

*MCGRAW HILL TELEVISION SERIES*

# Television Broadcasting

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**TELEVISION BROADCASTING**

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McGRAW-HILL TELEVISION SERIES  
DONALD G. FINK, *Consulting Editor*

## TELEVISION BROADCASTING

McGRAW-HILL TELEVISION SERIES  
DONALD G. FINK, *Consulting Editor*

BRETZ Techniques of Television Production

CHINN Television Broadcasting

DEUTSCH Theory and Design of Television Receivers

DOMÉ Television Principles

FINK Television Engineering, Second Edition

FOWLER and LIPPERT Television Fundamentals—Theory,  
Circuits, and Servicing

GROB Basic Television—Principles and Servicing

*To MENA and MARYANN*

## Preface

THIS BOOK HAS BEEN PREPARED for those who are interested in the technical aspects of television broadcasting. It covers in detail the equipment, the facilities, and the techniques that are the immediate concern of personnel who are responsible for the operations of television broadcasting establishments. In addition, for the designer of television studios and the associated equipment and systems, the text provides a valuable insight into the broadcasting field. As all capable engineers are well aware, regardless of how perfect the performance of any particular component or system, its usefulness and acceptability are limited unless it has been designed to meet the prevailing operating requirements.

A glance at the table of contents will indicate the scope of the subject matter. In determining the order in which the material is presented several alternatives were considered. One arrangement might have been to start with the staging and lighting techniques in the studio where a television program originates, then to proceed in logical order through the television camera and the remaining facilities of a broadcasting plant, ending up with the transmitting antenna itself, at which point the signal passes beyond the control of the television broadcasting engineer. Another approach could have been to consider television broadcasting facilities in the order in which they are placed into service by the average television station. This would have called for covering transmitters and their antennas first. The item activated next by almost every station is a film camera chain and the associated still and motion-picture projectors; next, field equipment; and last, permanent studio equipment. Neither of these "logical" approaches was considered the best for various reasons. As a result, an admixture of both is used, keeping in mind the need for presenting the information in an order that permits full comprehension of the topic under discussion without prior detailed knowledge of some chapter yet to come. Furthermore, the order of presentation and the scope of each chapter have been chosen so as to avoid needless repetition. Finally, every effort has been made to keep the pace through the book interesting and to place lighter chapters between the more technical ones. In any

event, every chapter is essentially complete in itself; consequently, in addition to covering the field as a whole, the book serves as a useful reference when some particular subject is of immediate interest.

There is sometimes a regrettable tendency to consider the term "television" as applying only to the transmission and reproduction of picture signals. In fact, in keeping with common usage, the term is sometimes so used in this book. Actually, of course, the accompanying sound transmission is vitally important. Furthermore, the sound pickup problems in television are much more complex than those encountered in aural broadcasting and, consequently, the audio facilities are considerably more extensive and complex. However, to cover this subject completely it would be necessary to increase the size of this book materially. Since this was not considered desirable, the audio transmission system, which is an important part of a complete television system, is only briefly described herein. Reliance is thus placed largely upon the fund of audio engineering knowledge and experience gained through several decades of aural broadcasting.

Without the cooperation of the various organizations that made available photographs, schematic diagrams, and other material, this text would have been difficult to prepare. This opportunity is taken to acknowledge this assistance and again to thank the individuals and the organizations who were so helpful. These included the Bell Telephone Laboratories, the Allen B. Du Mont Laboratories, Inc., the Eastman Kodak Company, the General Electric Company, the General Precision Laboratories, the Gray Research and Development Company, the Radio Corporation of America, the various television stations and companies that are individually named, and my colleagues in the Columbia Broadcasting System.

HOWARD A. CHINN

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## CHAPTER I

# Television-system Fundamentals

A COMPLETE TELEVISION BROADCASTING SYSTEM consists of (*a*) a suitable environment for the production of the program material, (*b*) a picture- and a sound-transmitting system, (*c*) the medium through which the transmissions take place, and (*d*) a number of receiving installations. The television broadcasting engineer is concerned, to a greater or a lesser degree, with all these elements. His prime interest, however, is usually in the picture- and sound-transmitting system. Partially, this stems from the fact that government regulation determines channel assignments in the radio spectrum, transmitter power, antenna gain, and antenna height, and the laws of nature govern radio-wave propagation. Furthermore, there is relatively little the practicing broadcaster can do, after the signals leave the transmitting antenna, to ensure their proper reception.

The picture-transmitting portion of a television broadcasting system consists, essentially, of a television camera for converting optical images into electrical waves, amplifiers for increasing the amplitude of this electrical energy, synchronizing generators for producing the control pulses necessary to lock the receivers in step with the transmitter, control equipment for the monitoring and adjustment of the television signal, means for carrying the electrical replica of the optical image (together with the synchronizing pulses) from the point of origination to the transmitter, a radio transmitter for converting this electrical energy into radio-frequency energy, and, finally, an antenna system for radiating this radio-frequency energy into space.

The sound-broadcasting system requires a corresponding series of elements to convert the original sound energy into radio-frequency energy which is also broadcast into space. The usual practice is to employ coordinated, but entirely separate, systems up to and including the transmitters for the sound and the picture channels. A common antenna is generally used for both the sound and the picture transmitters although separate antennas have been employed for each transmitter. Figure 1-1 shows in

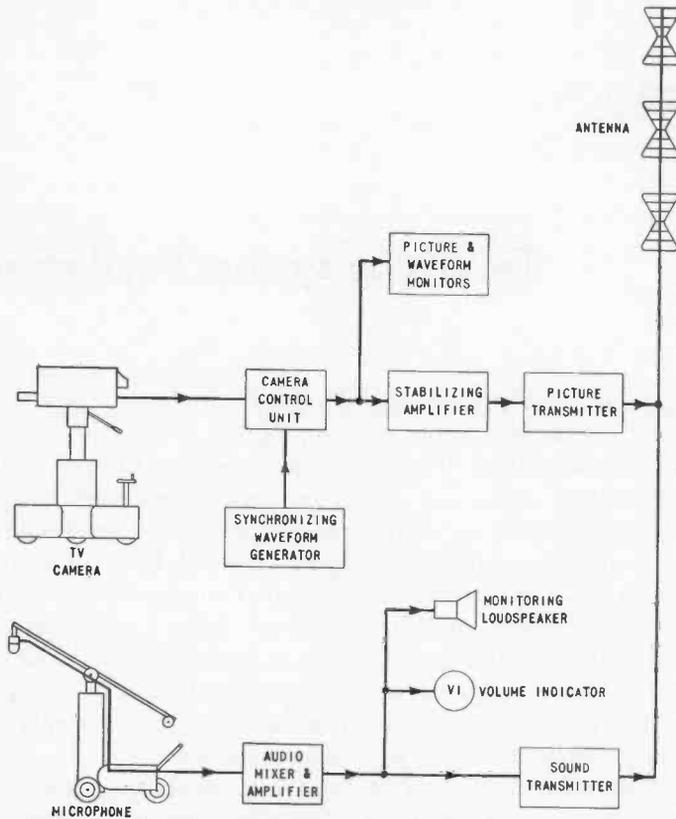


FIG. 1-1. The basic elements of a television transmitting system include means for generating, amplifying, monitoring, and radiating both picture and sound signals.

simplified block schematic form the major elements in a complete television transmitting system.

**1-1. Television-system Standards.** Television broadcasting, just as most other radio services, requires adherence to specified transmission standards. This is necessary to ensure that any standard television receiver within the service area of a television transmitter may satisfactorily reproduce its transmissions. The number and the complexity of transmission standards required for a practical television system are probably greater than those necessary for any other present-day public service radio application. A thorough knowledge of these standards is therefore a necessity for anyone responsible for or interested in the operation of television broadcasting equipment.

Some radio transmission systems require only a few standards to ensure

efficient use of available channels and to prevent interference between stations. Somewhat more complicated systems may, in addition, require standards to ensure a desired minimum fidelity of transmission. A television system, however, requires all these standards and many more since a television receiver designed for operation with a particular system is not likely to respond properly to transmissions adhering to other standards.

In addition to those factors which are the concern of all branches of the television industry and which have therefore been standardized by government regulation, there are others which have been adopted by the industry itself. These latter standards are of the type that concerns only the branch of the industry by which they were formulated. For example, many standards having to do with details of television broadcasting facilities need not concern the television-receiver engineer, and vice versa. The factors that are the mutual concern of all have been standardized by government regulation<sup>1</sup> and are summarized in the first part of Table 1-1. The principal industry-promulgated standards<sup>2</sup> pertaining to television broadcasting equipment are tabulated in the second part. In the following sections, the standards are described in detail and their significance discussed.<sup>3</sup>

**1-2. Scanning.** The standard method of scanning a television picture is from left to right and progressively from top to bottom in lines that are essentially horizontal. The scanning spot moves with a constant velocity both horizontally and vertically (although the velocities are not alike) during the picture-transmission portions of the scanning process. This method of scanning is known as unidirectional linear scanning and has a number of advantages over other possible methods, e.g., bidirectional, sinusoidal, velocity, or spiral. These advantages include an even distribution of detail, full use of the video bandwidth, and reasonable tolerances in the performance of the synchronizing system.

At the end of each line, the scanning beam is blanked out and is moved back, relatively rapidly, to the starting point of the next line. The time occupied in doing this is known as the flyback or retrace period. Similarly, at the end of each field, the beam moves rapidly from the bottom back to the top of the picture. The linear velocity of the spot during horizontal and during vertical retrace is not necessarily uniform. Although

<sup>1</sup> Federal Communications Commission, "Standards of Good Engineering Practice concerning Television Broadcasting Stations," effective Dec. 19, 1945, as amended Oct. 10, 1950, U.S. Government Printing Office, Washington, D.C.

<sup>2</sup> RTMA Standards Proposal No. 378, "Electrical Performance Standards for Television Studio Facilities," Radio-Television Manufacturers Association, New York.

<sup>3</sup> Roe, John H., *The Philosophy of Our TV System*, *Broadcast News*, Vols. 53, 54, and 55, pp. 73, 37, and 63, respectively (February, April, and June, 1949).

TABLE 1-1. PRINCIPAL U.S. TELEVISION SYSTEM STANDARDS

(Except as noted, the following apply to monochrome and color transmissions)

1. Government (Federal Communications Commission) Standards	
a. Scanning lines per frame.....	525 *
b. Scanning lines in picture area.....	483-499 *
c. Scanning directions .....	Left to right, top to bottom
d. Line interlace .....	2-to-1
e. Frame frequency .....	30 per second *
f. Field frequency .....	60 per second *
g. Picture aspect ratio.....	Horizontally: 4 units; vertically: 3 units
h. Composite waveform .....	See Fig. I †
i. Frequency spectrum assignment.....	54-216 Mc and 470-890 Mc
j. Channel width (picture and sound).....	6 Mc
k. Picture-to-sound carrier separation.....	4.5 Mc
l. Picture-carrier modulation .....	Amplitude modulation
m. Maximum picture-modulation frequency.....	Nominally 4 Mc (see Fig. II †)
n. Polarity of transmission.....	Negative (see text)
o. Polarization of transmission.....	Horizontal
p. Sound carrier modulation.....	Frequency modulation
q. Carrier swing for 100 per cent modulation.....	$\pm 25$ kc
2. Industry (Radio-Television Manufacturers Association) Standards	
a. Video signal polarity (at equipment terminals)...	Black-negative
b. Video signal amplitude (at equipment terminals)	1 volt, peak-to-peak
c. Video amplifier load impedance.....	75 ohms
d. Video circuit balance.....	One side grounded
e. Synchronizing pulse durations.....	See Table 1-2

\* Monochrome only (for color standards see Table 17-1).

† In Federal Communications Commission, "Standards of Good Engineering Practice Concerning Television Broadcasting Stations," effective Dec. 19, 1945, as amended Oct. 10, 1950, U.S. Government Printing Office, Washington, D.C.

the retrace time between successive lines is not available for picture transmission (as it would be in a bidirectional scanning system), good use is made of this interval for the transmission of horizontal synchronizing signals.

There are, of course, a large number of factors that enter into the choice of the number of scanning lines in a television frame.<sup>4</sup> The most important of these is the necessity of having enough lines to provide the requisite

<sup>4</sup> Kell, R. D., A. V. Bedford, and G. L. Fredendall, A Determination of Optimum Number of Lines in a Television System, *RCA Rev.*, Vol. V, No. 1, p. 8 (July, 1940).



is a whole number plus one half line. In a system of this type, the use of uniform vertical scanning periods and constant vertical scanning amplitude results in consecutive fields which are displaced in space with respect to each other by one-half a line, as illustrated in Fig. 1-2. In the standard 525-line monochrome television system, each group or field of scanned lines consists of  $262\frac{1}{2}$  lines. Two consecutive fields constitute a frame or a complete picture of 525 lines.

Even-line interlacing (total number of lines an even integer), although possible, is not employed for practical reasons. With even-line interlacing it is necessary that alternate fields be displaced vertically one half line with respect to each other. This requires the addition of a special component, having a repetition rate equal to one-half the field frequency, to the vertical scanning saw-tooth waveform. This frame-frequency component requires a degree of accuracy that is impractical either to attain or to maintain. Consequently even-line interlacing is not used for standard television transmission systems.

**1-4. Frame and Field Frequencies.** The bandwidth required to transmit a television picture depends upon a number of factors including the frame-repetition frequency. The minimum acceptable frame frequency is that required for the elimination of flicker. In addition, the frame frequency must be sufficiently high to avoid jerkiness or smearing, or both, when there is rapid motion in the picture subject.

Furthermore, the threshold of flicker increases as the brightness increases. The persistence of vision varies in different people, and those whose persistence characteristic is very short are the most susceptible to flicker as the brightness increases.

Still another important factor affecting flicker is the retentivity of the screen material in the picture tube. By using long-persistence screens, the flicker effect may be greatly reduced, but the smear becomes objectionable in moving objects because of the luminescence retained during the scanning of subsequent frames.

In addition to flicker considerations, the choice of frame and field frequencies is influenced by the frequency of the power systems from which the equipment is operated. Synchronization with the power-supply frequency minimizes the effects of hum and simplifies the problem of synchronizing the rotating machinery of film projectors and other devices in the television broadcasting station.

Taking into consideration these and others factors, the monochrome field frequency was standardized at 60 per second. In a 2-to-1 interlaced system, this automatically sets the frame rate (or number of complete pictures) at 30 per second. Since there are  $262\frac{1}{2}$  lines in a field, the horizontal scanning frequency is  $60 \times 262\frac{1}{2}$ , or 15,750 cps.

**1-5. Blanking.** In order to ensure extinction of the scanning beam of a picture tube during the retrace intervals, blanking pulses of suitable shape and duration are used. Two kinds of blanking pulses are required: one for the horizontal retrace intervals and the other for the vertical retrace interval. Basically, the blanking pulses are rectangular in shape and of sufficient amplitude and proper polarity to completely cut off the scanning beam of the picture tube. The duration of the blanking pulse is slightly longer than the time necessary for retrace in order to trim up the edges of the picture and eliminate any ragged edges.

Blanking pulses are also applied to the scanning beam in the camera tube. However, these pulses do not appear directly in the final signal radiated to the receiver. Their purpose is to turn off the camera-tube scanning beam during retrace time, to eliminate spurious signals, and, in the image orthicon, to establish a signal that bears a definite relation to reference black. Camera-tube blanking pulses are somewhat narrower than the corresponding picture-tube blanking pulses that are integral parts of the signal radiated to the receiver.

**1-6. Basic Picture Signal.** The general appearance of the basic camera signal is shown in Fig. 1-3a; parts of only two horizontal scanning periods are illustrated. If the signal shown is assumed to be that at the terminals of a video amplifier, then, in accordance with established standards, black signals, corresponding to black portions of the picture, are in the negative direction and white in a positive direction. The waveforms either side of the center of this illustration represent the picture signal for the end of one scanning line and the beginning of a second one. In between the waveforms corresponding to the picture signal, there is a spurious signal, generated during the retrace period, which does not contain any valuable picture information. Horizontal blanking pulses, as described in the preceding section, are therefore added to the basic picture signal in order to eliminate the spurious signals during retrace time and to blank out retrace lines on the picture tube.

The shape of the synthetically generated horizontal blanking pulses is shown in Fig. 1-3b. These signals are usually produced in the synchronizing generator from the same basic timing circuits that generate the scanning signals. Under these circumstances, they are accurately synchronized with the retrace periods. Upon combining the horizontal blanking pulse with the picture signal, the result shown in Fig. 1-3c is obtained. The spurious signal is now riding on top of the blanking pulse and can be clipped off, leaving the combined picture plus blanking signal shown in Fig. 1-3d. The horizontal blanking signal is a small fraction of a line in duration (approximately 18 per cent) and recurs at the end of each horizontal line, or at the rate of 15,750 cps.

At the end of each field, a vertical blanking pulse is applied in place of the horizontal pulses. Basically, the vertical blanking pulse is similar to the horizontal pulse. It is, however, very much longer in duration (between 13 and 21 scanning lines long) during which time the vertical retrace takes place. The vertical blanking pulses recur at the field-frequency rate, or at 60 cps.

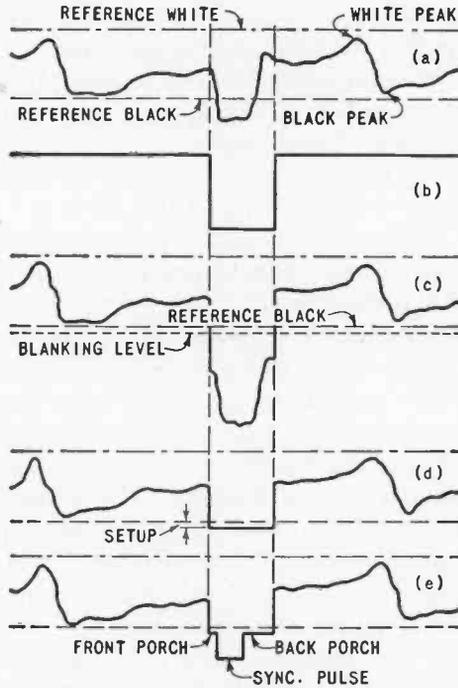


FIG. 1-3. The synthesis of a composite video signal starts with the camera signal (a), to which is added a blanking signal (b), which is clipped at the blanking level (c), to form a picture plus blanking signal (d), to which is added a horizontal synchronizing pulse to form a composite video signal (e).

The time required for the vertical retrace results in from 13 to 21 scanning lines being unavailable for the transmission of picture information in each *field* (the range being accounted for by the tolerance that is allowed in vertical blanking-pulse formation) or a total of 26 to 42 lines per *frame*. Thus it is evident that the actual television picture contains between 483 and 499 lines, say 490 lines as a round average number.

The next step in forming the complete composite picture signal is the addition of the synchronizing pulses which are required for triggering the horizontal and the vertical scanning circuits associated with the picture

tube. Like the blanking pulses, the synchronizing pulses are essentially rectangular in shape. They are, however, of shorter duration (8 per cent of a horizontal line) and are located on the "back" or top of the blanking pulses. The addition of a horizontal synchronizing pulse to the blanking signal is shown in Fig. 1-3e. Were this illustration inverted, *i.e.*, if it had been drawn to show negative-going signals in an upward direction, the concept of the synchronizing pulse riding on the back of the blanking pulse would, perhaps, be more obvious.

Since the direction and amplitude of the blanking pulses are such as to cut off the scanning beam, it is evident that the synchronizing pulse, which is of the same polarity but even greater relative amplitude, will also maintain cutoff of the scanning beam. The repetition rate of the horizontal synchronizing pulses is the same as that of the horizontal blanking pulses or the scanning-line rate of 15,750 cps.

The vertical synchronizing pulse which must be added to the basic picture signal is fundamentally similar in nature to the horizontal synchronizing pulse except as to time of duration (three horizontal lines) and repetition rate (60 cps). However, as detailed in following sections, the actual shape of the vertical synchronizing pulse used in practice is rather complicated.

