as close as possible to the leading edge of the line blanking pulse. However, it is unwise to endeavor to make the two leading edges simultaneous, whence an interval 0.01H is specified between them. In Figure 14 we give sketches showing two reasons for the provision of this interval.

On account of the fact that the various circuits involved do not pass an infinite width of frequency band, the response to an abrupt change of potential does not occur instantaneously. For example in sketch A of Figure 14 there is shown, in a dashed line, the response with a white scene, assuming that the line blanking and line sync are synchronous, that is assuming that the interval of 0.01H is not provided. It may be seen that at the black level, at which the synchronizing operation occurs, there is an appreciable delay in comparison with sketch B for a black scene. Such a displacement would result in a horizontal shift in the position of the scanning lines, and produce distortion of the picture.

In sketch C of Figure 14 there is shown another reason for providing the interval of 0.01H ahead of the line



A–Appreciable Delay in Response with White Scene in Absence of Preceding Black Interval.

B–Negligible Delay in Response with Black Scene.

C–Introduction of Gray Border by Early Application of Sync Pulse.

D–Placing of Sync Pulse with Preceding Black Interval.

Fig. 14. Reasons for Short Black Interval Preceding Line Sync Pulse

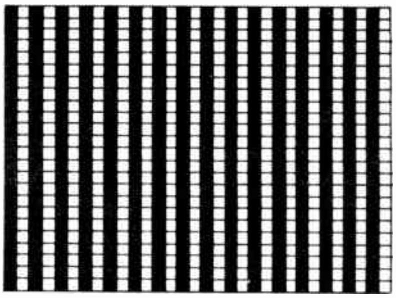
synchronizing pulse. This reason is that tolerances in the transmitter system prevent an exact agreement of timing between the blanking and synchronizing pulses, so that an effort to make them simultaneous would be likely to result in part of the sync pulse leading the blanking pulse and thus falling into the picture range, as shown in sketch C of Figure 14. Such an action would of course cause loss of the precise timing given by the leading edge of the sync pulse, which would be objectionable, and would produce a vertical gray border at the right edge of the picture, which, however, would be quite narrow.

The specified location of the sync pulse, according to which it follows with an interval of 0.01H after the beginning of the line blanking pulse, is shown in sketch D of Figure 14.

Accuracy of Line Synchronization

To consider the accuracy with which the line synchronization must operate, let us assume a scene consisting of vertical black and white bars so narrow that they are at about the limiting resolution of the system. In Figure 15 the upper diagram represents such a set of bars. Now we have noted in Figure 9 that the length of each scanning line is 547 points, each having a width equal to the spacing of scanning lines. We see therefore that if the alternate lines in the upper part of Figure 15 should shift horizontally by one point, that is one part in 547, the grille of bars will disappear and be replaced by a fine-grained checker-board arrangement of black and white points, as shown in the lower portion of the figure. Such a change is a considerable impairment of the definition, and we may therefore set a criterion that not over one-quarter of this shift shall occur. On this basis the required accuracy of line timing is one part in about 2200, since 4 times 547 has a value of about 2200. Since this treatment of the subject is only approximate, we may say that the required accuracy is roughly one part in 2000, or one-twentieth percent.

Reproduction of Closely Spaced Vertical Bars with Accurate Line Timing—



Reproduction of Same with Lines of One Field Displaced by Width of Bar Due to Faulty Timing—

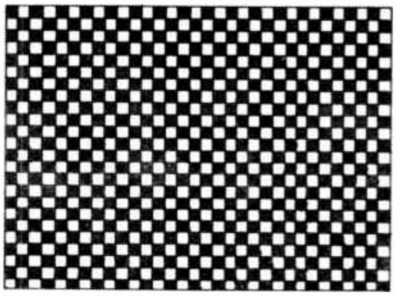


Fig. 15. Illustration of Incorrect Line Timing

A qualification in regard to the 547 points in the preceding paragraph should be noted. For simplification Figure 9 is drawn in terms of the center-to-center separation of adjacent scanning lines in the frame as the unit of length. However, on account of the nature of the scanning process it is not possible on the average to get a degree of resolution in the vertical direction as fine as this separation. Horizontal resolution depends on the range of video frequencies transmitted, and can be finer than the vertical resolution.

For the purposes of receiver design, we may regard the sync signals radiated by the transmitter as perfectly accurate. In the receiver the problem is therefore to avoid any effects which would introduce errors in the line synchronization of greater magnitude than permitted by the criterion above. In further chapters, in which synchronization and scanning will be considered in detail, we will discuss the subject of accuracy more fully.