The complete, composite video signal, then, consists of the basic picture signal plus horizontal and vertical blanking pulses plus horizontal and vertical synchronizing signals.

**1-7. Composite Video Signal.** The transmission of a composite video signal, constituted in accordance with existing standards, is one of the most important responsibilities of the television broadcaster. Unless this is done, conventional television receivers will not be able to receive a satisfactory picture and, of course, any nonstandard transmission would be contrary to government regulations. For this reason, a thorough knowledge of all details of the standard composite signal waveform is essential.

The standard composite waveforms as proposed<sup>5</sup> for television studio equipment are shown in Fig. 1-4. These waveforms pertain to the picture line amplifier output and, therefore, are video waveforms. They correspond exactly to the FCC (Federal Communications Commission) standards pertaining to the over-all transmission system except, where advisable, the tolerances are tighter in order to provide some leeway for possible modification by the transmitter.

Figure 1-4a shows, at the left, the waveforms of the last four scanning lines of a particular field, complete with horizontal blanking and synchronizing pulses (the "black" or negative video signal direction is shown

<sup>5</sup> RTMA Standards Proposal No. 378, "Electrical Performance Standards for Television Studio Facilities," Radio-Television Manufacturers Association, New York.



downward). The point at which the bottom of the frame is reached is indicated in the illustration, and to the right of this point the vertical blanking and synchronizing pulse occurs. Finally, by the time the right end of the illustration has been reached, the electron beam has been deflected to the top of the picture, and the first three scanning lines of the next field are shown.

Before exploring in greater detail the characteristics of the standard composite waveform, the series of pulses shown in Fig. 1-4*b* warrant review. This illustration shows, at the left end, the last  $3\frac{1}{2}$  scanning lines of the field that was started at the right end of Fig. 1-4*a*, the remainder of the illustration developing as for the one immediately above. Although similar, these two waveforms differ from each other in an important detail. In the first illustration (*a*), the bottom of the field was reached at the end of a complete horizontal scanning line. In (*b*), however, the last scan shown is only one-half a full line in length and is so labeled ( $0.5H$ ). Furthermore, the first scan at the right end of this waveform is only one-half a scanning line in length. As already discussed and illustrated by Fig. 1-2, these are necessary conditions for odd-line interlaced scanning.

**1-8. Blanking Pulses.** The duration of a typical horizontal scanning line is labeled  $H$  in Fig. 1-4*a* and is actually  $1/15,750$  second or 63.5 microseconds in duration. The duration of that portion of the scanning line that contains useful picture information is labeled "Picture." This is shorter than  $H$  by the time occupied by the horizontal blanking pulse, as illustrated.

In Fig. 1-4*a* the interval from the "bottom of picture" to "top of picture" is shown occupied by the vertical blanking pulse. Because of the many special pulses that are riding on top (downward, because of the negative-downward convention used for these illustrations) of the vertical blanking pulse, its existence as a blanking pulse is almost obscured. Note, however, that for the entire interval marked "Vertical Blanking Pulse" the amplitude of the signal (in the positive direction) never exceeds that of the blanking (or scanning beam extinction) level. All added pulses extend into the more negative or the "blacker-than-black" region.

**Horizontal Blanking Pulses.** Details of the horizontal blanking pulse and of the composite video waveform are shown in Fig. 1-4*c*. This illustration is an expanded view of the waveform between points A-A in Fig. 1-4*b*. The reference white level is defined by the upper dotted line. This is the level above which white signal peaks should not normally extend. The reference black level, or other picture signal extreme, is defined by the lower dotted line. All picture waveforms should normally be within these limits.

The duration of the horizontal blanking pulse must be sufficient to

blank out the horizontal retrace even in an inefficient receiver. Thus the circuit limitation in such receivers determines the minimum width of the horizontal blanking pulse in the standard waveform. This minimum, detailed in Fig. 1-4e as the sum of two dimensions ( $0.025H + 0.14H$ ) is  $0.165H$  or 16.5 per cent of the horizontal period  $H$ . The impossibility of producing infinitely steep sides on the pulse is recognized by the greater maximum width permitted at the base of the pulse. This value is  $0.18H$  or 18 per cent of the horizontal period. In absolute units, this amounts to  $0.18 \times 63.5 = 11.4$  microseconds. The duration of the picture-carrying portion of a complete line is, therefore,  $63.5 - 11.4$  or essentially 53 microseconds.

Because of the difficulty, in practice, of determining the width of a pulse at its exact top or bottom (because of distortion of the corners), measurements of pulse widths are made at the 0.1 and 0.9 amplitude points, as shown in Fig. 1-4e.

**Vertical Blanking Pulses.** The duration of the vertical blanking pulse is not limited by receiver circuit limitations as is the width of the horizontal blanking pulse. Here, the limiting factors are the requirements of the method often employed for projecting film for television broadcasting purposes, as described in Sec. 9-6. With these considerations in mind, the duration of vertical blanking pulses has been standardized as  $0.05V$  with a tolerance of plus 0.03V and minus 0, *i.e.*,  $0.05V$  to  $0.08V$ , where  $V$  is the duration of one complete field. In absolute units this amounts to 0.8 to 1.3 milliseconds since  $V$  is equal to  $\frac{1}{60}$  second or 16.6 milliseconds.

Within the confines of the vertical blanking pulse, there are additional series of pulses. Two of these intervals contain so-called equalizing pulses. Another interval is devoted to the vertical synchronizing pulse which, unlike the simple rectangular horizontal synchronizing pulse, contains six slots or serrations which are necessary to maintain continuity of horizontal synchronization during the vertical blanking interval. Finally, the remainder of the vertical blanking pulse carries regular horizontal synchronizing pulses. The special pulses included within the vertical blanking-pulse interval are described in detail in following sections.

**1-9. Synchronizing Pulses.** The horizontal and the vertical scanning circuits in a television receiver are completely independent systems, both of which require accurate synchronizing pulses to keep them in step with the corresponding scanning systems in the television pickup camera. The synchronizing pulses, which are rather short in duration, may, therefore, be added to the picture signal to increase the *peak* amplitude of the composite signal without greatly increasing the *average* power level of the transmitted signal. Amplitude discrimination methods can then be used to separate the synchronizing information from the composite signal.

It is necessary, however, to distinguish between horizontal and vertical synchronizing pulses. A second increase in amplitude could be used to do this but this is undesirable since it would still further raise the peak-amplitude requirement of all equipment involved. The synchronizing system that has been adopted as standard, therefore, utilizes horizontal and vertical pulses of equal amplitude but of different duration. Frequency discrimination is then used to separate them in picture-tube scanning circuits.

All synchronizing pulses appear below the blanking level which, in turn, is below the black level by the amount of setup in use (see Sec. 1-13, below). Being in the region that is sometimes called "blacker-than-black," the synchronizing pulses have no effect on the display on the face of the picture tube.

**Horizontal Synchronizing Pulses.** Horizontal synchronizing pulses, except during a portion of the vertical blanking interval, are rectangular pulses that ride on top of the blanking pulses. Their purpose is to stabilize the horizontal-frequency saw-tooth generators and maintain them in step with those at the picture-originating point. In Fig. 1-4, because of the negative-downward convention, the synchronizing pulses extend down from the inverted tops of the blanking pulses. The general shape of the standard horizontal synchronizing pulse is shown in Fig. 1-4c. The duration of this pulse is less than that of the blanking pulse, and the leading edge of the synchronizing pulse is delayed with respect to the leading edge of the blanking pulse upon which it rides. This forms a step in the composite pulse which is called a "front porch" (see also Fig. 1-3e). Similarly, the step formed by the difference between the trailing edges of the synchronizing and the blanking pulses is called a "back porch."

The purpose of the front porch is to ensure that the scanning beam of the picture tube is completely cut off before horizontal retrace begins. It also ensures that any discrepancies which may exist in the leading edge of the blanking pulse will not affect either the timing or the amplitude of the synchronizing pulse.

It is important to recognize that, unless the front porch of each synchronizing generator is kept within specified tolerances, there will be undesirable lateral shifts of the visible raster on the picture tube as video signals from sources employing different synchronizing generators are displayed. This stems from the fact that, regardless of the size of the front and back porches, the timing of the saw-tooth scanning generators, and hence the instantaneous position of the scanning spot, bears a constant relation to the horizontal synchronizing pulse. If the front porch is smaller than normal, the return trace will be initiated closer to the visible end of a horizontal line than normally, as illustrated in Fig. 1-5. Further, if all other

characteristics of the composite signal were standard, a smaller-than-normal front porch would be accompanied by a larger-than-normal back porch. Thus the horizontal scan would be unblanked farther from the beginning of the scan (left side of raster) than normal. Both of these conditions result in a shift of the picture or visible raster to the right. In the reverse situation, when the front porch is overly long and the back porch too short, the raster will be shifted to the left. If the picture tube is masked or framed, which is almost always the case, then part of the picture becomes hidden behind one edge or the other of the mask.

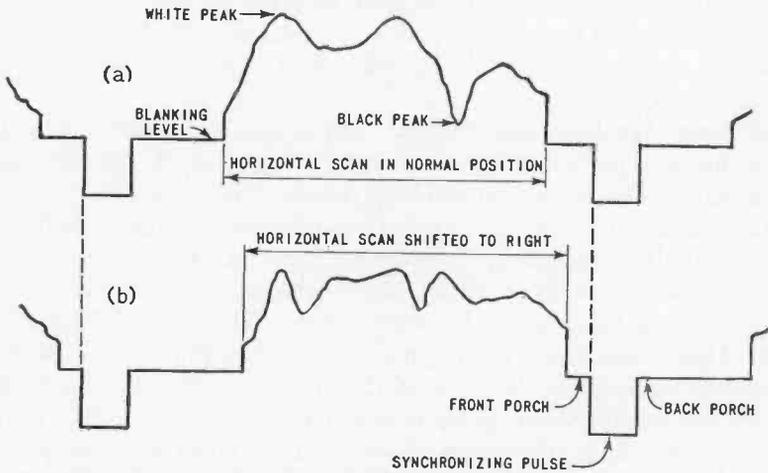


FIG. 1-5. A change in the length of the front porch, and hence the position of the synchronizing pulse, causes a lateral shift of the visible portion of a raster since the horizontal synchronizing pulse is usually employed to trigger the associated horizontal scanning generator.

Section C-C of Fig. 1-4c is detailed in part (e) of the illustration. This shows the exact dimensions of the horizontal synchronizing (and blanking) pulses. A nominal width of  $0.08H$  (8 per cent of the horizontal scanning period) has been chosen as standard for the horizontal synchronizing pulse. Four factors influenced this choice: First, the width should be as great as possible so that the energy content of the pulses will be large compared to the worse type of noise that may be encountered in the transmission system, thus providing a maximum immunity to noise. Second, the width should not be greater than is necessary to meet the first condition, in order to minimize average power requirements of the transmitter. Modulation of the picture transmitter is such that synchronizing pulses represent maximum carrier power (see Sec. 1-17); hence it is desirable to keep the duty cycle as small as possible. Third, the horizontal

synchronizing pulses should be kept as narrow as possible so as to maintain a large difference between these pulses and the segments of the vertical synchronizing pulses described in the following section. A large difference makes it easier to separate the vertical synchronizing pulses from the composite signal. Fourth, the back porch is useful for one type of clamping action for d-c restoration (see Sec. 1-15) and, to facilitate this application, should be as wide as possible.

**Vertical Synchronizing Pulses.** Fundamentally, the vertical synchronizing pulses are rectangular in shape and of the same amplitude as horizontal synchronizing pulses. The vertical pulses, however, are of much longer duration ( $3H$  vs.  $0.08H$ ), and it is this feature that makes it possible to separate vertical and horizontal synchronizing pulses by means of relatively simple circuits. However, each vertical pulse is complicated by the presence of six slots cut into it. These give it the appearance of a series of six pulses occurring at twice the horizontal scanning frequency, as shown by Figs. 1-4a and 1-4b. Compared to the equalizing pulses (see Sec. 1-10) or the horizontal synchronizing pulses, the six pulses appear relatively wide. The slots in these pulses are employed to provide uninterrupted information to the horizontal scanning circuits; they contribute nothing to the value of the vertical synchronizing pulse. It is the trailing edge (downward stroke) of the slots in the vertical pulses that triggers the horizontal scanning oscillators. Note, however, that for a given field only every other slot is effective; *i.e.*, every other slot is used for odd-field synchronizing and the alternate one for even fields.

The section between *B-B* in Fig. 1-4b is shown in detail in (*d*) of the figure. Here it is seen that the nominal dimension of the slot is  $0.07H$  or 7 per cent of the horizontal scanning period. This results in a nominal width of *each* of the six pulses appearing within the vertical synchronizing-pulse interval of about  $0.43H$  (43 per cent) or almost six times the width of the horizontal synchronizing pulse. The maximum permissible slope to the sides of the pulses is  $0.003H$ .

The nominal width of the slots in the vertical synchronizing pulses is almost equal to the width of the horizontal synchronizing pulses, *i.e.*, 7 vs. 8 per cent of the horizontal scanning period. The slots are made as wide as possible so that noise pulses or other discrepancies occurring just prior to the leading edge of a slot (*i.e.*, near the end of the preceding segment of a vertical pulse) do not trigger the horizontal oscillator. Premature triggering can take place if the noise pulse is high enough and if it occurs very close in time to the normal triggering time. Increased time separation (a wider slot) reduces the likelihood of such premature action. Here again, the requirements of special clamping also are met more easily if the slots are made as wide as possible.

**1-10. Equalizing Pulses.** Before and after each vertical synchronizing pulse there are groups of six narrow equalizing pulses (Fig. 1-4a) that serve two purposes: First, like the slots in the vertical blanking pulse, they serve to maintain a continuous flow of synchronizing information to the horizontal scanning circuit. Second, they perform the very vital function of providing means for obtaining correct interlacing by equalizing the difference in the spacing in odd and even fields between the last horizontal synchronizing pulse and the beginning of the vertical blanking pulse.

Like the slots in the vertical synchronizing pulses, the repetition frequency of the equalizing pulses is twice the frequency of the horizontal synchronizing pulses. This doubling of the frequency is necessary to accomplish the two purposes for which the equalizing pulses are intended. By choice of the proper series of alternate pulses, the desired continuity of horizontal synchronizing intelligence is maintained. Examination of Fig. 1-4a will show that the first, third, and fifth equalizing pulses are used for the fields that end in complete scanning lines. On the other hand, as shown by Fig. 1-4b, the second, fourth, and sixth equalizing pulses are used for fields that end in one-half length scanning lines (see Fig. 1-2). In either case, it is the leading edge (downward stroke) of each equalizing pulse that triggers the horizontal scanning circuits; therefore, the  $H$  and  $H/2$  intervals apply to these edges.

Perhaps the most difficult problem in synchronizing, and the one in which there is the largest number of failures, is that of maintaining accurate interlacing. Discrepancies in either timing or amplitude of the vertical scanning of alternate fields will cause displacement, in space, of the interlaced field. The result is nonuniform spacing of the scanning lines which reduces the vertical resolution and makes the line structure of the picture visible at normal viewing distance. The effect is usually called "pairing" of the scanning lines. The maximum allowable error in scanning-line spacing on the picture tube, while avoiding the appearance of pairing, is probably 10 per cent or less. This means that the allowable error in timing of the vertical scanning is less than 1 part in 5,000.

The presence of any 30-cps component in the vertical scanning signal will impair the accuracy of the interlace. This occurs because alternate fields are presented at a 30-cps rate, and a spurious signal of this frequency would affect the odd fields with respect to the even (or vice versa). Unfortunately, the *horizontal* synchronizing signal has an inherent 30-cps component. This stems from the fact that the odd and even fields are not identical but are displaced from each other by one-half of a scanning line. This means that the synchronizing waveforms for successive fields differ from each other in certain details. Since alternate fields occur at a 30-cps rate, the fundamental frequency of the modifying com-

ponent is of this period. It is necessary, therefore, to take precautions to prevent the transfer of any of this 30-cps component from the *horizontal* synchronizing signals into the *vertical*-deflection circuits. This is accomplished with the aid of the double-frequency equalizing pulses, as explained below.

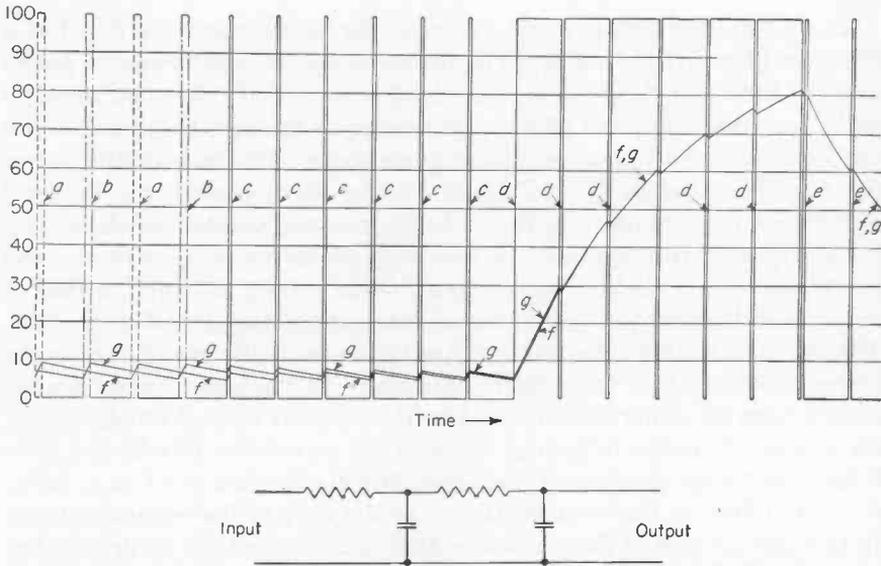


FIG. 1-6. The output signals (*f* and *g*) resulting from integration of the synchronizing waveforms are identical in the vicinity of the vertical synchronizing pulse for fields ending in either half (*b*) or whole (*a*) lines by virtue of the presence of equalizing pulses.

The vertical synchronizing pulses are separated from the composite video signal by discriminating against the horizontal synchronizing pulses with an integrating network similar to that shown in Fig. 1-6. In practice three-stage integrating networks are often employed in place of the two-stage illustrated. The composite video signal is applied to the input of the network. The output, as will be shown, contains a signal that is related only to the vertical synchronizing pulse. It is used to control the vertical sweep oscillator.

The action of the equalizing pulses that precede the vertical synchronizing pulse is such as to make the integrating network “forget” that there is a difference in the synchronizing and blanking waveforms of successive fields. These differences are clearly evident by comparing Figs. 1-4*a* and 1-4*b*, particularly in the regions immediately before the point marked “bottom of picture” and immediately after the “top of picture” point.

In Fig. 1-6 the waveform consisting of pulses *a*, *c*, *d*, and *e* correspond,

respectively, to the horizontal synchronizing (*a*), the equalizing (*c*), the serrated vertical synchronizing (*d*), and the second group of equalizing pulses (*e*) shown in Fig. 1-4*a* except that for the purposes of this illustration they are inverted (negative, upward). Similarly, pulses *b*, *c*, *d*, and *e* correspond to the waveform of the following field, as shown in Fig. 1-4*b*.

The integrating action of one section of the circuit shown in Fig. 1-6 is illustrated by curves *f* and *g*. The former is for the *acde* series of pulses and the latter for the *bcde* series. At first (left end), the two curves *f* and *g* are completely out of step. However, as the equalizing pulses are encountered, the two curves gradually converge. By the time the last of the equalizing pulses (*c*) of the first group have passed, the curves *f* and *g* have come almost together. As the serrated vertical synchronizing pulse (*d*) itself is integrated, the two original curves merge into one and rise together in a slightly jagged form. This action, however, is that of only one of the two (and often three) integrating stages used in practice. The effect of further integration not only results in the two curves being merged into one but, in addition, practically all the irregularities are removed from the rising pulse formed by the serrated vertical synchronizing waveform. Thus the difference between the waveforms of odd and even fields (the 30-cps component) has been effectively eliminated in so far as it has an effect on the accurate timing of the start of the vertical retrace. In this manner one of the conditions that must be met for accurate interlace is fulfilled.