FIELD BLANKING.AND SYNC

Field Blanking Pulse

In Figure 8 the vertical blank-pulse, which is called the field blanking pulse, and the field pedestal, is shown as having a duration of 7% of the field period, that is 7% of 1/60 second, which amounts to 15.45 line periods or 1167 microseconds. It is expected that in direct pickups, television transmitters will operate with this value of vertical blanking. However, on account of the different arrangements used for the transmission of motion-picture film by television, it has heretofore been necessary in film program numbers to use a longer field blanking, namely about ten percent; this will probably be reduced to 7 percent at a later date. From a receiver standpoint the shorter field blanking is the critical value, and therefore the one of chief interest. Within this interval of 0.07V, where V is the field period, the scanning system of the receiver must initiate retrace, complete the retrace, start the downward motion, and achieve uniformity of velocity. No serious difficulty should be encountered in satisfying these requirements.

With a receiver designed to accommodate a vertical blanking of 0.07V no trouble will be experienced in the reception of signals radiated with blanking of 0.10V; the effect of the longer field blanking at the transmitter will be to cause the black border along the top of the picture to be slightly lower than would otherwise be the case, and a few lines of the picture, which would otherwise be received, will not be present.

Broad Pulses as Field Sync Signal

The pulses inserted during the field blanking period for the field synchronization must of course be electrically distinguishable from the line sync pulses. Since it is desirable from other standpoints that the field sync pulses be of the same amplitude as the line sync pulses, and also that both be rectangular, as discussed above on page 81, this leaves only the duration and internal waveform of the field pulses available for modification. In practice it is both feasible and convenient for the field pulses to differ in duration alone. They are therefore specified in Figure 8 as rectangular and of maximum permissible duration consistent with the introduction of regular upstrokes at double line frequency for the maintenance of the line scanning. The field sync signal consists of six of these broad pulses.

The length of each broad pulse at the base, that is at the black level, is specified as 0.43H, leaving 0.07H as the duration of the following interval at the black level. It may be seen that this interval between the broad pulses can be regarded as an inverted line pulse, assuming use of the full 0.005H transition time which is the maximum allowed.

Accuracy of Field Synchronization

We have seen on page 80 that an incorrect relation on the screen between the two sets of fields of interlaced operation, produces an impairment of the interlacing in the picture, causing the raster to show pairing of the scanning lines. In

Figure 11 we have shown such pairing; the amount of pairing in this figure represents the case where one field period has a duration of 220.4 lines, (0.1 line period short) and the other field has a duration of 220.6 lines (0.1 line period long). (This cause of pairing is chosen for simplicity in discussing accuracy of the field scanning; other causes also are encountered in practice.) Pairing to the extent shown in Figure 11 is sufficient to make the line structure of a television image easily evident at normal viewing distances, each pair of lines appearing as a single line. For the establishment of a criterion of accuracy for the field scanning, we may take this amount of pairing as the maximum permissible. On this basis the error allowable in the field timing is one-tenth part in 220.5 or one part in 2205; from this we conclude that the required value of field scanning accuracy is roughly one part in 2000, or about the same as the corresponding requirement for the line scanning, which is discussed above on page 85. It is considered practical to obtain accuracy of field timing considerably better than the criterion just given. Examination of the raster with good television receivers shows no perceptible pairing.

In case pairing is observed a condition is likely to be encountered in which the line scanning is accurately interlaced during field retraces, but has the observed pairing during the field traces. This possibility arises from the method of synchronization of the scanning oscillators in the receiver, and in particular from the fact that their retrace is initiated by the received sync signals, while their trace is locally initiated. The beginning of the field trace may on this account be upset by interference from the line oscillator affecting the field oscillator. To make this clear we mention the following two facts: (1) the field scanning starts before the termination of the field blanking pulse (in fact it must have settled down to a constant velocity by the time the field blanking terminates), and the point of interest is the portion of its trace completed at the instant that the field blanking terminates and the reproduction of the picture begins; and (2) although line doubling pulses, or equalizing pulses, are received following the vertical sync signals, and although the field retrace terminates while these equalizing pulses are being received, the line oscillator itself is usually designed to remain at line frequency, and not assume the double line frequency during the field blanking. From these conditions, we see that a small amount of interference reaching the field oscillator from the line oscillator may cause the field oscillator to terminate its retrace at different times for the two sets of fields, thereby producing pairing of the interlace. This condition is frequently encountered, the pairing often amounting to about ten percent, which is the value shown in Figure 11. One remedy is to remove the coupling between the line and field oscillators by thorough shielding and isolation; by this means the interlace during trace, which is the effect of interest, can be made as good, or practically as good, as that obtained during retrace.

Leading Set of Equalizing Pulses

Equalizing pulses and double-frequency line strokes during the field sync signal are provided to satisfy the two requirements of (1) maintenance of line scanning during the field blanking, and (2) similarity of conditions in vicinity of the field sync signal for the two fields of each frame.

The equalizing pulses ahead of the field sync pulses can be seen in Figure 8 to be identical for the two fields of a frame. If these equalizing pulses were not provided, the field sync pulses would be preceded by different conditions for successive fields. Under these circumstances field sync circuits of the integrating type would act differently for successive fields and produce pairing of the interlace in the picture. In Figure 16 we show a circuit that will produce an output waveform which is the integral of the waveform at the input. The integrating type of field sync circuit is not the only one available, but it was considered desirable to provide these pulses to accommodate it.

In Figure 16 the waveforms in the left-hand column show conditions when the equalizing pulses are provided. The similar conditions existing immediately preceding the field sync pulses of the two fields are apparent. The building-up of the output wave by integration of the broad sync pulses is shown; this is the same for the two fields since the inputs are the same for practical purposes. A critical level, as indicated with a horizontal dashed line, is used to trip the field oscillator, and this will occur at the time indicated by the vertical dashed line.

In the right-hand column of Figure 16, the timing difficulty is shown assuming that the equalizing pulses are not provided and an integrating circuit is used. The horizontal dashed line again designates the level at which the field oscillator is tripped. The field sync pulses of the second field in this case produce integrated potentials slightly greater than for the first field, whence the time of tripping of the oscillator is