Details of the equalizing pulses are shown in Fig. 1-4*d* which is an enlargement of section *B-B* in Fig. 1-4*b*. The width of the standard equalizing pulse is  $0.04H$  or 4 per cent of the horizontal scanning period. This is just half the width of the horizontal synchronizing pulses. This width is chosen so as to avoid any shift of the a-c axis when the transition takes place, at the bottom of the picture, from horizontal synchronizing pulses at scanning-line frequency to equalizing pulses at double scanning-line frequency. If the equalizing pulses were of the same width as the horizontal synchronizing pulses the a-c axis would shift upward and cause the integrated waveform in Fig. 1-6 to begin to rise before encountering the vertical synchronizing pulses. This could cause premature triggering of the vertical synchronizing circuits.

**1-11. Driving Pulses.** The processes just described for synchronizing scanning circuits are those employed in picture-tube monitors or in receivers where a composite waveform (the combination of picture-signal, blanking, and synchronizing pulses) is involved. At the pickup terminal of the television system, scanning must also be undertaken in the camera tubes. Here, however, since the television cameras and synchronizing

generator are relatively close to each other, there is no need for transmitting blanking together with horizontal and vertical synchronizing pulses over a single channel. Under these circumstances, it is usually practical to provide individual circuits for the transmission of each of the waveforms.

TABLE 1-2. DURATIONS OF SYNCHRONIZING WAVEFORMS—  
INDUSTRY (RTMA) STANDARDS \*

	<i>Relative</i> ( <i>H</i> = horizontal period; <i>V</i> = vertical period)		<i>Absolute</i> (microseconds)	
	<i>Min</i>	<i>Max</i>	<i>Min</i>	<i>Max</i>
Scanning times:				
Horizontal, <i>H</i> .....	.....	.....	63.5	
Vertical, <i>V</i> .....	.....	.....	16,667	
Blanking times: †				
Horizontal .....	0.165 <i>H</i>	0.18 <i>H</i>	10.5	11.4
Vertical .....	0.05 <i>V</i>	0.08 <i>V</i>	833	1,333
Synchronizing pulses: †				
Horizontal .....	0.07 <i>H</i>	0.08 <i>H</i>	4.4	5.1
Vertical .....	3 <i>H</i>	3 <i>H</i>	180	180
Vertical serrations .....	0.06 <i>H</i>	0.08 <i>H</i>	3.8	5.1
Front porch .....	0.025 <i>H</i>	.....	1.6	.....
Equalizing pulse † .....	.....	0.04 <i>H</i>	.....	2.5
Driving pulses:				
Horizontal .....	0.09 <i>H</i>	0.18 <i>H</i>	57.1	114.1
Vertical .....	0.025 <i>V</i>	0.08 <i>V</i>	416	1,335
Pulse rise time .....	.....	0.003 <i>H</i>	.....	0.19

\* See Table 17-2 for government (FCC) standards.

† At "base" of pulse, *i.e.*, 10 per cent amplitude point.

It is customary, therefore, to use what are called driven scanning circuits in cameras and, sometimes, in the picture monitors used with the cameras. Separate pulse signals, called driving signals, are produced in the synchronizing generator for exclusive use in the terminal equipment. The driving-signal pulses trigger directly the saw-tooth generators which produce the scanning waveforms. This method reduces interlacing errors in the terminal equipment to whatever small errors may be inherent in the driving signals. The horizontal and the vertical driving-pulse widths are usually shorter in duration than their respective blanking-pulse widths for reasons that will become evident (*e.g.*, see Sec. 2-3, *Horizontal-deflection Circuits*). Industry standards covering driving pulses, as detailed in

Fig. 5-1, specify that vertical and horizontal driving-pulse widths shall be adjustable from  $\frac{1}{2}$  to 1 times their respective blanking-pulse widths. Under these circumstances, vertical driving pulses may range from  $0.025V$  (one-half the minimum vertical blanking-pulse width) to  $0.08V$  (the maximum vertical blanking-pulse width) or from 416 to 1335 microseconds in duration. Horizontal blanking pulses, on the other hand, may range from  $0.09H$  to  $0.18H$ , or from 57 to 114 microseconds in duration.

A summary of the minimum and maximum durations of the synchronizing waveforms described in the preceding sections is presented in Table 1-2 in terms of both relative and absolute units.

**1-12. Television Signal Terminology.** In broadcasting operations it is frequently necessary to refer by name to specific portions of the composite television signal. Therefore, to avoid confusion or ambiguity, a standard terminology has been adopted to identify all significant portions of the composite waveform.<sup>6</sup> The six important amplitude levels of the television signal are illustrated in Fig. 1-7 which shows a picture signal for one horizontal scan together with two sets of associated horizontal synchronizing and blanking pulses. The terms designated in this illustration are defined as follows:

*Reference White Level.* The level at the point of observation corresponding to the specified maximum excursion of the picture signal in the white direction.

*White Peak.* The maximum excursion of the picture signal in the white direction at the time of observation.

*Black Peak.* The maximum excursion of the picture signal in the black direction at the time of observation.

*Reference Black Level.* The level at the point of observation corresponding to the specified maximum excursion of the picture signal in the black direction.

*Blanking Level.* The level of the signal during the blanking interval. It coincides with the level of the base of the synchronizing pulse.

*Synchronizing Level.* The level of the peaks of the synchronizing signal.

**Reference White.** The reference white level represents the maximum permissible signal amplitude in the white direction. Normally it corresponds to that level which ensures full use of the associated facilities without overloading, cross talk, or some other limiting factor becoming

<sup>6</sup> IRE Standard No. 50 IRE 23.S1, "Standards on Television," Institute of Radio Engineers, New York, 1950.

objectionably large. In almost every television program there is something that is white. Generally the white peaks corresponding to white objects are adjusted until they correspond to the reference white level.

**White Peak.** At any given instant, the maximum picture signal in the white direction will have some particular amplitude. This may or may not correspond to reference white, depending upon a number of factors. These include whether or not there is a truly white object in the particular scene televised at the moment and whether the gain of the video chan-

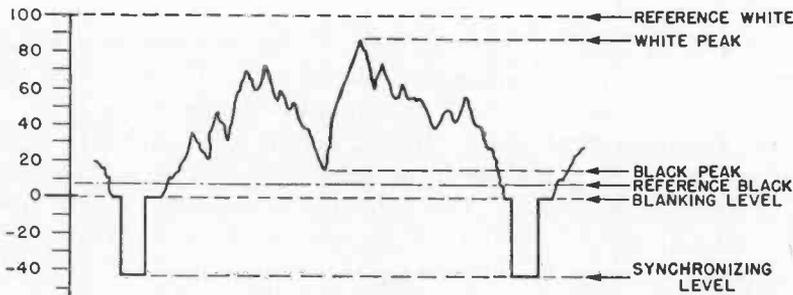


FIG. 1-7. The standard waveform monitor scale and the terminology used for measuring and identifying, respectively, the various portions of a composite picture signal.

nel is adjusted so as to bring such white peaks as do exist to the reference white level. In any event, the maximum signal amplitude in the white direction that exists at the moment of observation is known as the white peak level.

**Black Peak.** The blackest object in a television scene at any given moment produces a signal in the black direction whose amplitude is referred to as a black peak. The magnitude of the black peak at the instant of observation may or may not coincide with reference black depending on factors similar to those mentioned in the preceding paragraph. The darkest object in a particular scene may be gray rather than black, in which case the black peak would not correspond to reference black. Again, the maximum signal excursion in the black direction that exists at the moment the measurement is made is called the black peak level.

**Reference Black.** A signal level, known as reference black, is usually established below which, for several reasons, it is undesirable for black peaks to extend. Under normal conditions the black peaks corresponding to truly black objects are adjusted so as to come just to the reference black level. Any signal peaks that extend to lower levels may be subject to compression or clipping, depending upon the subsequent processing of

In Fig. 1-8a are shown the waveforms corresponding to three white lines, followed by three black lines, and the beginning of another white line. This signal, which contains a d-c component, is characterized by a constant level for the negative peaks of the synchronizing pulses. However, upon passing through an a-c coupled system (which eliminates the d-c component) the signal seeks to adjust itself in a consistent manner about an a-c axis as shown in Fig. 1-8b. The rate at which it succeeds in doing this is a function of the time constants of the circuit. In any event, the synchronizing peaks no longer fall at a constant level, nor do the signals corresponding to black level remain in the correct relation to those corresponding to white level.

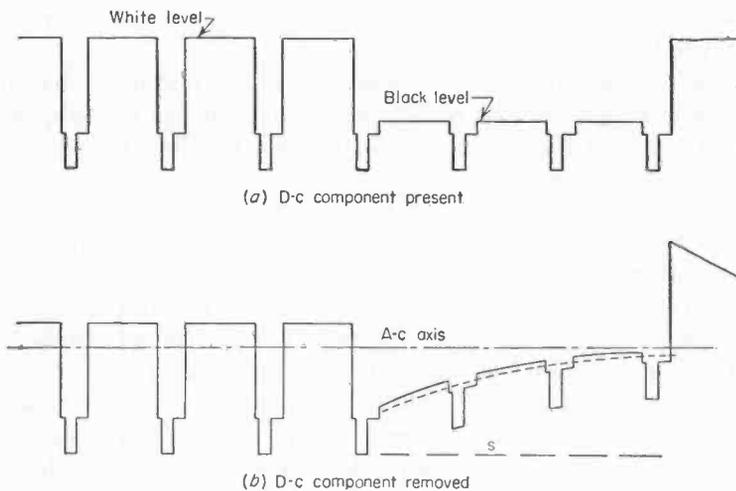


FIG. 1-8. When the d-c component is removed from the waveform shown at (a), the remaining signal seeks to align itself about the a-c axis as shown at (b). As a result, the pulses corresponding to black-level signals no longer bear the correct relation to the white-level pulses, nor do the negative peaks of the synchronizing pulses fall at a constant level.

The a-c axis of a wave is a straight line through the wave, positioned so that the area enclosed by the wave above the axis is equal to the area enclosed by the wave below the axis. The broken line marked "a-c axis" in Fig. 1-8b is actually the correct axis only for a wave composed of a long series of pulses like the first four at the left. During the transient condition following introduction of the black-level pulses, the line shown is not the true a-c axis but represents the operating point of the a-c coupled system. The true a-c axis of the short pulses (shown by the dotted line) gradually adjusts itself to coincide with the operating point of the system.

This adjustment is shown by the exponential rise of the signal which, in the example given, is interrupted before completion by the resumption of the white-level pulses. Thence a second transient condition takes place leading to a gradual restoration of the signal to the form shown at the left.

The departure of the synchronizing-pulse peaks from the original constant level is the result of losing the d-c component. It is to be noted that this loss causes an increase in the peak-to-peak amplitude of the signal, a condition which is undesirable, especially in high-level amplifiers and transmitters (see Sec. 13-9).

**D-c Insertion.** Any system of measurement must have a fixed standard reference unit or level. This rule applies, of course, to the problem of reproducing light intensities in a television system. The simplest reference for such a system is zero light, or black level as it is often called. This is a reference level which can be reproduced arbitrarily at any point in the system. Therefore, if the television signal can be synthesized in such a way that frequent short intervals have some fixed relationship to actual black in the scene, then it becomes possible to restore the d-c component by forcibly drawing the signal to a fixed arbitrary level during these intervals.

It now becomes apparent that an extremely important step in the synthesis of the television signal is that of making the peaks of the blanking pulses bear a fixed relationship to the actual black level in the scene. It was pointed out previously that the amplitude of these pulses is produced by clipping off unwanted portions of the signal, as illustrated in Figs. 1-3c and 1-3d. A second, and most important, function is performed when the clipping is controlled in such a way that the resulting peaks have the required fixed relationship to black level. This process of relating the blanking peaks to actual black level is called d-c insertion, or insertion of the d-c component.

**D-c Restoration.** Because the blanking or retrace periods are not useful for transmitting actual picture information, they offer convenient intervals for performing special control functions such as d-c restoration. If the peaks of the blanking pulses are coincident with black level or differ from black level by a constant amount, then d-c restoration can be accomplished simply by restoring these peaks to an arbitrary reference level. Thus, in Fig. 1-8b, if the peak of each pulse can be restored to the line *s*, then the signal will appear as in (*a*) and the d-c component will have been restored. The process of bringing these peaks back to an arbitrary reference level is called d-c restoration. D-c restoration must be accomplished at the input of the final reproducing device (*e.g.*, the picture tube) in order to reproduce the scene faithfully when a-c coupled amplifiers are used.

It is desirable to restore the d-c component at other points in the system also, because the process reduces the peak-to-peak excursions of the signal to a minimum by removing increases in amplitude caused by loss of the d-c component, as explained in Sec. 13-9. In a similar way, it is possible to remove switching surges, hum, and other spurious signal components which have been introduced after d-c insertion by pure addition to the signal. In professional applications, d-c restoration is usually accomplished by a process called clamping.

**1-15. Clampers.** In television receivers it has been the general practice to employ relatively simple circuits for d-c restoration. This is usually accomplished right at the grid of the picture tube. On the other hand, it is sometimes undertaken in the grid circuit of the video amplifier that drives the picture-tube grid. In any case, the arrangement employed restores what is essentially the tip of the synchronizing pulses to a common reference point. The time constants of the circuits used for this purpose must necessarily be such that the control voltage generated to achieve the desired results persists for at least the duration of one horizontal scanning line. In practice, however, it often lasts longer, perhaps for several lines, because of the simple circuit arrangements employed. Since the average brightness of the background illumination seldom changes very rapidly, this is a suitable arrangement. Nevertheless, small errors may result, corresponding to the displacements in level between successive pulses, but since the effect is not cumulative, the d-c restoration is sufficiently accurate for most television-receiver applications.

In professional television equipment, on the other hand, more elaborate circuit arrangements are desirable and justifiable. A so-called "clamping" circuit is, therefore, often employed for d-c restoration purposes. Although considerably more complicated than the simple d-c restoration circuits used in receivers, the clamping circuit offers several advantages: First, the d-c restoration or clamping is done on a line-to-line basis. No discrepancies can, therefore, result from even small changes in line-to-line background brightness variations. Second, the back porch of the composite signal can be used for the reference point. Because of its longer time duration and greater immunity to compression (should this be present in the system) the back porch is generally considered a better reference point than the tip of the synchronizing pulse. In general, then, a clamper is a pulse-operated device which functions during a portion of the blanking interval of the picture signal to set a signal reference level to some predetermined fixed value.

In order to clamp on a line-to-line basis, some means must be employed to establish the necessary value of control voltage immediately before the

beginning of each line, hold it for the duration of the line, and then discard it entirely and start afresh. This operation requires switching arrangements (electronic) since simple time-constant circuits, such as are used in television receivers for d-c restoration, cannot perform this relatively intricate operation.

The horizontal synchronizing signal makes ideal keying pulses for operation of the electronic switch. The horizontal synchronizing pulse occurs shortly after the end of each horizontal line. It is, therefore, often used to close an electronic switch which drains off the control voltage used for establishing the d-c reference level for the preceding scanning line. However, the electronic switch is permitted to open before the end of the blanking pulse. Consequently, the remainder of the blanking pulse, *i.e.*, the back porch, may be used to establish the operating point for the next scanning line (see also Sec. 6-7).

**1-16. Picture-carrier Modulation.** The choice of amplitude modulation for television picture transmitters was made after comparison of the results of amplitude- and frequency-modulated transmissions in actual field tests. The results indicated clearly that frequency modulation is not suitable for use in television broadcasting systems where multiple-path transmission can be encountered. Multipath transmission takes place when signals arrive at the receiving antenna from two or more directions. One of the signals is usually the direct signal from the transmitting to the receiving antenna. The others follow indirect paths along which the signals are reflected by objects which are off to the side of the direct path. Sometimes an object directly behind the transmitter or directly behind the receiver will reflect waves also.

In the amplitude-modulated case, a reflected signal which arrives after the direct signal produces a single ghost or repetition of the scene displaced to the right of the original scene. The amount of the displacement is a function of the extent of the delay of the reflected signal as compared to the direct signal. The intensity of the ghost depends upon the relative strength of the two signals. There can be as many ghosts as there are reflected signals.

In the frequency-modulated case, the delay of the reflected signal may be such that two distinct carrier frequencies arrive at the receiver simultaneously. Under these circumstances, the beat between the two frequencies appears in the picture in the form of a moiré or multiple-ghost pattern. The spacing of the moiré or the frequency of repetition of the ghosts is a function of the brightness contrast between adjacent areas in the scene. As a result, it changes constantly with every movement or change in scene. The most objectionable moiré is probably that pro-

duced by the blanking pulses because they usually represent the greatest possible black-to-white contrast ratio. Where multiple-path transmission is not present, as in point-to-point relaying systems using highly directive antennas, frequency modulation may be used with excellent results (see Secs. 3-9 and 12-8).

**1-17. Polarity of Transmission.** In this country, negative transmission is standard for the television picture carriers. "Negative" transmission means that the carrier is modulated so that an *increase* in picture brightness results in a *decrease* in carrier amplitude. Under these circumstances, the tips of the synchronizing pulses represent maximum carrier level, and the highlights in the picture correspond to minimum carrier amplitude. Among the advantages of negative transmission is the ability to make full use of the nonlinear transmitter modulation characteristic sometimes encountered at high modulation levels. Because the synchronizing pulses are rectangular in shape, any compression or saturation taking place during the modulation process only reduces their amplitude and does not otherwise materially affect their shape. Therefore, it is possible to compensate for any compression by simply preemphasizing the synchronizing pulses before modulation takes place. Thus the correct picture-to-synchronizing-pulse amplitudes are readily maintained. In a positive transmission system, on the other hand, where the highlights in the picture correspond to maximum carrier, any nonlinear region of the modulation characteristic cannot be used without white compression of the picture signal. Furthermore, a large portion of the low-percentage end of the modulation characteristic (which is usually completely linear) is used up by the synchronizing pulses.

Another advantage of negative transmission is that noise peaks result in black rather than white spots or streaks in the reproduced picture. Black "noise" is generally less objectionable than white "noise" particularly if the amplitude of the latter is so great as to produce blooming of the picture-tube scanning beam. In a sense, the picture tube acts as a noise limiter in a negative transmission system since the interference cannot become any "blacker" than black.

In the negative transmission system the average power rating of the transmitter, for a given peak power, can be less than for a positive transmission system. This results from the fact that the duty cycle of the synchronizing pulses is relatively small as compared to that of the average picture waveform. Consequently, the average transmitter power requirements are lower when the synchronizing pulses determine the maximum peak power needs (as in negative transmission) rather than the picture waveform (as in positive transmission). Negative transmission also offers several advantages in television-receiver design including relatively sim-

ple automatic-gain-control circuits<sup>8</sup> and the possibility of making use of an intercarrier sound-receiving system.<sup>9</sup>

**1-18. Polarization of Transmission.** The choice of the standard carrier-wave polarization was made as a result of both theoretical studies and field trials of both vertical and horizontal polarization for television transmission.<sup>10, 11</sup> These tests indicated predominantly stronger signals for horizontal polarization than for vertical. There was some evidence that vertical polarization was preferable within a short radius of the transmitter, but the proportion of the total service area over which this was true was very small.

Horizontal polarization also offers advantages in so far as multipath transmission is concerned. Both theoretical and experimental evidence shows that horizontally polarized waves are reflected less from the usual type of obstructions encountered in practice than are vertically polarized waves.