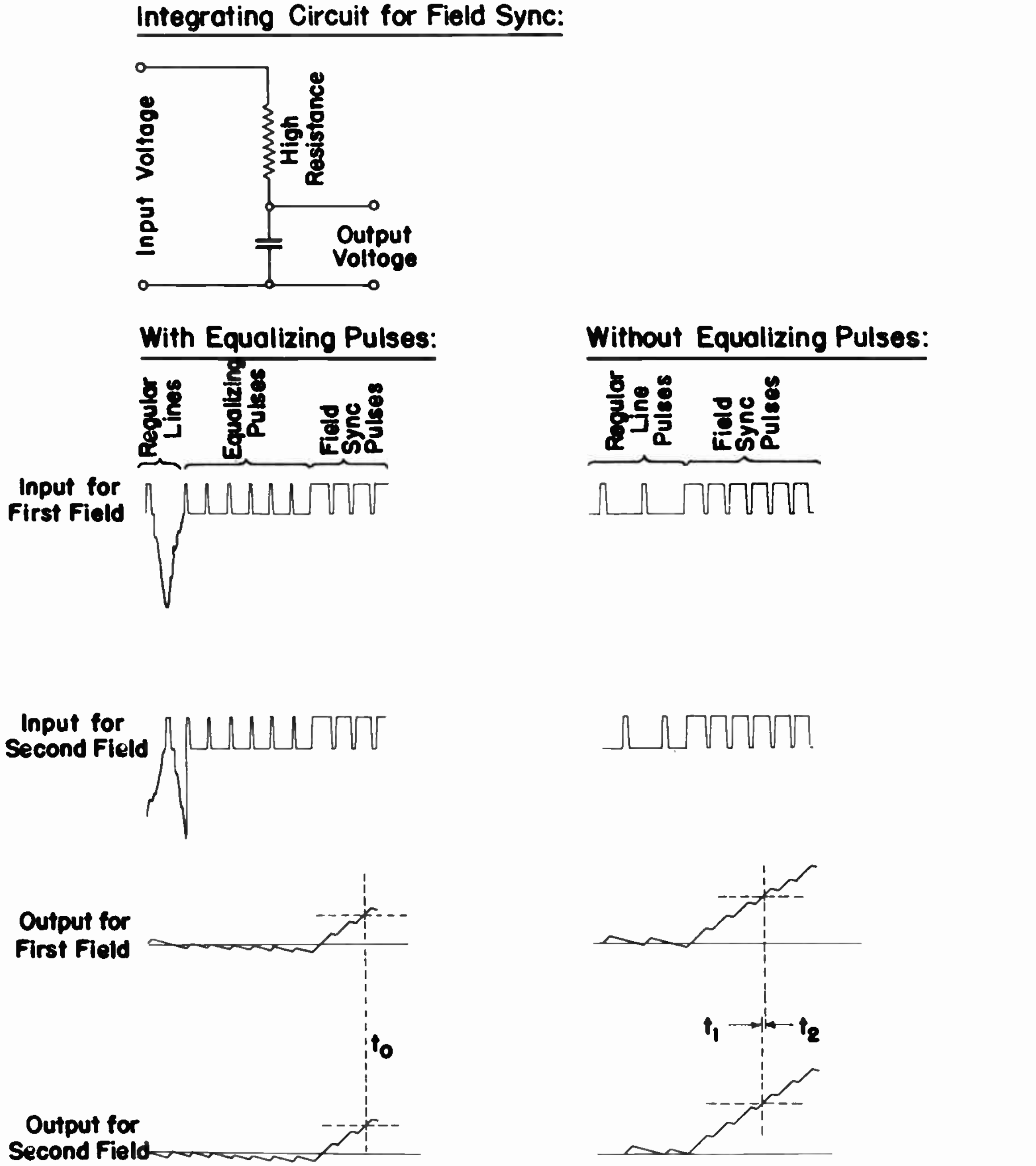


Fig. 16. Dependence of Field-Sync Integrating Circuit on Presence of Leading Set of Equalizing Pulses

earlier. This is shown in the drawing by the fact that time t_2 is later than time t_1. The presence of the equalizing pulses preceding the broad pulses is thus seen to equalize the effects of successive field cycles on the field synchronizing system.

The width of the equalizing pulses is made equal to half that of the regular line sync pulses as another accommodation for the integrating type of field sync circuit. These half-width pulses, taken in connection with their double frequency, give the same integrated area of the sync pulses during the equalizing-pulse period as during the preceding reproduction of the last lines of the scene, and thereby avoid a disturbance which might produce a premature field tripping.

Lagging Set of Equalizing Pulses

The lagging equalizing pulses are provided because they eliminate one source of interference with the constancy of the retrace duration of the field oscillator. In case there is imperfect inter-sync separation, some of the line sync signals may reach the field oscillator during its retrace and affect the timing of the initiation of its trace. If the lagging equalizing pulses were not provided, that is if there were only the normal line-frequency sync pulses during this period, the disturbing conditions would be different for the two fields of each frame; the timing of the start of the field trace might then be different for the two fields, resulting in pairing of the interlace.

These lagging pulses are terminated before the end of the field blanking period because in some receivers the line oscillator operates at double frequency while supplied with double-frequency sync pulses, and a recovery interval must be allowed in such a case to permit the re-establishment of normal operation at line frequency before the termination of the field blanking.

SENSITIVITY AND THERMAL NOISE

In the foregoing sections there is given a description of the television wave, which establishes various requirements that the receiver must meet. The reasons leading to the choice of important characteristics of this wave are stated. We come now to the requirements on the television receiver in other respects, and take up first the subject of sensitivity and the related matter of thermal noise.

Definition of Sensitivity

The preparation of a standard definition of sensitivity for a television receiver has not yet gotten under way, whence such a statement must await the results of engineering conferences which will undoubtedly consider the matter in the future. We give in the present section a definition which appears to be reasonable in the light of conditions at this time. On this basis the sensitivity of a television receiver is the input signal voltage required for operation under the following conditions: (1) the scene has a full black-and-white range of contrast; (2) the controls of the receiver are set for maximum sensitivity; (3) the reproducing picture tube is actuated sufficiently to be swung over its full operating characteristic; and (4) the signal is sufficient to provide reliable synchronism (if this condition should not be met, the sensitivity is the input signal voltage required for satisfactory synchronization).