From the viewpoint of man-made noise signals, investigation showed that relatively few had appreciable horizontally polarized components. Accordingly, there is less tendency for horizontally polarized receiving antennas to pick up this type of noise signals. Furthermore, horizontal antennas are somewhat easier to build for both receiver and transmitter installations, particularly where directional arrays are required. Finally, the directivity of simple horizontal dipoles is, in itself, a substantial aid in reducing the pickup of interfering signals at a receiving location.

<sup>8</sup> Wendt, K. R., and A. C. Schroeder, Automatic Gain Controls for Television Receivers, *RCA Rev.*, Vol. XI, No. 3, p. 373 (September, 1948).

<sup>9</sup> Dome, R. B., Carrier-difference Reception of Television Sound, *Electronics*, Vol. 20, No. 1, p. 102 (January, 1947).

<sup>10</sup> Wickizer, G. S., Mobile Field Strength Recordings of 49.5, 83.5 and 142 Mc from Empire State Building, New York—Horizontal and Vertical Polarization, *RCA Rev.*, Vol. IV, No. 4, p. 387 (April, 1940).

<sup>11</sup> Brown, H., Vertical vs. Horizontal Polarization, *Electronics*, Vol. 13, No. 10, p. 20 (October, 1940).

## CHAPTER 2

# The Image Orthicon Camera

IN THE UNITED STATES the image orthicon tube (Fig. 2-1) is almost universally used in television field and studio cameras. It is sometimes employed in film camera chains also, but for this service iconoscopes are more often used, particularly when "stills" in the form of opaques or slides are being televised. The image orthicon camera is especially suitable for converting an optical image into a video signal where low light-intensity levels are encountered.

The image orthicon television camera usually consists of a lens turret, the image orthicon tube with its focusing and deflection coils; a video amplifier and sweep generating circuits; a view finder, generally electronic in nature; and the necessary controls and accessories. Associated with the television camera there is usually a camera-control unit, power supplies, and other auxiliaries. A knowledge of the operating principles of the image orthicon is essential for understanding the performance of the television camera. This subject is covered in this chapter, therefore, before proceeding in the next chapter to a description of the camera itself and its associated facilities.

**2-1. Image Orthicon Tube.** For purposes of analysis, the image orthicon<sup>1,2</sup> may be considered as being divided into three functional sections: (a) the image section, (b) the scanning section, and (c) the electron-multiplier section, as illustrated in Fig. 2-2. In the following paragraphs, the operation of each section and that of the tube as a whole are described.

**Image Section.** As the name implies, it is in the image section that the optical image of the scene to be televised is focused. The image section consists of (a) a semitransparent photocathode mounted immediately inside the optically flat face of the tube, (b) an electron accelerator grid (grid No. 6), and (c) a very thin glass target immediately in front of

<sup>1</sup> Janes, R. B., R. E. Johnson, and R. S. Moore, Development and Performance of Television Camera Tubes, *RCA Rev.*, Vol. X, No. 2, p. 191 (June, 1949).

<sup>2</sup> Janes, R. B., R. E. Johnson, and R. R. Handel, A New Image Orthicon, *RCA Rev.*, Vol. X, No. 4, p. 586 (December, 1949).

which is a very fine mesh wire screen. When an optical image is focused on the photocathode, the resulting electron emission varies in intensity with the luminous flux incident on the face of the photocathode. Since the light strikes the photocathode on one side and the electron emission is desired from the other side, it must necessarily be semitransparent.

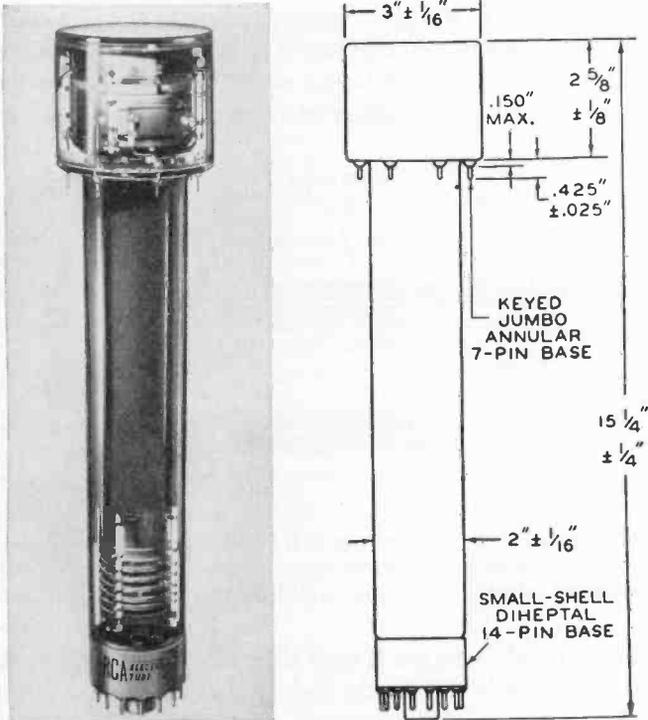


FIG. 2-1. The appearance and major dimensions of a commonly used image orthicon camera tube.

The photocathode is operated at a high negative potential with respect to the glass target, while the fine mesh screen is only slightly positive. The potential gradient between the photocathode and the glass target causes the electrons resulting from the photoemission to be accelerated toward the target with sufficient velocity to pass through the slightly positive target screen, strike the glass target, and cause secondary emission from the glass. The glass target is not photoelectrically sensitive; it is simply a uniformly flat insulating surface capable of emitting secondary electrons.

The target screen, being slightly positive with respect to the glass target, collects the secondary electrons and returns them to the ground or refer-

ence potential point. The electrons or negative charges having been removed, there remains a positive charge distributed over the face of the glass target which varies in accordance with the light intensity of the original optical image. However, since the ratio of secondary emission is greater than unity, the charge configuration on the glass target is several times as great as the original charge emitted by the photocathode. The charge is most positive in the areas corresponding to the picture highlights since it is here that the greatest number of electrons or positive charges are released. Furthermore, the insulating character of the glass target preserves or stores the charge configuration between successive scanings.

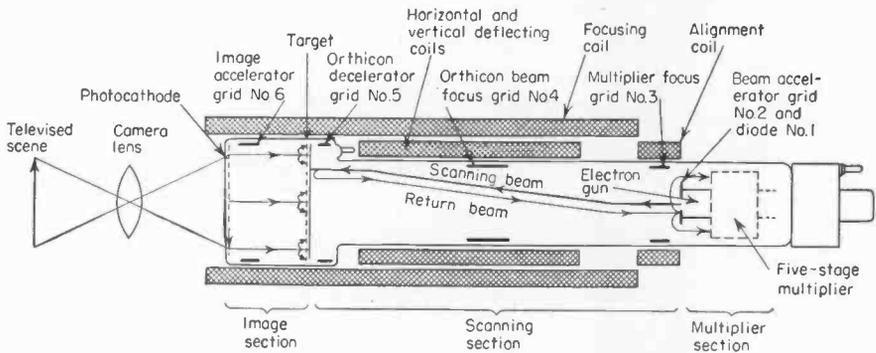


FIG. 2-2. The location of the camera lens (left) with respect to the photocathode of an image orthicon, the arrangement of the internal elements of the tube, and the position of the associated focusing, alignment, and deflection coils shown schematically.

However, since the glass target is very thin, the ratio of its transverse to longitudinal resistivity is sufficiently high so that the charge configuration on the front of the target is transmitted to the rear without appreciable loss of resolution.

The purpose of the target screen is to ensure that the secondary electrons will be collected rather than allowed to fall back on the target and produce spurious effects. It is to be noted that the potential of the target screen also determines the potential of the glass target, since, as soon as the glass target becomes much more positive than the target screen, the secondary electrons are subjected to a retarding field that prevents them from reaching the target screen. Therefore, for all values of light above a particular threshold, there is an upper limit to the potential that the glass target may reach.

In the image orthicon tube, the electron image formed by the photocathode is focused on the target by means of an electron lens system consisting of the electrostatic field set up by the ringlike accelerator grid

No. 6 and the axial electromagnetic field set up by the focusing coil. The latter is a simple random-wound solenoid long enough to enclose both the vertical- and the horizontal-deflection coils and the image section of the image orthicon tube, as shown in Fig. 2-2.

**Scanning Section.** The rear side of the glass target is scanned by a low-velocity electron beam produced by the electron gun in the scanning section. This gun contains a conventional thermionic cathode, a control grid (grid No. 1), and an accelerating grid (grid No. 2). The beam current is controlled by the potential of grid No. 1 and is accelerated toward the target at a velocity determined by the potential of grid No. 2. The beam is focused at the target by the electrostatic field of ringlike grid No. 4 and by the axial electromagnetic field created by the focusing coil. Alignment along the axis of the tube of the beam from the gun is accomplished by a transverse magnetic field from an external coil (the alignment coil, Fig. 2-2) located at the gun end of the tube.

The electronic beam decelerates as it approaches the target, and grid No. 5 serves to adjust the shape of the decelerating field to obtain uniform landing of the electrons over the entire target area. The potential applied to this grid determines the flatness of the orthicon focus field. If the target is at zero or negative potential at the point of landing, then the beam reverses and is accelerated back toward the gun end of the tube by virtue of the relatively high positive potentials that exist at this point. If, on the other hand, the target should have a positive charge at the point of landing, the beam will give up enough electrons to neutralize the charge before returning to the gun end of the tube. By this process the electron beam becomes amplitude-modulated in conformance with the charge configuration on the back of the glass target. In other words, the value of the current in the return beam at a given instant will depend upon the charge on the portion of the target being scanned at that time.

As explained in the preceding section, the charge on the target will be most positive in those areas corresponding to picture highlights. As a result, the electron beam will give up the maximum number of electrons in these areas. Consequently, the electron-beam modulation is such that minimum current in the returning beam corresponds to picture highlights and maximum current to picture shadows. The deposition of electrons on the target leaves the glass with a negative charge on the scanned side and a positive charge on the photocathode side. However, these charges neutralize each other by conductivity through the glass in less than the time of one television frame.

By causing the electron beam to systematically scan the entire surface of the target, the picture information becomes available in the modulated returning beam in a form suitable for television purposes. Scanning is

therefore produced by passing saw-tooth scanning currents through horizontal- and vertical-deflection coils (Fig. 2-2). These coils are located inside the focusing coil which creates the axial magnetic field throughout the scanning and the image section.

The section of a target that has just been scanned has no positive charge remaining (assuming proper beam-current adjustment), and consequently it is in the same condition as a section of the target that corresponds to black. This makes it essential that the scanning beam be prevented from striking the target during the sweep retrace times, since this would cause the charge pattern to be neutralized along the path of the retrace beam. This, in turn, would cause black lines to appear in the picture information when the neutralized portions of the target were scanned in the regular course of events. In order to prevent this action, it is necessary to make the target negative during retrace time so that the scanning beam will not reach it. This is accomplished by introducing negative blanking pulses on the target screen during horizontal and vertical retrace periods. These blanking pulses will, therefore, establish a black level in the modulated electron beam by preventing it from landing on the target during the retrace periods.

It is important that the influence of the magnetic scanning fields does not extend into the image section of the tube. Any scanning in the image section would result in loss of resolution in the picture because of displacement of the photoelectrons at scanning frequencies. To prevent loss of definition from this cause, it is necessary to shield the image section effectively from the stray magnetic fields of the deflecting coils. One method that has worked out well in practice is to wrap the outside of the external focusing coil with magnetic material such as silicon steel or mu metal. In order to avoid high absorption of the scanning power, the shielding material is usually in thin strips and wound in several layers separated by insulating material. For the same reason, the strips making up each layer are usually not very wide. The use of such a winding tends to pull the stray flux away from the photocathode and into the shielding material. Resolution gains of as much as 200 lines have been achieved by this method.

**Electron-multiplier Section.** The electron-multiplier section of the image orthicon tube consists of a multiplier-focus electrode grid No. 3 (Fig. 2-2), five multiplier dynodes, and a signal collecting plate. An electronic multiplier utilizes the phenomenon of secondary emission to amplify signals composed of electron beams. The purpose of signal multiplication in the image orthicon by secondary emission is to obtain a relatively noiseless multiplication of the small signal that modulates the return beam. In this way the signal may be increased to a level that is well above the

noise level of the first stage of the video amplifier; thus, amplifier noise need not be a limiting factor. The multiplier section amplifies the picture signal several hundredfold so that the limiting noise of the image orthicon tube is that resulting from the random noise of the electronic beam. The portion of the scanning beam that does not land on the target returns and strikes the accelerating grid No. 2 which also serves as the first dynode of the signal multiplier. However, the amount of deflection received in going to the target is not quite balanced by that received in returning; consequently, the return beam scans a small portion of the first dynode. This results in the formation of dynode spots (see Sec. 2-6).

The purpose of the cylindrical multiplier-focus grid No. 3 is to direct all the secondary electrons from the first stage to the second stage of the multiplier. Any failure to collect all the secondaries at the second dynode will lead to a picture that is darker in one section than in another. This condition, which is referred to as "shading," shows up most clearly when there is no signal caused by light. This shading signal differs from iconoscope shading (see Sec. 8-4, *Spurious Signal*) in that it is smaller than the picture signal and can usually be canceled by the insertion of a simple horizontal-frequency saw-tooth component in a following amplifier stage. Furthermore, it does not vary greatly with illumination, as does iconoscope shading, but depends almost entirely upon the beam current. As a result, the shading control requires little readjustment once it is set.

As the electrons strike the No. 2 dynode, there is further electron multiplication because of secondary emission. The multiplying process is repeated in each successive stage, with an ever-increasing stream of electrons. Finally, those emitted from the last dynode are collected by the anode and constitute the picture-signal current utilized in the output circuit. The maximum output current is of the order of several microamperes, and a load resistor of perhaps 20,000 ohms may be used in practice. Under these circumstances, the output voltage is sufficiently great so as to avoid the need for very-high-gain video amplifiers.

The polarity of the output current is such that maximum current corresponds to picture shadows, *i.e.*, the amplitude of the video signal increases as the scene brightness decreases. Consequently, the signal developed across the load resistor connected to the signal plate will become more negative (with respect to ground) as the picture becomes darker. This is termed black-negative transmission.

**2-2. Camera Optics and Lenses.** Advantage has been taken of the relatively small size of the image orthicon tube in designing a compact television camera (Fig. 2-3). Typical cameras, complete with electronic view finder but without lenses, are approximately 20 in. long, 12 in. wide, and 18 in. high. The weight ranges from about 75 to 100 lb.

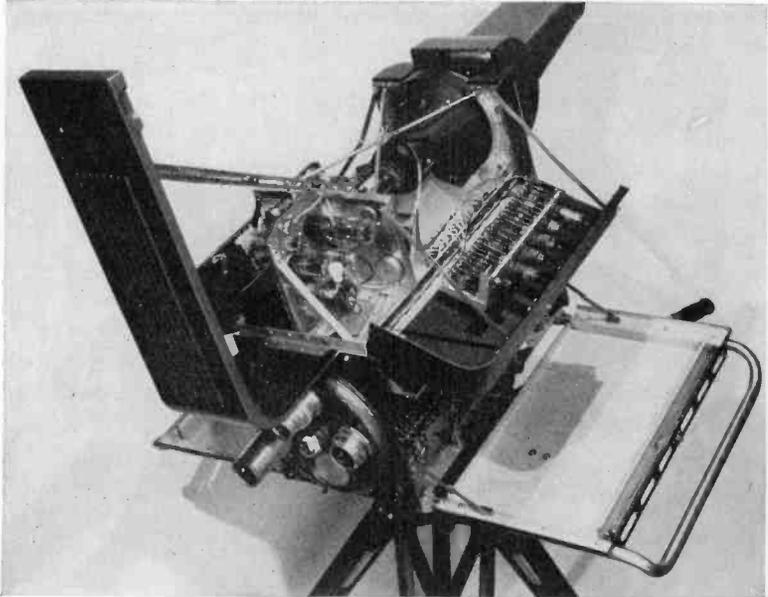


FIG. 2-3. An exploded view of an image orthicon camera showing the ready access to all parts for maintenance purposes. The upper portion of the assembly contains the view-finder picture tube (upper right) and its supporting circuits. The lower portion houses the image orthicon tube (which is located immediately behind the uppermost lens in the four-position turret) and the circuits associated with the camera tube.

**Lens Turret.** As a rule, television cameras are equipped with a turret in which four lenses of different focal lengths may be mounted. Selection of the desired lens is accomplished from the rear or operator's side of the camera either by means of a handle as shown in Fig. 2-4, or by the method described in the next paragraph. Means are provided for automatically and accurately indexing the lens with respect to the pickup tube, and changing from one lens to another requires less than 2 seconds. In some instances, a trigger switch is built into the lens-changing handle to turn off the picture signal while the lenses are being changed. In all cases, lens focusing is accomplished from the operator's side of the camera and, in some instances, the lens iris opening can also be controlled from the rear of the camera or from a remote point.

At least one manufacturer of image orthicon cameras<sup>3</sup> employs a motor-driven lens turret—a feature which permits the selection of lenses with the aid of a set of four push buttons (one for each lens) which may be located at any convenient place either on the camera (as shown in Fig. 4-12) or

<sup>3</sup> Pourciau, L. L., Television Camera Equipment of Advanced Design, *J. SMPTE*, Vol. 60, No. 2, p. 166 (February, 1953).

elsewhere. This camera, in addition, employs a selsyn-type focusing system together with a remote lens iris-control arrangement. Thus, the selection of lenses, their iris opening, and their focusing can all be undertaken at a point remote from the camera head itself, *e.g.*, at the camera-control unit.

**Conventional Lenses.** The useful area of the image orthicon target is such that the image focused on the photocathode should be rectangular in shape and with a diagonal of 1.6 in. The aspect ratio is 4:3 corresponding to television standards (see Table 1-1). Consequently, the width of the rectangle is 1.28 in. and the height 0.96 in. Fortunately, the image orthicon tube can accommodate a wide variety of lenses since the photocathode surface is within approximately  $\frac{1}{8}$  in. of the front surface of the tube. This permits the use of a very short focal lens for wide-angle coverage.

TABLE 2-1. TYPICAL LENSES FOR IMAGE ORTHICON CAMERAS

Focal length *	Maximum aperture	Angular field of view (degrees)	
		Horizontally	Vertically
35 mm (1.4 in.)	<i>f</i> /3.3	50	38
50 mm (2 in.)	<i>f</i> /1.9	36	27
90 mm (3.5 in.)	<i>f</i> /3.5	20	15
135 mm (5.3 in.)	<i>f</i> /3.8	14	10
7 in.	<i>f</i> /2.5	10	8
8½ in.	<i>f</i> /3.9	8	6
13 in.	<i>f</i> /5.0	6	4
15 in.	<i>f</i> /5.0	5	4
17 in.	<i>f</i> /5.0	4	3
25 in.	<i>f</i> /5.0	3	2

\* The nomenclature used conforms with markings on the lenses; *i.e.*, smaller focal-length lenses are commonly rated in millimeters, larger ones in inches.

Because of these factors, the image orthicon television camera can make use of many of the excellent lenses that have been designed for miniature photographic camera use. These lenses vary in size from the short-focal-length wide-angle lenses to the long-focal-length telephoto lenses. In the smaller sizes at least, these lenses are light in weight and lend themselves readily to turret operation. In addition, special lightweight lenses have been built for television service with focal lengths of 20 in. and more, having apertures as large as *f*/5 and weighing only 3 lb or so.

A representative list of the conventional-type lenses available for use with the image orthicon camera is given in Table 2-1. In this table the

focal length of some lenses is given in millimeters while that of others is in inches. This may seem confusing but it is in keeping with common practice and, in fact, is in keeping with the actual markings on the lenses themselves.

Many of the lenses are equipped with an adjustable iris, and the lens speed shown is for maximum aperture opening. The horizontal and the vertical fields of view are given on the basis of the lens being focused to infinity. The horizontal angular field of view is of great importance for both field and studio pickup work. The vertical angle, however, is of interest primarily for field work where very high viewing angles may be encountered (*e.g.*, from a location high up in an athletic field grandstand or from the balcony of a sports arena).

**Special Lenses.** In addition to the conventional type of lenses, there are also available for use on image orthicon cameras several especially designed lenses. One of these is the Zoomar which is a special-effects lens whose focal length (and consequently the picture area covered) is continuously variable over an appreciable range by manipulation of a single push-pull lever which operates from the back of the camera. One Zoomar lens has two operating ranges, one extending from 3 in. (75 mm) to 13 in. and the second extending from 5 in. (125 mm) to 22 in. The maximum speed of the lens when used for focal lengths up to 12 in. is  $f/5.6$ . Above 12-in. focal length, the full aperture should not be used. The highest recommended speed is  $f/8$ . For any focal length, the lens can be stopped down to  $f/22$  if desired.

The over-all length of the lens is 30 in., and it weighs 11 lb. Because of its length, other lenses cannot be mounted on the same turret with the Zoomar since it would extend into their field of view. A special turret is supplied for the Zoomar with the focusing control extending back through the turret axis and thereby becoming available to the operator at the rear of the camera.

The resolution of the Zoomar lens is dependent upon the iris opening employed. When stopped down to  $f/16$ , there is little difference in definition between the Zoomar and a conventional lens. At  $f/11$ , however, the definition is reduced to about 90 per cent that of a conventional lens, and at  $f/8$  to perhaps 80 per cent. When used wide open at  $f/5.6$ , the definition is approximately 75 per cent of that of a good conventional lens. Comparison of these figures with those given in Table 2-1 for conventional lenses indicates that the Zoomar is materially slower than single-focal-length lenses.

The longest focal-length lens that has been made available specifically for television applications is the Video Reflectar lens which has a focal length of 40 in. (Fig. 2-4). This unit is actually a lens without lenses.

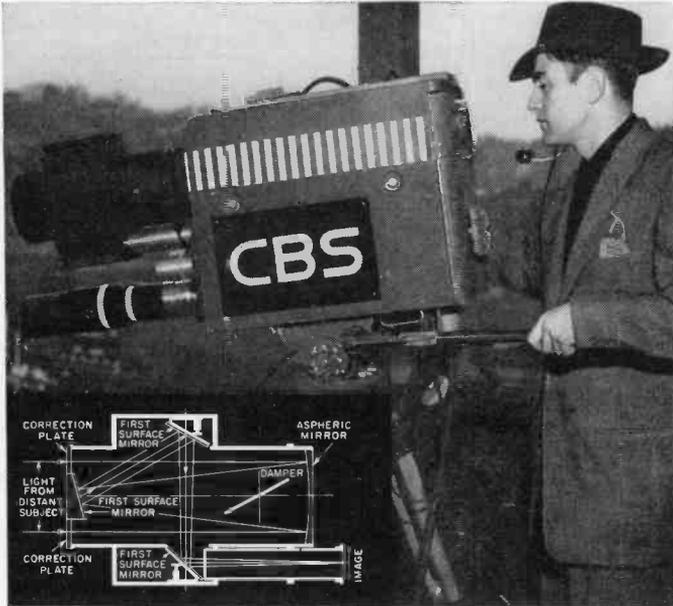


FIG. 2-4 The Video Reflector lens, shown in the upper or working position of the lens turret, is the longest focal-length lens (40 in.) in regular television service. The ingenious optics employed in this lens to keep its over-all length to 16 in. while providing a 40-in. focal length are detailed in the insert.

It employs one aspherical and three flat reflectors to obtain the desired result. A conventional lens of this focal length would be at least 40 in. long and weigh in the neighborhood of 40 lb. The Video Reflector, however, is only 16 in. long and weighs 6 lb. The speed of the lens is  $f/8$ . A highly specialized lens of this type, while indispensable in some circumstances, has limited general usefulness. Its prime field of application is, of course, for outdoor pickups where the camera may necessarily be located at rather great distances from the scene of action. In any event, lenses with very long focal lengths require an exceedingly steady mount when used. Furthermore, relatively slow and very smooth panning procedures must be followed.

**Lens Focusing.** For all conventional lenses, optical focusing is accomplished in a television camera by the novel method of moving the image orthicon tube back and forth, together with its focus and deflection-coil assembly, instead of by motion of the lens as in standard photographic practice. The advantage of the system is the great simplification of the lens turret which needs only carry the lenses in a fixed plane rather than having to provide for their back-and-forth movement. Another important

advantage is the increased range of focus obtainable when lenses with individual focusing mounts are used. Under these circumstances the total available relative motion between lens and photocathode is the sum of the individual motions. This increases the range of camera-to-object distances over which correct focus can be obtained. In fact, with any of the lenses listed in Table 2-1, the camera can approach to within 1 ft of an object and still bring it into focus.

**2-3. Camera Circuits.** It is the usual practice to include the picture-signal preamplifier and the horizontal- and vertical-deflection circuits in the camera in order to reduce the number of major units required for a complete television camera system. Furthermore, to make it possible to operate the camera at the end of a long cable, it is necessary to locate these circuits either in the camera or in an auxiliary unit immediately adjacent to it. By locating the deflection circuits and perhaps part of the video amplifier in an auxiliary unit, it is possible to keep the size and weight of the camera to a minimum. This arrangement, however, tends to complicate the system by increasing the number of equipment units, the number of connecting cables, and the time and effort in setting up, dismantling, and transporting the equipment. In field pickup service, this last factor is of particular importance. Furthermore, in studio operation it is not uncommon to move a camera 100 ft or more in going from set to set during the course of a production. Under these circumstances, an auxiliary unit that could not be a corresponding distance away from the camera itself would have to be carried along on the pedestal or dolly supporting the camera. For all these reasons, there are included in the camera as many of the associated circuits as are required to minimize the difficulty of operating the camera at the end of a long cable.

The circuits in a typical image orthicon camera include:

- a.* Picture-signal preamplifier for increasing the picture-signal output of the image orthicon tube to a suitable level for transmission to a camera-control unit.
- b.* Horizontal shading control for elimination of unwanted shading.
- c.* Blanking circuits for mixing, clipping, and amplifying horizontal and vertical driving pulses for application to target screen as blanking signals.
- d.* Horizontal-deflection circuits for increasing the amplitude of the horizontal driving pulses and generating horizontal saw-tooth waveforms for the image orthicon scanning-beam deflection.
- e.* Horizontal damper circuit for utilizing the reactive currents in the secondary winding of the horizontal-deflection transformer and in the horizontal coil of the deflection yoke.

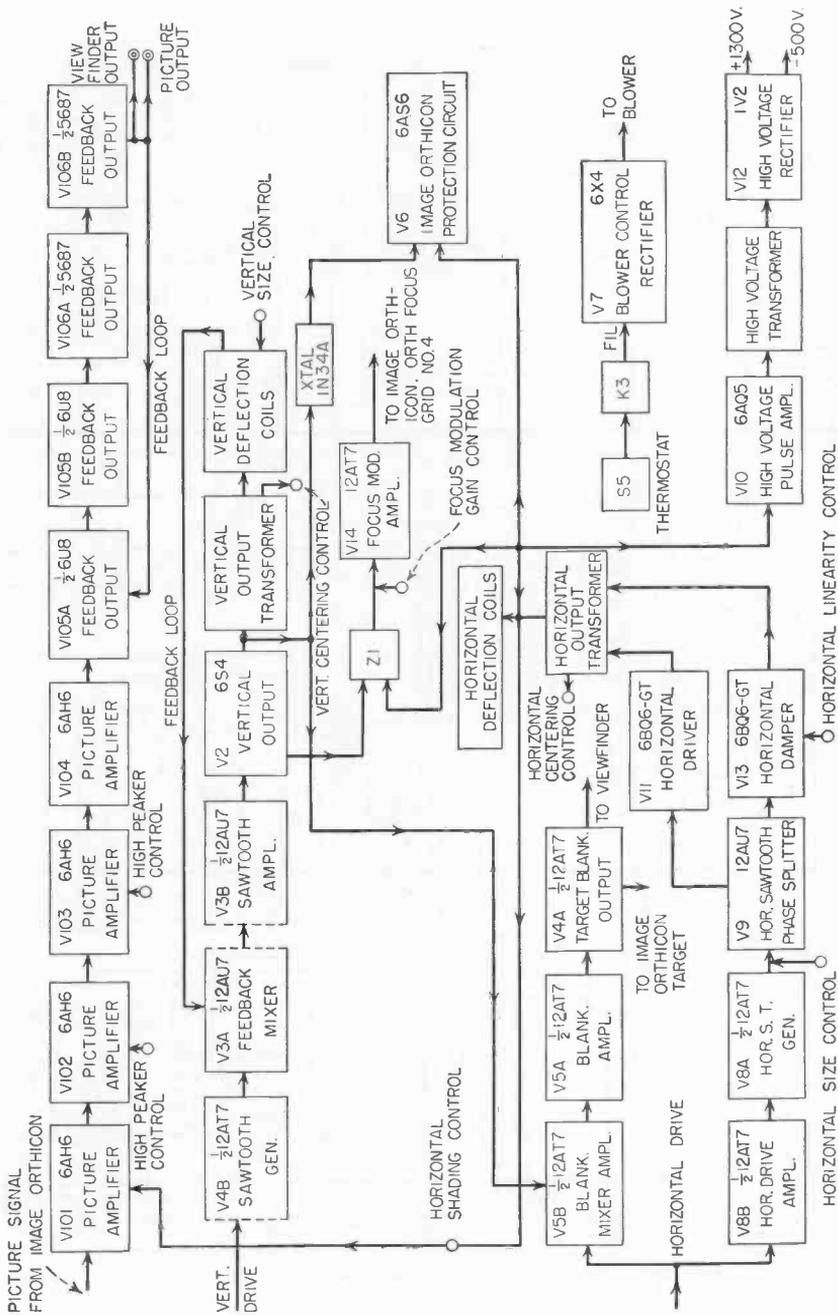


FIG. 2-5. Schematic block diagram of the video amplifier, scanning and high-voltage circuits in an image orthicon camera.

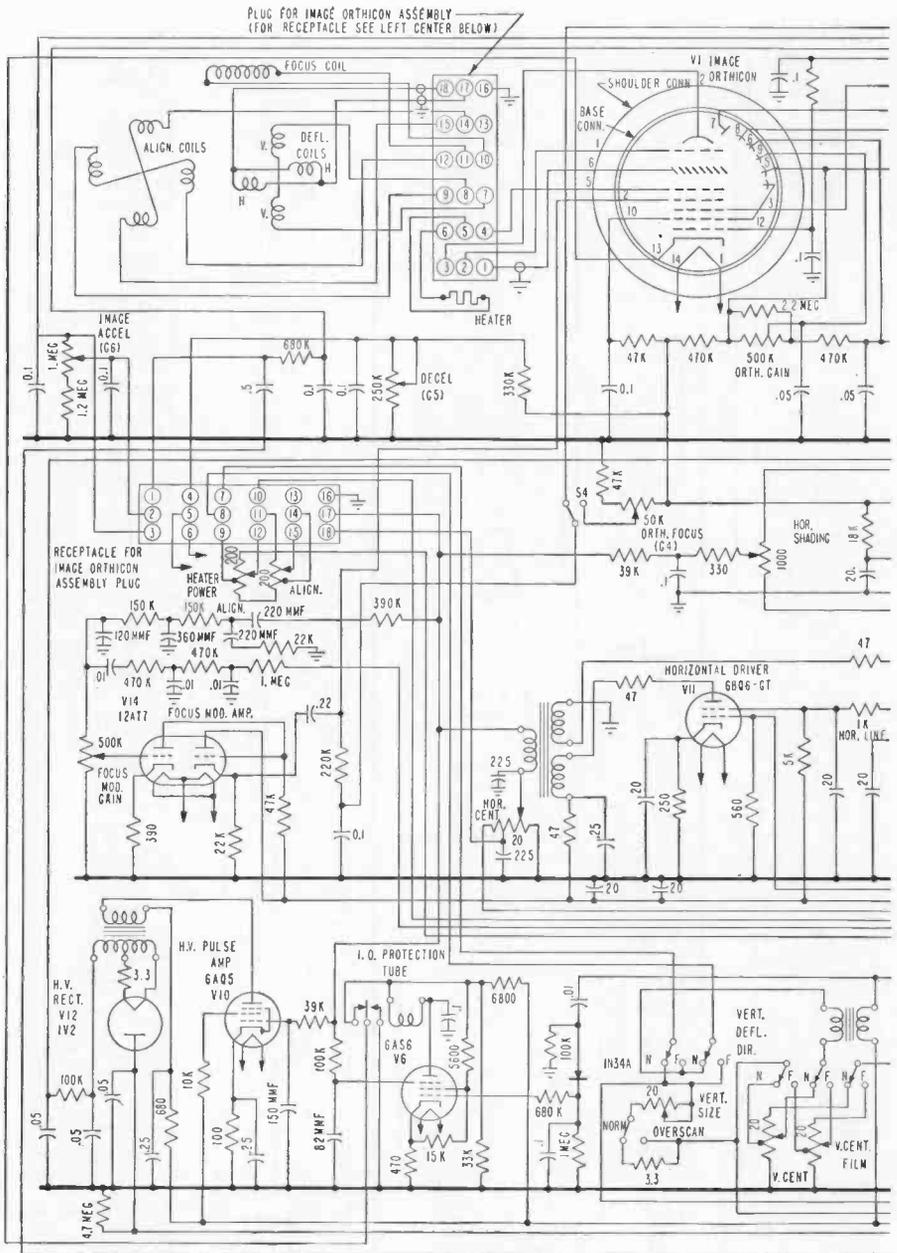
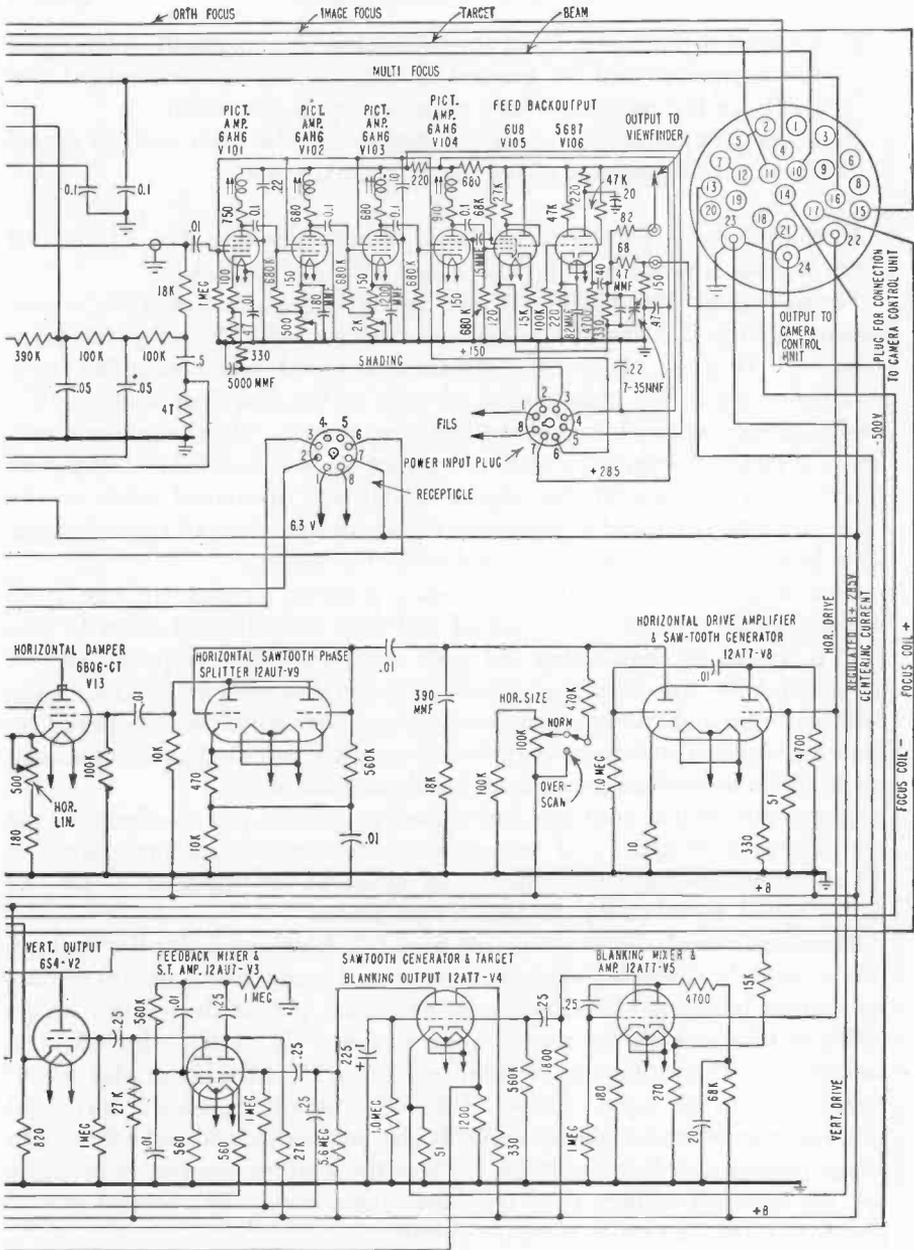


FIG. 2-6. Circuit diagram of an image orthicon camera.



NOTES: ALL RESISTOR VALUES IN OHMS AND ALL CAPACITOR VALUES IN MICRO-FARADS UNLESS OTHERWISE INDICATED  
 N = NORMAL SCANNING DIRECTION    F = FILM, i.e. REVERSED SCAN.

- f. Vertical-deflection circuits for increasing the amplitude of vertical driving pulses and for generating and amplifying the vertical saw tooth for the image orthicon scanning-beam deflection.
- g. High-voltage power supply for generating the high voltage necessary for the operation of the image orthicon tube.

In the following paragraphs a description of the operation of each of these circuits is given for a typical image orthicon camera.

**Picture-signal Preamplifier.** The picture-signal preamplifier circuit shown in Figs. 2-5 and 2-6 is typical of those found in image orthicon cameras. It is an eight-stage resistance-coupled video amplifier with shunt peaking in the plate circuit of each of the first four stages and a feedback loop applied around the last four stages. The complete amplifier is capable of nominally uniform output up to about 8 Mc. The final stage serves to transmit the picture signal over a coaxial cable to the camera-control unit and to provide a signal for operation of the electronic view finder which is commonly used with the camera.

Resistance-capacitance high-frequency peaking circuits are employed in the cathode circuits of the second and third amplifiers in order to provide a means for equalizing the poor high-frequency response that is introduced by the coupling circuit between the output of the image orthicon tube and the input of the picture-signal amplifier. Variable resistors associated with these high-frequency peaking circuits permit adjustment of the over-all response in two independent steps.

The picture-signal amplifier is designed to operate into an effective load impedance of 50 ohms and to supply a black-negative picture signal of 0.4-volt peak-to-peak amplitude. In addition, it supplies a 1.0-volt peak-to-peak signal to the electronic view finder.

**Shading Control.** As explained in Sec. 2-1, *Electron-multiplier Section*, it is inherently characteristic of the image orthicon for the picture to contain some horizontal shading even when all potentials on the image orthicon tube are set for an optimum picture. To nullify this effect, a saw-tooth voltage at horizontal frequency is fed from the horizontal output transformer to the input of tube V101. This circuit includes a horizontal shading potentiometer which controls the amplitude and polarity of the compensating saw-tooth voltage. When the shading control is properly set, the injected voltage is of the same value but is 180 degrees out of phase with the unwanted picture shading.