Thermal Noise

A sound receiver for operation in the region of 10 or 15 megacycles may well have a tuned-circuit impedance, across which the first tube obtains its signal voltage, of the order of 13,000 ohms, and an audio range, with the tone control at a representative position, extending to 2500 cycles, corresponding to a total bandwidth of 5 kilocycles for the purpose of thermal-noise computation. Under these conditions a thermal-noise voltage of 1 microvolt will be present on the grid of the first tube. In the case of a television receiver, a similar value of resistance may be representative, but the bandwidth is many times greater. We may take the figure of 3 megacycles as representative for this purpose, on the basis of sesqui-sideband transmission allowing about 1 mega cycle on one side and 2 megacycles on the other side. This gives a bandwidth 600 times that of the assumed sound receiver, whence the noise will be greater in the ratio of the square root of 600, which gives a figure of about 25 microvolts on the first grid of the television receiver. These values of noise are of course root-mean-square. If we assume an antenna gain for the telereceiver lying between one and two times, the root-mean-square noise at the antenna terminals will lie between 12 and 25 microvolts. The random character of noise makes it impossible to state a definite peak-to-peak equivalent of this root-mean-square value. For practical purposes a figure of 4 times has sometimes been used to get the peak-to-peak value; on this basis the peak-to-peak noise at the antenna terminals would be 50 to 100 microvolts.

Required Sensitivity

From the discussion of thermal noise in the preceding section it is seen that there is no necessity of making a television receiver as sensitive as considered normal for broadcast sound receivers. Experience to date indicates that a sensitivity figure of the order of 1000 microvolts will be satisfactory for manufactured receivers.

The extreme in the other direction, in which very strong signals are encountered, will be experienced in a very few locations such as with sound receivers, wherever a fair-sized antenna is used near a transmitter. It is expected that television receivers designed to accept a maximum signal strength between 0.5 and 1 volt will be satisfactory.

Sensitivity of Television Sound Receiver

The sound receiver which is part of the complete television receiver should be somewhat more sensitive than the associated television receiver, but there is no need for very much greater sensitivity since ordinarily the two carriers from a particular station will be of comparable strength. The sound television receiver operates of course with a much smaller bandwidth than the picture receiver, so that the same thermal-noise limitation does not apply. With the ample room for wide-band audio transmission, and with the relatively strong signal strength, it is expected that high-fidelity sound reception will be normal as an accompaniment for picture reception. Since television receivers, at least initially, will be in a high-priced class of merchandise, it appears advisable to include a high-fidelity sound channel which will afford a realistic reproduction of program sounds as well as speech and music.

SELECTIVITY AND CHOICE OF INTERMEDIATE FREQUENCY

One requirement in the selectivity of the picture receiver is that it provide a specified part of the 6 decibels attenuation of the picture carrier, as discussed above on page 69. This figure has not yet been standardized.

A second selectivity requirement on the picture receiver is that it discriminate against the associated sound carrier which is separated by approximately 4.5 megacycles. An attenuation of about 40 decibels for this purpose has been found to be satisfactory, provided it is so distributed in the receiver that no cross-modulation occurs. If this attenuation is insufficient, the sound reception will produce disturbing interference effects on the picture screen.

A third selectivity requirement is that there must be sufficient attenuation against transmission on the next channel below. However, the exact requirements in this respect are not known as yet because we have not had two television stations in operation on adjacent channels. It is our expectation that an attenuation of 40 decibels for frequencies less than the picture carrier by 1.25 megacycles or more, will be sufficient.

The figures of attenuation in the preceding paragraph state the loss for the particular side frequencies in terms of the peak response for the medium and higher-frequency components of the television signal. Since these components fall at the peak of the receiver selectivity curve, the figures are with respect to this peak.

Intermediate frequencies for the picture receiver lie far from the range used in sound broadcast receivers. The lower intermediate frequencies introduce greater difficulty from image-frequency response, but have the advantage of higher gain. The choice of the intermediate frequency should be based partly on the avoidance of tweets caused by harmonics of either the picture or sound intermediate frequencies lying in important television channels.

With respect to gain, the higher intermediate frequencies would not be inferior to the lower intermediate frequencies if the tube characteristics, particularly the input impedance and the grid-plate reactance were the same as at the lower frequencies; it is the failure of these conditions that makes the gain less for the higher intermediate frequencies.

The various limitations listed above point to a choice for the intermediate frequency of the picture receiver at some value between 6 and 20 megacycles.

ADDITIONAL REQUIREMENTS ON PICTURE SYSTEM

In addition to the requirements on the receiver which are given in the foregoing sections of the present chapter there are certain other important conditions with which the receiver must comply.

In particular it must handle the very wide range of video frequencies, the upper limit being not less than 2 megacycles and for best resolution, a good deal more than this. On page 13 (Report 1776) a brief discussion of this matter is given. Closely related to this are the subjects of phase requirements and picture detail. On page 13-15 (Report 1776) a brief treatment of phase requirements is presented. The picture detail obtained in television reproduction depends on these and other factors.

Another requirement evidently existing is sufficient linearity of the saw-tooth scanning waves. In Figures 18, 29, and 30 of the preceding chapter (pages 59 and 61 of Report 1822) we show a reproduced picture with faulty linearity of scanning, and the related scanning waveforms.

All the matters mentioned in the present section will be treated further in later chapters of this series.

REFERENCES

Some of the references which are given in preceding chapters include material on receiver requirements. We do not mention these again in the present section unless they are of special interest. References relating specifically to the magnitude of the video range, to phase requirements, and picture detail will be given in the next chapter, which will be devoted to these subjects. We also defer references describing specific television receivers or circuits to the appropriate later chapters.

The following papers deal with the sideband analysis of waves and the sesqui-sideband method: (1) "Relations of Carrier and Side-Bands in Radio Transmission", by R. V. L. Hartley, Bell Telephone Laboratories, in PROCEEDINGS OF THE I.R.E., February 1923, pages 34-56, and in BELL SYSTEM TECHNICAL JOURNAL, April 1923, pages 90-112; (2) a theoretical paper, "Certain Topics in Telegraph Transmission Theory", by H. Nyquist, now of the Bell Telephone Laboratories, TRANSACTIONS OF THE A.I.E.E., April 1928, pages 617-644, including a treatment of sesqui-sideband operation in the section, "Analysis of Carrier Wave", and the related Appendix V; (3) "Symposium on Wire Transmission of Symphonic Music and Its Reproduction in Auditory Perspective: Transmission Lines" by H.A. Affel, R.W. Chestnut, and R. H. Mills, Bell Telephone Laboratories, in BELL SYSTEM TECHNICAL JOURNAL, April 1934, pages 285-300, (the sesqui-sideband method was used and is described briefly on pages 290 and following); (4) "Television Over the Coaxial Cable", by M. E. Strieby, Bell Telephone Laboratories, in BELL LABORATORIES RECORD, February 1938, pages 188-195, (includes description of sesqui-sideband method for

New York-Philadelphia transmission); (5) "Partial Suppression of One Side Band" by W. J. Poch and D. W. Epstein of RCA Manufacturing Company, in PROCEEDINGS OF THE I.R.E., January 1937, pages 15-31, and in RCA REVIEW, January 1937, pages 19-35, and also in TELEVISION, Volume II, the second bound volume of RCA reprints, pages 134-150; and (6) U. S. patents 2050,679 and 2050,680 to H. A. Wheeler of the Hazeltine staff.

The general development of receivers by RCA is reported in the following papers: (1) "Description of Experimental Television Receivers", by G. L. Beers, in the PROCEEDINGS OF THE I.R.E., December 1933, pages 1692-1706, and in TELEVISION, Volume I, the first volume of RCA reprints, pages 187-201; (2) "An Experimental Television System - Part III, The Receivers" by R. S. Holmes, W. L. Carlson and W. A. Tolson, in PROCEEDINGS OF THE I.R.E., November 1934, pages 1266-1285, and in TELEVISION, Volume I, pages 279-299; and (3) "RCA Television Field Tests" by L. M. Clement and E. W. Engstrom, RCA REVIEW, July 1936, pages 32-40, and in TELEVISION, Volume II, pages 28-37.

The following two papers by RCA personnel relate to interlacing: (1) "A Study of Television Image Characteristics - Part II, Determination of Frame Frequency for Television in Terms of Flicker Characteristics", by E. W. Engstrom, in PROCEEDINGS OF THE I.R.E., April 1935, pages 295-310, and in TELEVISION, Volume I, pages 129-145; and (2) "Scanning Sequence and Repetition Rate of Television Images", by R. D. Kell, A. V. Bedford, and M. A. Trainer, PROCEEDINGS OF THE I.R.E., April 1936, pages 559-576, and in TELEVISION, Volume I, pages 355-374.

A discussion of characteristics of the television wave used in England is given in the first pages of the Marconi-E.M.I. series of papers, to which reference is made on page 64 in the preceding chapter (Report 1822).

The following sections in the text, "Television Engineering", by J. C. Wilson, relate to topics of the present chapter: synchronization and stabilization, pages 344-353; complete waveforms, pages 333-336; interlacing, pages 100-101; and thermal noise, pages 174-175.