**Blanking-pulse Amplifier.** The blanking signal for the image orthicon tube is derived from horizontal driving signals from the camera-control unit which are applied to the grid of the blanking mixer tube V5B and from a portion of the vertical output (from tube V2) which is differenti-

ated and applied to the cathode of tube V5B. Thus, horizontal and vertical driving pulses are combined in mixer tube V5B, from which they are applied to blanking amplifier V5A. Here, in addition to being amplified, the pulses are clipped before being applied to the target-blanking output tube V4A. The output of this cathode-follower stage is then coupled to the target screen of the image orthicon tube. By preventing the beam electrons from reaching the target during retrace periods, this blanking signal ensures that no retrace lines will appear in the reproduced picture. Also, since no beam electrons reach the target during these periods, all beam electrons return to the signal multiplier and thus provide a reference potential which corresponds to black level.

**Horizontal-deflection Circuits.** Horizontal driving pulses from the camera-control unit are applied to the grid of the horizontal driving-pulse amplifier V8B. The output of this tube, in turn, drives the saw-tooth gen-

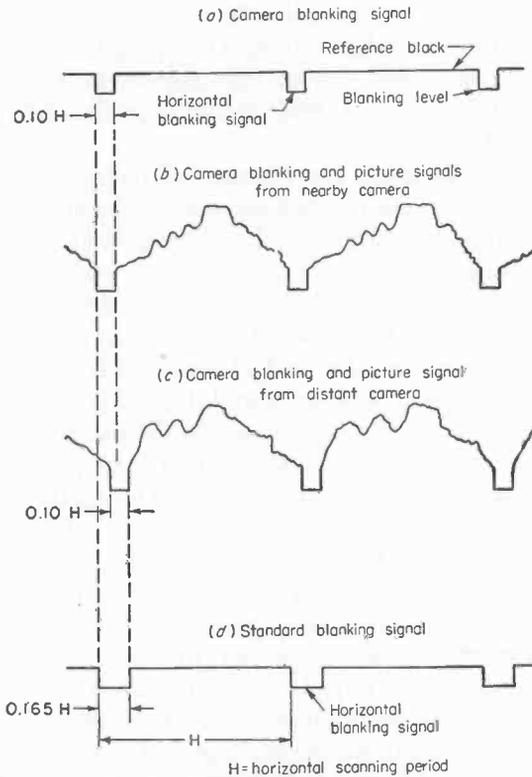


FIG. 2-7. The use of a special camera-blanking signal (top) that is shorter in duration than the standard blanking pulse (bottom) provides a means for coping with the difference in delay of picture signals from both near and distant cameras.

erator tube V8A. The resulting saw-tooth signal is applied to a parallel-connected dual triode V9 which serves as a phase splitter. An output signal obtained from the cathode circuit of the phase splitter operates the horizontal driver tube V11 while a signal obtained from the plate circuit of V9 simultaneously drives the horizontal damper tube V13. Both the horizontal driver tube V11 and the horizontal damper tube V13 supply deflection current to the horizontal-deflection coils (of the image orthicon tube) through a suitable horizontal output transformer.

The horizontal retrace period is made about 10 per cent of a horizontal scanning period, in order to avoid the necessity of compensating for the delay in long camera cables. The standard horizontal blanking width is 16.5 per cent of a horizontal scanning period (see Sec. 1-8). The difference between this latter value and the retrace time in the camera is 6.5 per cent or 4.1 microseconds. This is slightly in excess of the time required for a round trip (2,000 ft) in a 1,000-ft coaxial cable, the maximum length with which it is intended that the equipment be operated. Under these circumstances, when standard blanking pulses are applied to the picture signals, they will "cover" the retrace time of all cameras whether they are at the end of 1,000-ft cables or at the end of very short cables, as shown in Fig. 2-7.

**Horizontal Damper Circuit.** The function of damper tube V13, mentioned above, is to utilize the reactive currents in the secondary winding of the horizontal output transformer and in the windings of the horizontal-deflection coils. During trace time, the magnetic field builds up in the transformer, and current is fed to the yoke because of the increasing plate current of V11, in response to the saw-tooth input from tube V9. At the end of the saw-tooth voltage input to V11, the tube is cut off. The magnetic fields built up in the transformer and deflection coils then collapse rapidly and induce a high-voltage surge across the transformer.

Normally, the circuit will tend to oscillate at a frequency determined by the inductance and distributed capacitance. During the first half cycle of oscillation, the surge of voltage across the yoke and damper tube is negative, so that the damper tube is nonconductive. However, at the end of the half cycle the voltage reverses and becomes positive. At the same instant the oscillating current reaches a negative maximum. However, the damper tube starts to conduct current, prevents continuation of the oscillation because of its low impedance, and passes the current through the deflection coils in a manner determined by the voltages applied to the control grid and plate. Thus, during the first part of the scanning period, the damper tube supplies current derived from the energy in the magnetic field during the previous scanning period while horizontal driver tube V11 is controlled so that it supplies very little current to the yoke. On the

other hand, during the latter part of the scan, the damper tube supplies a relatively small fraction of the current, and horizontal driver tube V11 contributes a major portion. The useful current in the yoke is the algebraic sum of the two currents.

**Vertical-deflection Circuits.** Vertical driving pulses from the camera-control unit are applied to the cathode of the vertical saw-tooth generator tube V4B. The resulting saw-tooth output voltage is then amplified by both sections of the dual triode V3 and by the vertical output amplifier tube V2. It is then applied to the vertical-deflection coils associated with the image orthicon tube via a suitable output transformer. Negative feedback is employed in the vertical-deflection circuit, as illustrated, in order to achieve two important things; it eliminates almost entirely (*a*) the effect of iron saturation in the vertical output transformer core and (*b*) any nonlinearity in the saw-tooth amplifiers.

**Image Orthicon Protection Circuit.** In order to prevent damage to the target of the image orthicon tube in the event of a failure of either the vertical- or the horizontal-deflection circuit, a protection circuit is incorporated in the camera. The circuit consists principally of tube V6 and an associated relay which, in an energized condition, connects the cathode of the image orthicon to its normal ground circuit; but when the relay becomes deenergized the cathode of the image orthicon is biased at a sufficiently high positive potential (75 to 125 volts) to prevent electrons from reaching the target. Energy to operate the relay is obtained from tube V6, which has rectified vertical-deflection pulses applied to its control grid and horizontal-deflection pulses to its suppressor grid. The tube is operated in a manner such that plate current can flow (and hence the protection relay operates) only when both vertical- and horizontal-deflection pulses are present.

**2-4. Electronic View Finder.** In the past, television cameras have been equipped with a wide variety of view finders, ranging from two ordinary screwheads used as rifle sights, through wire frames and double-lens systems to electronic finders in which the scene is reproduced on small picture tubes mounted beside or above the cameras. Each type has advantages, and no one type has all the desired characteristics.

In the image orthicon camera, the ground-glass, double-lens type of optical finder becomes completely useless when the equipment is used under low-intensity lighting conditions. This results from the fact that the image orthicon can operate with such low illumination that the optical image on a ground-glass screen is practically invisible. Thus the electronic view finder is the only type capable of indicating both focus and the outline of the scene. It has two distinct advantages over the optical system: (*a*) it is entirely free of parallax errors, and (*b*) it provides an

erect image where a single-lens direct optical finder provides an inverted image. The electronic view finder has a disadvantage in that it cannot include anything outside of the televised scene. However, to assist in bringing the camera to bear on the general area of interest, a ring sight is sometimes used on top of the camera.

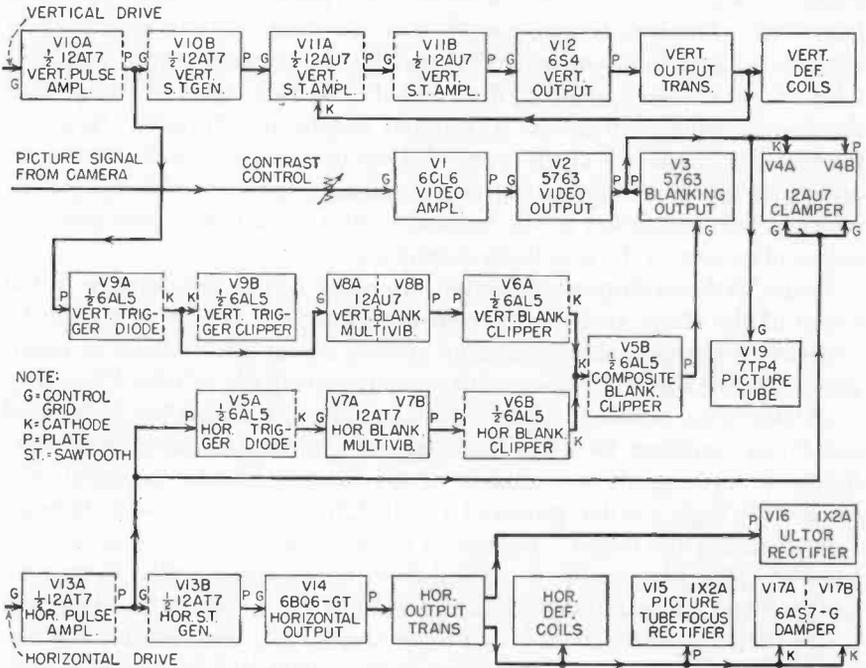


FIG. 2-8. Schematic block diagram of the video amplifier, scanning and high-voltage circuits employed in the electronic view finder associated with an image orthicon camera.

The view finder designed to be used with the image orthicon camera generally employs a flat-faced 5- or 7-in. picture tube with perhaps 7 to 10 kv on the ultor or second anode. This arrangement provides a picture with sufficient brilliance to be seen readily even with considerable ambient light falling on the face of the picture tube. The view finder is usually constructed as a separate unit to be mounted on the top of the camera. The two units are styled to appear as a single unit when assembled (Fig. 2-4).

In the following sections the pertinent details of a typical electronic view finder are described. A block diagram of the circuits used in a unit of this type is shown in Fig. 2-8, and the corresponding schematic wiring diagram is given in Fig. 2-9.

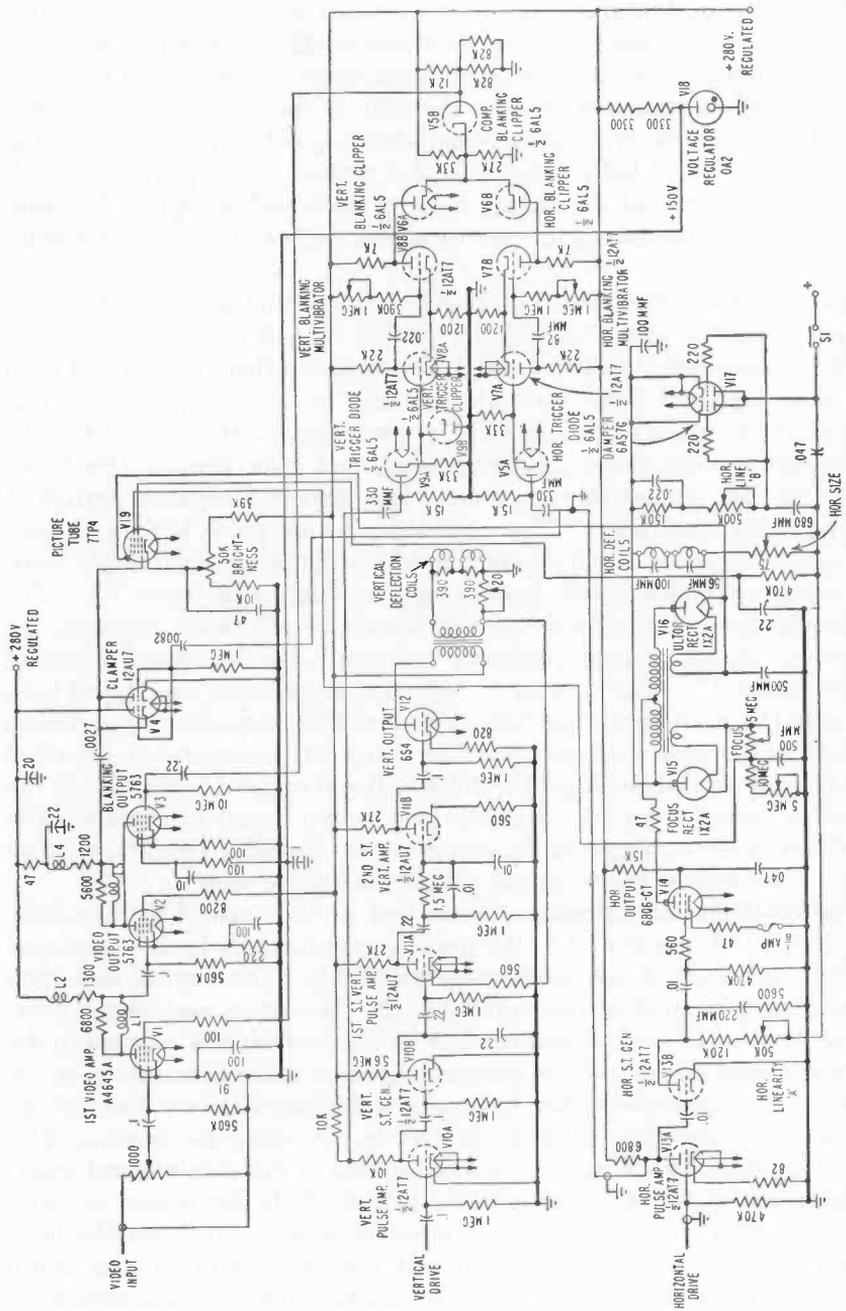


Fig. 2-9. Circuit diagram of an electronic view finder for an image orthicon camera.

**Picture-signal Amplifier.** A two-stage video amplifier is used to drive the picture tube in the electronic view finder. The camera picture signal (approximately 1-volt, peak to peak, black-negative) is applied to a gain or "contrast" control and then to the grid of the first picture-amplifier tube V1. Series-shunt frequency-compensating networks are included in the plate circuits of both tubes. The d-c portion of the picture signal is restored at the grid of the picture tube by the keyed clamper V4. Thus, a-c and d-c components of the picture signal are fed to the grid of picture tube V19.

**Blanking-pulse Circuits.** The blanking signal that is required for the proper operation of the view-finder picture tube is derived from 2-volt peak-to-peak vertical and horizontal driving pulses that are obtained from the camera-control unit. In both instances the driving pulses are first amplified (by tubes V10A and V13A, respectively, for the vertical and the horizontal driving pulses), differentiated, and then clipped (by tubes V9A and V5A, respectively) to remove the unwanted negative portion of the resulting waveforms. The vertical-frequency pulse is then clipped again by V9B, after which it is employed to trigger the monostable vertical blanking multivibrator employing the dual-triode tube V8. The horizontal-frequency pulses, without benefit of additional clipping, are employed in an analogous manner to trigger the horizontal blanking multivibrator V7. The outputs of the two multivibrators are clipped individually (by blanking clipper tubes V6A and V6B, respectively) and combined in a common load resistor. The composite horizontal and vertical blanking signal is then clipped by tube V5B and applied to the grid of the blanking output tube V3. The blanking output signal from tube V3 is combined with the output of the picture-signal amplifier (see above), and both signals are fed to the control grid of the picture tube.

**Vertical-deflection Circuits.** The output of the vertical driving-pulse amplifier V10A, mentioned in the preceding paragraph, is also employed to drive the vertical saw-tooth generator V10B. The vertical-deflection signal thus generated is then applied to the three-stage amplifier consisting of the dual triode V11 and triode V12, after which it is coupled to the vertical-deflection coils of the picture tube via a suitable transformer. A feedback loop extending from the output of the transformer to the cathode of saw-tooth amplifier V11A is effective in correcting for nonlinearities caused by tube operation or by iron saturation in the output transformer.

**Horizontal-deflection Circuits.** The output of the horizontal driving-pulse amplifier V13A, mentioned previously, is used to trigger the horizontal saw-tooth generator V13B. In turn the output of this tube is amplified by V14 and then applied to the horizontal-deflection coils associated with the picture tube of the view finder.

A portion of the output of horizontal output tube V14 is also used to generate the high voltages required for the focusing anode and for the ultor (second anode) of the picture tube. An autotransformer (which also incorporates rectifier filament windings) is used to step up the output voltage of V14 before applying it to the ultor rectifier V16. By this means a d-c potential of 11 kv is obtained for application to the picture-tube ultor. Rectifier V15, on the other hand, is supplied with a lower input voltage and develops a d-c potential of 2 kv for application to the focusing electrode of the picture tube.

**2-5. Camera-control Units.** The operations, not undertaken in the camera itself, necessary to the formation of a complete composite television signal (picture signal plus blanking plus synchronizing pulses) are performed in a camera-control unit. After the picture-signal output of the camera has received its initial evaluation by means of the electronic view finder associated with the camera, it is necessary to subject the signal to further monitoring as well as to add the other components of the composite signal. The camera-control unit, therefore, includes circuits and controls to perform the following functions:

- a. Amplification of the picture signal to the standard level required for transmission on the outgoing video circuits.
- b. Establishment and maintenance of the desired relationship between the peaks of the blanking pulses and the true black level, *i.e.*, restoration of the d-c component.
- c. Addition of horizontal and vertical synchronizing pulses in cases where only one camera is in use. In more complex systems, this function is necessarily performed in the switching system (see Sec. 3-2, *Synchronizing-signal Amplifier*, and Sec. 6-7).
- d. Monitoring of the picture quality, on both picture and waveform monitors, to check the accuracy of optical and electrical focus in the camera and the quality of the over-all performance of the camera chain.
- e. Monitoring of the picture signal for adherence to standard video transmission practices.
- f. Remote controlling of the electrical focus and the other parameters involved in the operation of the image orthicon camera.

From a consideration of these functions, it is apparent that the camera control is necessarily a complex unit, for it includes all the circuits and components found in that part of a television receiver which follows the second detector, also those required for a wide-band cathode-ray oscilloscope, and in addition, amplifiers, special circuits, and controls required for operation of the camera.

Two general types of camera-control units are often employed: one for permanent or fixed installations (Fig. 6-4) and the other for field or temporary installations (Figs. 2-10 and 3-2). Both the studio and field types perform the same basic functions although not necessarily in the same way. The auxiliary functions performed by each unit also differ to some

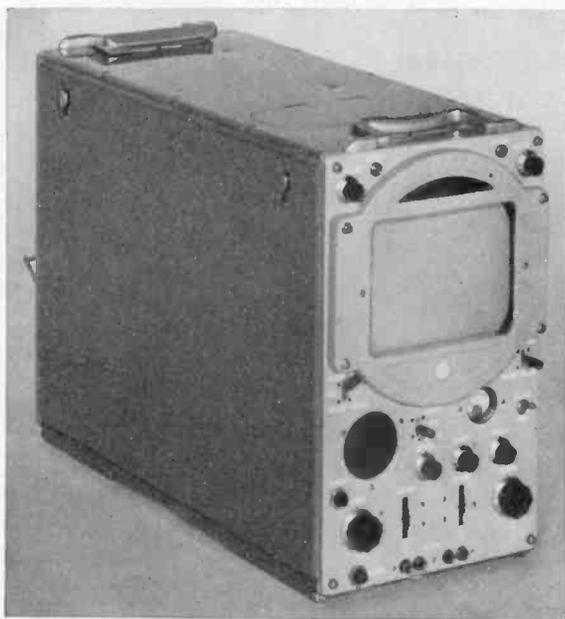


FIG. 2-10. This portable camera-control unit features a means for opening and closing by remote control the iris of the lens that is in use on the camera associated with the control unit. An indicating instrument on the control panel (as well as a similar one on the cameraman's side of the camera) shows the lens opening in use at any given moment. (Courtesy of General Precision Laboratory, Inc.)

extent. Physically, the portable-type units are compact and convenient in size for handling in the field, but the controls are sometimes crowded and not always in the position which makes for maximum ease of operation. These latter inconveniences are not serious, however, and are completely overshadowed by the need for having available equipment that is small and light enough to be handled by one man in the field.

The permanent type of camera-control units can, within limits, afford as much space, size, and weight as justified in the interests of arranging the controls so that they may be operated for long periods of time without fatigue, arranging the equipment for easy installation and maintenance and providing picture and waveform monitoring facilities that are in keeping with the needs of television studio program production.

All major operating controls on portable-type units are mounted on the front panel which also has openings for the picture and the waveform monitor tubes. Additional controls that require adjustment during initial setup are often contained in a small covered compartment in the top of the unit. A block diagram and a schematic circuit diagram are given in Figs. 2-11 and 2-12, respectively, of the typical portable camera-control unit shown in Fig. 3-2. The manner whereby these circuits accomplish the functions of a camera-control unit enumerated above is described in the following paragraphs.

**Picture-signal Amplifier.** The picture-signal amplifier consists of an eight-stage frequency-compensated video amplifier. A black-negative picture signal of 0.4-volt peak-to-peak amplitude from the camera picture-signal preamplifier (see Sec. 2-3, above) is applied to the grid of the first picture-amplifier tube V1 through a gain control. Amplification of the picture signal first takes place in tubes V1, V2, V13, V6, and V7A in the order named. The signal is clamped at the grid of V13 by the first picture clamper tube V3, at the grid of V6 by the second clamper V5, and at the grid of V9 by a third clamper V8. Final amplification of the picture signal is then undertaken in a three-tube feedback amplifier comprised of tubes V9, V15, and V18. Two outputs are obtained from the cathode of the output amplifier stage, V18, through individual 75-ohm isolation resistors.

With the aid of peaking coils in the first five amplifier stages and the use of feedback over the last three stages, the picture-signal amplifier described is capable of substantially uniform response over the band of frequencies up to 8 Mc. It is capable of delivering a 1.4-volt peak-to-peak, black-negative signal to two 75-ohm resistive loads.

For most applications, several camera chains are used and their respective outputs applied to a switching unit to provide means for selecting between the various cameras. Under these circumstances, the synchronizing signals that are necessary to form a standard composite waveform are added to the picture signal in the switching unit. In those instances where only one camera is in service the output of the camera-control unit may be transmitted directly to the remainder of the broadcasting system. In this case, however, the requisite synchronizing signals must first be added to the picture signal. In the camera-control unit illustrated, this may be accomplished by applying combined horizontal and vertical synchronizing pulses to amplifier tube V16B, the output of which is clipped by tube V16A and then combined with the picture signal in the cathode circuit of feedback amplifier tube V9. A potentiometer control provides means for adjusting the amplitude of the synchronizing pulses to the prescribed value.



**Transfer Characteristic Control.** When operated in the vicinity of the knee of its transfer characteristic curve (see Fig. 2-14), the output of an image orthicon camera tube is not directly proportional to its input. Rather, the output increases at a slower rate than does the input, and since this would occur for the highlights of a scene, the process is termed "white compression." To a degree, this effect may be corrected by causing the normally linear transfer characteristic of the picture-signal amplifier to curve in an opposing direction to that of the image orthicon. Thus, the compressed white signals may be "stretched" and a somewhat greater contrast range obtained.

In the black or shadow region, on the other hand, picture tubes normally show some compression. In this instance the use of black stretching circuits will correct for this phenomenon to some extent and contribute further to a greater over-all contrast range. In practice, the successful application of transfer characteristic control circuits depends upon a number of contributing factors including (a) the contrast range of the scene being televised, (b) the amount of lens flare and other phenomena that degrade the contrast range, (c) the effect upon the signal-to-noise ratio, and (d) the transmission capabilities of the broadcasting or recording system involved.

In the picture-signal amplifier described above, tube V6 with the aid of supporting circuits employing crystals CR3 and CR4, provides means for modifying the inherent transfer characteristic of the image orthicon camera tube. This is accomplished by varying, independently, the curvature of the top and bottom portions of the amplifier's transfer characteristic. Switches S2 and S3 permit the application of white and black stretch (a) together, (b) independently, or (c) not at all. In addition, potentiometer controls permit separate adjustment of the degree of curvature introduced at the white and the black ends of the transfer characteristic of the picture-signal amplifier.

Successful operation of the transfer characteristic control circuit requires that picture signals of a given amplitude always be located at the same point on the operating characteristic of the transfer-modifying amplifier V6. This is accomplished by clamping the signal on a line-to-line basis at the grid of V6 by means of clamper tube V5.

**Blanking-pulse Shaper and Clipper.** Blanking pulses (Fig. 1-3b) are added to the picture signal (Fig. 1-3a) by combining both signals in a plate load resistor that is common to picture amplifier V2 and to blanking-pulse shaper V12B. The resulting signal has the general appearance of that shown in Fig. 1-3c. Any spurious signals riding on the top of the blanking pulse are then clipped off by blanking clipper V4, which is located between the third and fourth picture-amplifier stages.

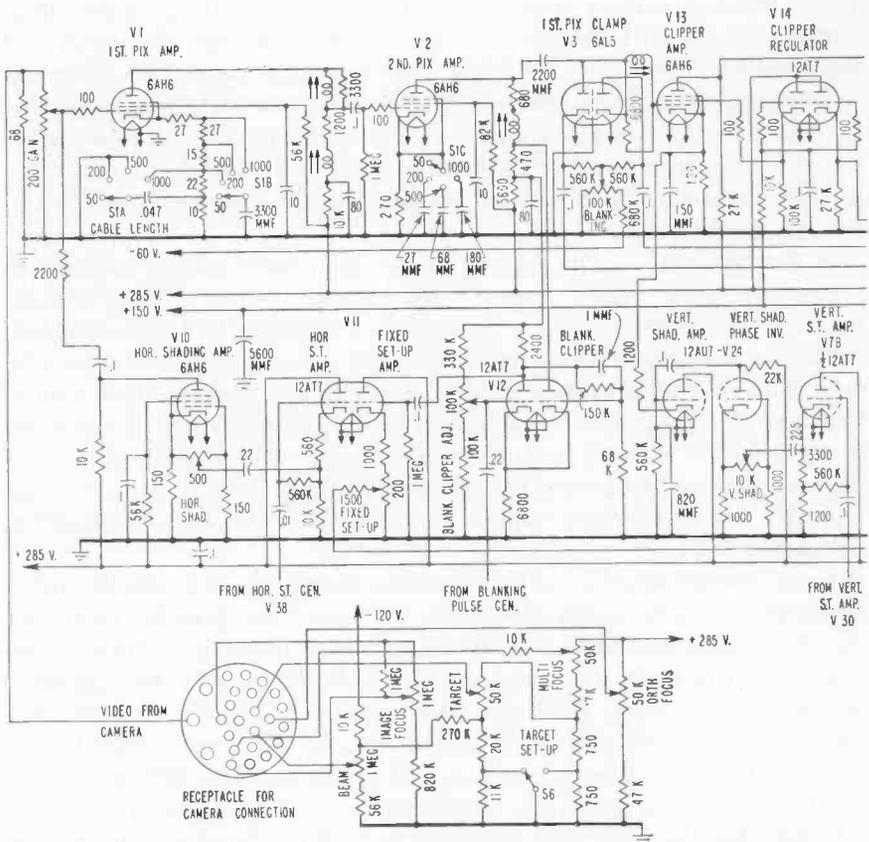


FIG. 2-12a. Circuit diagram of the picture-signal amplifier, the horizontal and vertical shading amplifiers, the transfer characteristic control, and the clamping portions of the field-type camera-control unit whose schematic block diagram is shown in Fig. 2-11. In addition, the several operating controls that determine the potentials applied to the various elements of the image orthicon camera tube are shown at the lower left portion of the illustration. These include (a) an image-focus potentiometer whose



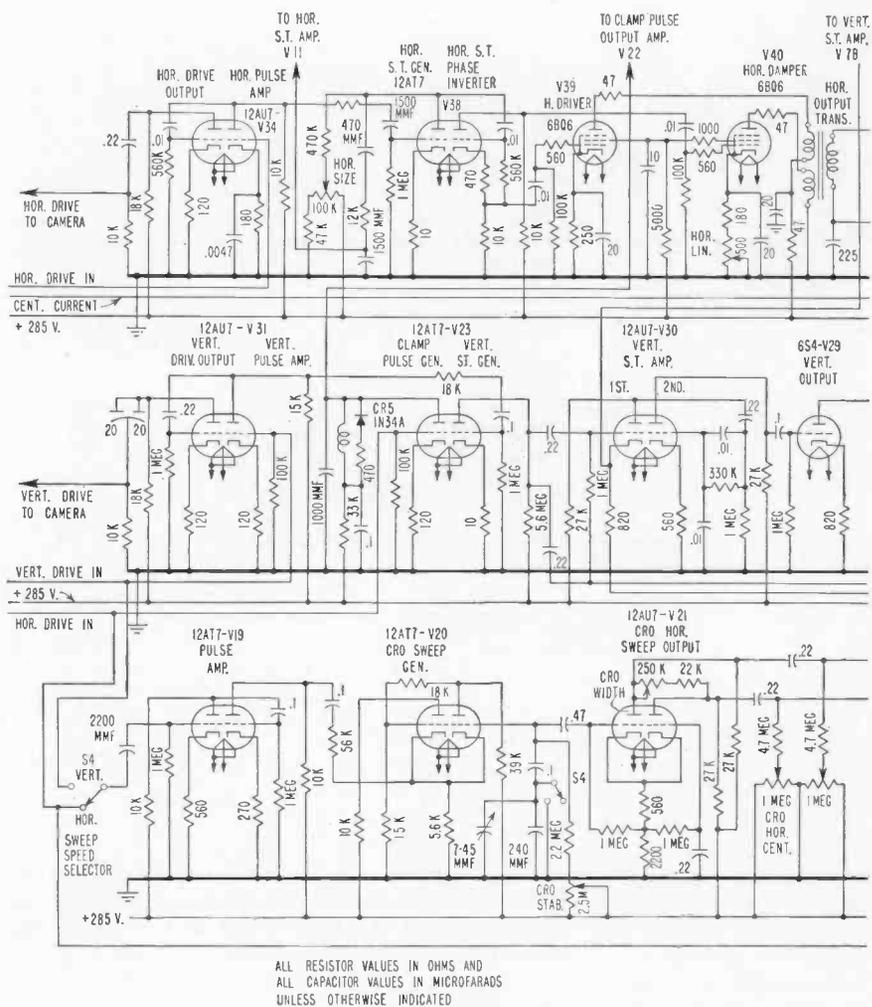
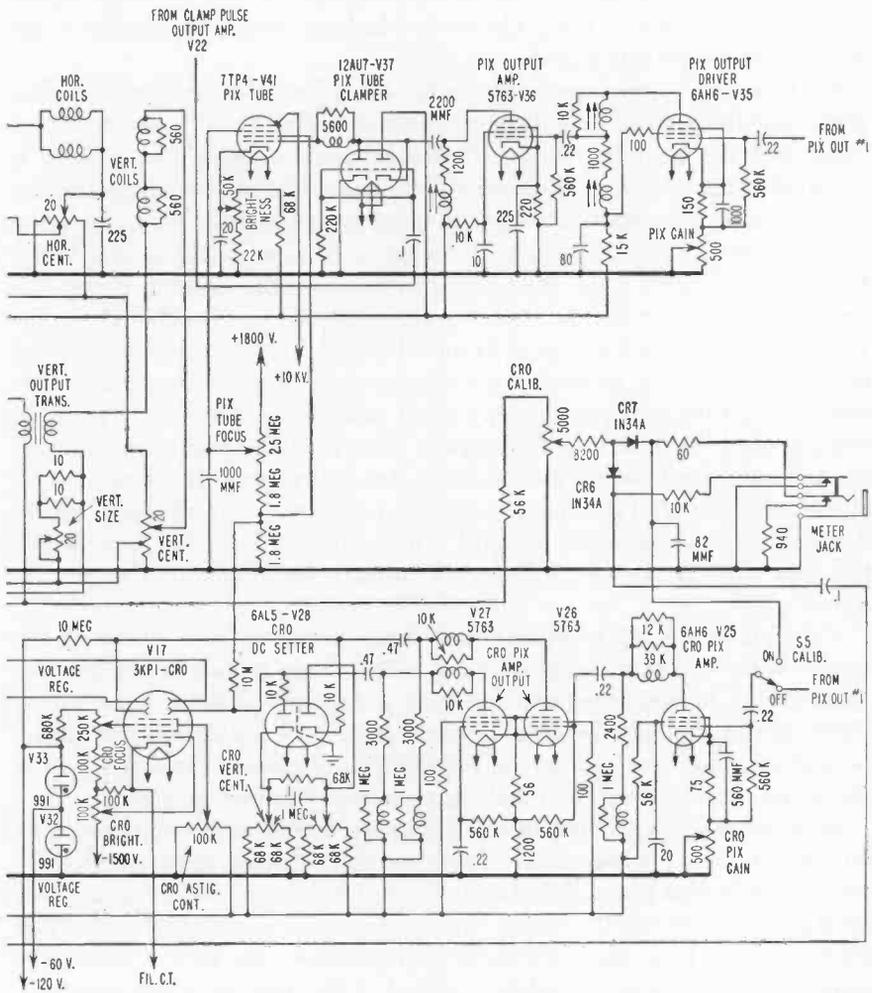


Fig. 2-12b. Circuit diagram of the horizontal and vertical driving-pulse amplifiers, the clamping-pulse generator, and the picture and waveform-monitor portions



of the field-type camera-control unit whose schematic block diagram is shown in Fig. 2-11.

The blanking-pulse shaper, V12, is driven by blanking pulses derived from an associated synchronizing waveform generator. The shaper serves to decrease the rise time of the pulses and clips off any spurious signals riding on their tops. Thus, clean-cut blanking pulses are available for addition to the picture signal.

**D-c Insertion.** One stage of the video amplifier, V13, performs the very important function of establishing a definite relation between reference black and the blanking level. To do this, the control grid of V13 is clamped at the end of each scanning line to an arbitrary reference potential. Because the target in the image orthicon is blanked during the scanning retrace (*i.e.*, made sufficiently negative to repel the scanning beam, as explained in Sec. 2-3), the picture signal from the camera during this retrace period is fixed with respect to reference black, even though it may vary continuously with respect to an arbitrary fixed potential because of the addition of hum, power-supply surges, or other spurious signals. The clamping action serves to set up a fixed relationship between the actual camera black level during the retrace periods of the picture signal and the arbitrary fixed value by connecting the control grid mentioned above to the fixed potential through a very low impedance. At all times, except during the retrace periods, the grid is disconnected from the fixed potential and thus is free to follow the normal variations in the picture signal.

A double diode, V3, is utilized in a clamp circuit to hold, or clamp, the grid of tube V13 at the desired level. The clamp circuit establishes the peaks of the incoming camera blanking pulses at a definite point below cutoff on the clipper tube (V13) characteristic. A potentiometer control provides a means for setting the control grid of picture amplifier V13 at the proper level during the blanking periods in the picture signals.

An important by-product of this clamping action is the elimination of the low-frequency components of any spurious signals, provided they do not have sufficient magnitude to cause amplitude modulation in any preceding stage. Hence, the clamp circuit removes power-supply surges and low-frequency hum and minimizes microphonics. In fact, it limits the amplitude of any spurious additive signal to the amount which occurs in the period of one scanning line.

**Clamper Keying Pulses.** The horizontal-rate keying pulses that are necessary for driving the picture-signal clamper tubes V3, V5, and V8, and the picture-monitor clamper V37, are developed from horizontal driving pulses obtained from a synchronizing waveform generator. These pulses are applied to the grid of clamping-pulse generator V23A. The plate circuit of this tube contains an inductance-capacitance circuit that is shock-excited by each driving pulse. The negative portion of the resulting

transient waveform is clipped off by a crystal diode, but the positive portion is applied to a cathode-follower stage, V22A. The output from this tube is used to key the picture-monitor clamper V37 and also to drive a second cathode follower, V22B. With the aid of a clamping-pulse output transformer, this latter tube supplies both positive and negative keying pulses for picture-signal clampers V3, V5, and V8.

**Horizontal and Vertical Shading.** Provisions are made in the camera-control unit described for the generation and insertion of both horizontal and vertical shading signals, the former supplementing those applied in the camera itself (see Sec. 2-3, *Shading Control*). To generate the horizontal shading signals, negative horizontal driving pulses of approximately 4-volt peak-to-peak amplitude from a synchronizing waveform generator are applied to horizontal pulse amplifier V34B. A portion of the output of this tube is employed to drive horizontal saw-tooth generator V38A, the output of which is applied to the grid of horizontal saw-tooth amplifier V11A. The amplified saw-tooth waveform from this latter tube is applied to horizontal shading amplifier V10 through an adjustable potentiometer in a manner such that both the amplitude and the polarity of the shading signal may be varied until it is equal in amplitude but opposite in phase to any spurious horizontal saw-tooth signal that may be present. Thus, spurious signals of this type may be canceled out.

Horizontal pulse amplifier V34B also feeds a horizontal-drive output amplifier stage, V34A. This tube supplies the horizontal driving pulses required for operation of the camera, as explained in Sec. 2-3, above.

Vertical shading signals for use in the camera-control unit and vertical driving pulses for the camera itself are derived from vertical driving pulses in a manner similar to that just described for horizontal-rate pulses. The circuits and tubes employed for the vertical-rate signals may be traced with the aid of Figs. 2-11 and 2-12.

**Picture Monitor Circuits.** The deflection circuits for the 7-in. aluminized picture tube employed in the portable camera-control unit described are of the driven type and similar to those used in the camera itself. Approximately 4-volt peak-to-peak, negative vertical driving pulses are amplified by V31B. A portion of the output of this tube is employed to trigger saw-tooth generator V23B. Both triode sections of tube V30 are connected as a cascade resistance-coupled amplifier to increase the saw-tooth pulse level from V23B to the proper driving level for vertical output amplifier tube V29. The output from this latter tube is then coupled to the vertical-deflection coils of the picture-tube yoke through a suitable transformer. Feedback is applied from the output of this transformer to the cathode circuit of amplifier V30A and serves to correct for nonlinearities introduced by the amplifiers or the transformer within the feedback loop.

The horizontal-rate deflection waveforms for the monitor picture tube are derived from a portion of the output of the horizontal saw-tooth generator, V38A, mentioned in the preceding section. This signal is applied to a horizontal saw-tooth phase inverter, V38B, which, in turn, drives horizontal damper tube V40 from its plate circuit and horizontal driver tube V39 from its cathode circuit. The outputs from the plates of these two tubes (V39 and V40) are connected to separate primary windings of a horizontal output transformer, the secondary of which is connected to the horizontal-deflection coils of the picture-tube yoke. Damper tube V40 provides control of deflection linearity and assures full utilization of the available power.

Video signals for application to the grid of the picture monitor tube are derived from a portion of the output of picture-signal amplifier V18. The signal is coupled to the grid of picture-tube driver amplifier V35, the output of which is applied to the grid of picture-tube output amplifier V36. This amplifier stage drives the control grid of the picture tube V41. Restoration of the d-c component is accomplished at this point by clamping the grid of the picture tube, on a line-to-line basis, with clamper V37. This clamper is driven by clamper keying pulses obtained from cathode follower V22A as described under *Clamper Keying Pulses*, above.

**Waveform Monitor.** In the process of producing a television signal, it is essential to monitor both the amplitude and the waveform of the camera amplifier output. This is customarily done by means of a cathode-ray oscilloscope of more or less conventional design. In the typical unit whose schematic block and wiring diagrams are given in Figs. 2-11 and 2-12, respectively, signals for driving the cathode-ray oscilloscope are obtained from a portion of the output of picture-signal amplifier V18. This sample of the output signal from the camera-control unit is applied to the grid of oscilloscope amplifier V25, the output of which is used to drive the push-pull amplifier consisting of tubes V26 and V27, the latter obtaining its input signal from the cathode of the former. The output of the push-pull amplifier is then applied to the vertical-deflection plates of the 3-in. cathode-ray oscilloscope tube V17. Restoration of the d-c component is accomplished at this point with the aid of dual diode V28, in order to hold the negative peaks of the signal at a fixed position on the screen of the oscilloscope tube.

A very important adjunct in portable camera-control units is a built-in source of standard voltage that can be used for calibrating purposes. In the unit described two crystal diodes, CR6 and CR7, are employed in a circuit which, with the aid of horizontal driving pulses, produces pulses whose amplitude may be adjusted to a prescribed value with the aid of an adjustable potentiometer and a plug-in microammeter. Switch S5 permits

connection of the input of the oscilloscope amplifier either to this calibration voltage or to the output of the picture-signal amplifier.

The usual practice in waveform monitors is to provide means for selecting, at will, either one or the other of two horizontal scanning frequencies. One of the two possible scanning frequencies is equal to one-half the television horizontal scanning rate; the other is equal to one-half the vertical scanning rate. With these two horizontal scanning rates available, the cathode-ray oscilloscope may be used to display two cycles of either the horizontal or the vertical impulses, as detailed in Sec. 16-1. These scanning voltages are produced by a regulation saw-tooth generator, V20, the control pulses for which are obtained from dual triode pulse amplifier V19. Either horizontal or vertical driving pulses may be selected by means of switch S4 for application to the grid of this two-stage cascade amplifier. The former are employed to trigger the oscilloscope at one-half the line rate while the latter are used for a one-half field frequency rate. The saw-tooth output from V20 is applied to the grid of one section of dual triode V21, which constitutes a push-pull amplifier. The second section of this tube derives its driving voltage from the cathode circuit of the first section. The output from this horizontal-sweep output amplifier is applied to the horizontal-deflection plates of oscilloscope tube V17.

**2-6. Image Orthicon Application.** The image orthicon tube is admittedly a complex device. Consequently, in order to ensure proper operation and optimum performance from the tube, attention must be paid to a large number of details concerning its application. These include:

- a. Physical orientation limitations to guard against internal damage to the tube.
- b. Operating temperature ranges within which the tube will perform satisfactorily.
- c. Target-scanning precautions that must be taken to avoid premature failure of the tube.
- d. Dynode-spot limitations and their control.
- e. Ion-spot detection and correction.
- f. Retention of scene (picture sticking), avoidance and correction.
- g. Moiré pattern, limitation and avoidance.
- h. Resolution capabilities.

**Operating Position.** Image orthicons should preferably be operated in positions that avoid the possibility of any loose particles in the neck of the tube from falling down and striking or becoming lodged on the target. Under these circumstances, it is recommended that the tube never be placed in a vertical position with the base or multiplier end up and the

image end down. As a matter of fact, the tube should never be placed in any position where the axis of the tube makes an angle of less than 20 degrees with the vertical. This recommendation does not present any serious restrictions in television program production since exceedingly high angle "bird's-eye" views are very seldom encountered. Even when called for, the 20-degree-from-vertical restriction is not severe since (except for some very special need for an absolutely vertical shot) very high angles can be obtained while still observing the recommended precaution.

It is important to note, however, that the precaution should also be observed when the image orthicon is being handled during shipment, when being installed in a camera, or when set aside for storage purposes. The optically flat face at the image end of the tube presents a very inviting surface upon which to rest the tube when it is set aside for one purpose or another. Not only would such practice promote marring of this optical surface, but it would also risk the possibility of loose particles falling on the target.

**Operating Temperature.** The operating temperature of the target in the image orthicon tube must be maintained within certain prescribed limits if satisfactory performance is to be realized. Operation at too low a temperature is characterized by the appearance, upon removal of the light image focused upon the photocathode, of an afterimage which is of opposite polarity from the original and which gradually disappears. Operation at too high a temperature will cause loss of resolution because of reduced lateral insulation resistance of the target. The temperature of the target is essentially the same as that of the adjacent glass bulb, and experience indicates that the latter should be maintained between 35 and 60° C (95 and 140° F) for satisfactory operation.

It is also important that no part of the bulb should run more than 5 degrees hotter than the target section to prevent cesium migration to the target. Such migration will result in loss of resolution and in probable permanent damage to the tube. Like other photosensitive devices employing cesium, the image orthicon may show fluctuations in performance from time to time. Rigid observance of the above recommendations with respect to operating temperature will not completely eliminate these variations but will greatly improve the stability of the characteristics during the life of the tube.

When the equipment design or operating conditions are such that the recommended maximum temperature rating or maximum temperature difference will be exceeded, provision should be made to direct a blast of cooling air from the base or electron-multiplier end of the tube along the entire length of the bulb surface, *i.e.*, through the space between the bulb surface and the surrounding deflecting coil and its extension. Any at-

tempt to effect cooling of the tube by circulating even a large amount of air around the focusing coil will do little good. On the other hand, a small amount of air directly in contact with the bulb surface will effectively drop the bulb temperature. For this purpose, a small blower is satisfactory, but it should run at low speed to prevent vibration of the image orthicon and the associated amplifier equipment. Unless vibration is prevented, distortion of the picture may occur.

To keep the operating temperature of the large end of the tube from falling below 35° C (95° F), some form of controlled heating should be employed. Ordinarily, adequate heat will be supplied by the focusing coil, deflection coils, and associated amplifier tubes so that the temperature can be controlled by the amount of cooling air directed along the bulb surface. If, in special cases, a target heater is required, it should fit snugly between the focusing coil and the bulb near the shoulder of the tube. Target heaters are often included in the focusing-coil assembly of image orthicon cameras.

In practice, after the operating voltages are applied to the image orthicon, and with the camera lens capped, ½ to 1 hour should be allowed for warm-up of the tube. Ordinarily, adequate heat will be supplied by the focusing coil, deflection coils, and the associated amplifier tubes to bring the image orthicon tube temperature within its operating range. However, when the weather is cold, the warm-up period may be materially shortened by use of the target heater. Except under extremely cold conditions, it is not recommended that the target heater be used for more than about 5 minutes as excess heat may evaporate the cesium from the photocathode and impair the performance of the tube.

During the warm-up period, it is important that the deflection circuits be operating properly to cause the electron beam to scan the target. As a matter of fact, the deflection circuits should be adjusted so that the beam will overscan; *i.e.*, so that the target area scanned, both horizontally and vertically, is greater than its sensitive area. This procedure during the warm-up period is recommended to prevent burning on the target a raster smaller than that used during regular pickup operations. Note that *overscanning* of the image orthicon target creates a *smaller-than-normal* display on the picture monitor. This results from the fact that, when overscanning, no picture information is transmitted during part of each scan (in both the horizontal and the vertical direction). Consequently, with the raster of the picture monitor adjusted to normal size, those areas corresponding to the no-signal portions of the image orthicon scan will be blank in the picture-tube display.

**Scanning of Target.** The image orthicon target should always be scanned to full size. This type of operation can be assured by first adjust-

ing the deflection circuits to overscan the target sufficiently to cause the corners of the target to be visible in the picture and then by reducing the scanning until the corners just disappear. In this way, the maximum signal-to-noise ratio and maximum resolution can be obtained. Full-size scanning will also reduce the prominence of a beat pattern (see *Moiré Pattern*, below). If the target is underscanned for any length of time, a permanent change of target cutoff voltage of the underscanned area takes place, with the result that the underscanned area thenceforth is visible in the picture when full-size scanning is restored.

In order to ensure full-size scanning of a camera-tube target at all times, special monitoring procedures must be followed. It is not satisfactory, for example, simply to adjust the size of the scan until the image seen on a picture monitor just fills the area within the mask. The size of this display is, of course, a function of the height and width controls in the picture monitor and in this respect bears no relation to the size of the camera-tube raster. On the other hand, by always displaying the four corners of the picture produced by the camera tube, it is possible to determine precisely when the largest possible area of the target is being scanned.

Most picture monitors associated with camera-control units, however, employ a rectangular mask with rounded corners. If the picture display on these tubes is adjusted to fill the area within the mask, then the corners of the target are hidden from view by the rounded mask corners. Therefore, in order to display the four corners of the picture and ensure full scanning of the target, it is necessary to reduce the size of the display on the picture monitor tube below that normally used; *i.e.*, the raster must be brought inside the rounded corners of the picture monitor mask, as shown in Fig. 2-13.

Adjusting the size of the camera-tube scanning raster until a rectangular display with square corners is obtained is not sufficient, in itself, to ensure full-size scanning. As a matter of fact, any size of raster smaller than the maximum possible will result in a square-corner display. Therefore, in addition to observing the four corners, still another precaution must be taken.

The actual shape of the target in a camera tube is round, and the rectangular raster is normally located symmetrically within this area. If the camera-tube target were to be grossly overscanned, the resulting display on the picture tube would be a circle corresponding to the shape of the target as a whole. On the other hand, if the scanning is made just a trifle larger than the maximum possible for a truly rectangular raster, a small portion of the periphery of the target will be seen in the corners of the resulting display (see enlarged section of Fig. 2-13). The scanning raster

formed by the monitor tube will be rectangular of course, but the display in the roughly triangular area where the corresponding camera-tube raster runs off the target will be a dark area. Therefore, to ensure that the camera-tube raster is located symmetrically upon the circular target and is of the maximum possible size, the size and the centering of the camera scanning should be adjusted so that a minute portion of the periphery of the target is seen in each of the four corners of the picture.

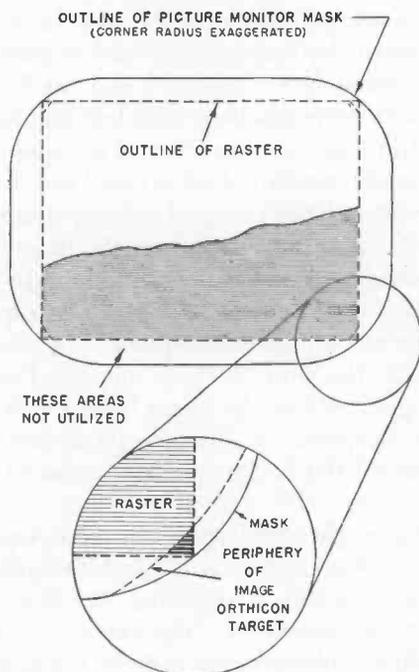


FIG. 2-13. Adjustment of the size of the display on an associated picture monitor, to show the corners of the raster, aids in avoiding underscanning of the target of an image orthicon.

Failure of the scanning for only a few minutes when light is incident on the photocathode may permanently damage the surface of the target. The damaged area shows up as a spot or blemish in the picture during subsequent normal operation. Removal of the multiplier voltage will not, of course, be of any assistance because the beam still will strike the target. Removal of the photocathode voltage is only a partial solution because light passes through the photocathode and strikes the target which, being nearly always somewhat photosensitive, will charge up and allow the beam electrons to land. The only positive method of preventing damage

in the event of scanning failure is to bias off the target screen. This may be accomplished by increasing the target-screen bias to at least  $-10$  volts. An automatic method of accomplishing this is to use a tube-actuated relay which is controlled by a portion of the scanning-pulse voltage developed across both the horizontal- and the vertical-deflection coils. It is important that failure of either the horizontal or the vertical scanning pulse results in the relay being actuated.

Another important precaution that must be observed in order to avoid premature failure of image orthicon tubes concerns the peculiar effect which may result when the beam of the tube is turned off (by biasing grid No. 1 to approximately  $-120$  volts) and the lens is capped. If a tube is operated under these conditions for half an hour or more and the beam is then raised to normal value without uncapping the lens, a white cloud of charge becomes evident. In this cloud may be seen some bright, sparkling points. Although the charge itself may disappear quickly, small semipermanent white spots may be left on the target of the tube at the points where the sparkling occurred. Unless the tube has been operated a number of times or for a long time with the lens capped and the beam off, these white spots will gradually disappear. In general, the better the resolution of the tube, the more likely is this effect to occur. To avoid this trouble, it is suggested that the beam be left at its normal operating point when the lens is capped. If there is a possibility of losing scanning, it is desirable to bias off the target screen in order to prevent damaging the target.

**Dynode Spots.** The slight scanning of the first dynode by the returning electron beam, as described in Sec. 2-1, *Electron-multiplier Section*, presents quite a serious problem in requiring that the dynode surface be completely free from imperfections. The amount of the scan is perhaps  $\frac{1}{4}$  in. and, as a result, any blemishes or spots on the dynode will be magnified manyfold in the final television picture. For example, when viewed on a 16-in. picture tube, a dynode surface imperfection appears magnified about 60 times. The system is, of course, a low-power electron microscope. Incidentally, the aperture of the gun, which has a diameter of about 0.002 in., is always present in the center of the dynode surface.

Fortunately, the dynode is usually not quite in focus for the best focus of the target. In some instances, especially for dark, low-key scenes, it may be necessary to defocus the picture very slightly in order to minimize dynode spots. When this must be done, it will usually be found that, if the potential of the orthicon beam focus grid No. 4 is *reduced* very slightly, the spots will go out of focus rapidly whereas the picture focus is imperceptibly affected. On the other hand, if the potential of this grid is *increased*, both the picture *and* the spots go out of focus at about the same

rate. A satisfactory compromise cannot be effected under the latter circumstances.

Dynode spots (see Fig. 7-3a) are always most prominent in the dark portions of a scene and, as a matter of fact, are the most severe limitation on resolution in low-key lighting. The spots are always white, indicating lower secondary emission from the areas where the imperfections are present.

**Ion Spots.** Occasionally, a white spot, which does not change in size when the beam-focus voltage is varied, may be observed in the center of the picture. Such a spot, especially if it is visible on the monitor with the camera lens capped, is probably an ion spot. If the spot begins to grow in size with continued operation of the tube, the tube should be removed from service at once and returned to the manufacturer for reprocessing. Continued operation of an image orthicon with an ion spot will eventually damage the target permanently.

**Retention of Scene.** Retention of a scene, sometimes called a "sticking picture," may be experienced if an image orthicon is focused on a stationary bright scene for several minutes or if it is focused on a bright scene before reaching operating temperature. Often the retained image will disappear in a few seconds, but sometimes it may persist for long periods before it completely disappears.

As mentioned in Sec. 2-1, *Scanning Section*, in a cycle of operation, the charges remaining on the target after the beam has scanned it must be neutralized by conduction through the glass target in the time interval of one frame or  $\frac{1}{30}$  second. Unless this occurs, a sticking picture, which will be of opposite polarity to the original one, will be seen when the original picture is removed and the camera focused on another scene. The sticking properties of an image orthicon depend upon the thickness and conductivity of the target glass and also the target-to-mesh spacing, particularly when the latter is very close. With a close-spaced assembly, the capacitance is larger and, consequently, the amount of charge to be neutralized is greater.

The sticking problem places a top limit on the resistivity of the target glass. On the other hand, in order to obtain good resolution the lateral leakage must be kept as low as possible by the use of a high-resistance glass and a glass target as thin as possible. Mechanical handling puts a lower limit of about 0.0001 in. on the thinness of the target. These two contradictory requirements are further complicated by the fact that, as with all materials, the resistivity changes with temperature. Consequently, at low temperatures, sticking becomes a problem, while at high temperatures the loss of resolution must be faced.

To avoid retention of scene, image orthicon tubes must always be

allowed to warm up properly as detailed in foregoing paragraphs. Furthermore, the camera should never be permitted to remain focused on a stationary bright scene for more than a few minutes. Finally, the amount of illumination on the photocathode should be limited, by proper choice of lens iris openings, to the amount necessary to obtain an excellent picture; more illumination than is necessary serves only to increase the possibility of scene retention.

A retained image can sometimes be removed by flashing the target with a beam of light or by focusing the image orthicon on a clear, white screen and allowing it to operate for several hours with an illumination of about 1 foot-candle on the photocathode. This value is equivalent to 50 to 100 foot-candles on the screen with an  $f/2.8$  lens.

**Moiré Pattern.** The target mesh of an image orthicon tube is spaced from the target by only a few thousandths of an inch at the most. Because the mesh is so close to the target, it is nearly at the point of focus of the scanning beam. As a matter of fact, if a wide-band amplifier is used, the mesh can be seen by careful observation of the resulting picture on a monitor tube. However, with the standard television bandwidth, it is just noticeable. Nevertheless, the problem of a moiré pattern caused by "beating" of the scanning lines with the lines of the target mesh does exist.

The maximum number of wires in a target mesh of practical construction is approximately equal to the number of scanning lines in the standard television frame. As a result, the wires in the mesh (it is actually produced by an electroplating process and has an equivalent wire diameter of about 0.0004 in.) can beat with the scanning lines to produce a low-frequency beat or moiré pattern. In practice, the possibility of this happening is reduced to a minimum by mounting the mesh so that its wires are at a 45-degree angle with the scanning beam. Yet, a moiré pattern (sometimes called a "swirl") may appear, particularly in large, highly illuminated areas of the scene. These patterns, if they appear, can be eliminated at a small sacrifice in resolution by slightly defocusing the scanning beam (grid No. 4). At times, a slight change in the vertical or horizontal size controls of the camera may be helpful in reducing the moiré pattern effect. Finally, by scanning as large a part of the target as possible so as to keep the picture height at a maximum, the beat pattern can be minimized.

**Resolution.** When the photocathode highlight illumination from a test chart (see Sec. 16-6) is above the knee of the signal-vs.-output curve, as explained in Sec. 2-7, *Photocathode Illumination*, the image orthicon is capable of producing a center resolution of the order of 600 lines in the horizontal direction (vertical test wedge). The vertical resolution, on the

other hand, is limited by the 525-line television standard. These values of resolution are those obtained after optimum adjustments have been made for all tube-operating parameters and are predicated on the associated video amplifiers and picture monitors being of adequate bandwidth to support this value of resolution.

**2-7. Image Orthicon Alignment.** The problem encountered in operating image orthicon tubes is a measure of the complexity of the tube. This complexity, however, makes it possible for the image orthicon to do what other camera tubes cannot do. In addition to its good resolution, an outstanding advantage of the tube is its exceptional sensitivity that enables it to pick up scenes illuminated at very low light levels. This not only extends the range of outdoor subjects that can be televised but also permits a great depth of field in studio productions with light intensities that are entirely reasonable. With a little training and experience, almost anyone can obtain reasonably good pictures from image orthicon camera equipment of good design. However, it takes considerable skill and the touch of the expert to obtain the best possible pictures that these cameras are capable of producing. For this reason the factors that go into making the best image orthicon pictures are described in detail in the following paragraphs.

**Scanning-beam Alignment.** Proper alignment of the scanning beam in an image orthicon camera is one of the most important steps in obtaining an excellent picture. Proper alignment is obtained when the resulting picture as seen on a picture monitor tube merely goes in and out of focus and does not rotate or swirl as the orthicon focus voltage (grid No. 4) is varied about the best-focus position. An even more critical test is that of observing the action of the dynode spots (which are most prominent with no illumination on the photocathode) when the amplitude of the alignment-coil current and the direction of the magnetic field are varied. When the alignment is correct, one of two things will happen: either the dynode spots will change focus without changing their location on the screen, or they will be astigmatic in appearance, becoming elongated in one direction for a value of orthicon focus voltage slightly less than normal and elongated in another direction for a focus voltage slightly more than normal. The importance of obtaining the best alignment on the resolution, the signal-to-noise ratio, and the over-all picture quality cannot be overemphasized.

**Focus-coil Current.** If the focus-coil current is changed, the alignment may no longer be correct for the new operating condition. A fixed value of current in the focus coil, which corresponds to the correct value of magnetic field (*e.g.*, 75 gauss) in the center of the focus coil, is usually recommended.

It is not good practice to attempt to adjust performance by varying the focus-coil current as it leads to misalignment of beam, change in orthicon focus voltage, and change in image focus voltage. This unduly complicates adjustment procedures, offers no advantages, and should, therefore, be avoided. One should keep in mind that a given focus field automatically determines both the orthicon focus voltage and the image focus voltage for an image orthicon tube. Manufacturing tolerances for image orthicons can be held to such narrow limits that tubes can be switched in a camera, and after alignment of the scanning beam, only small adjustments of orthicon and image focus voltages are necessary to obtain optimum focus conditions.

**Beam Current.** The adjustment of the beam current of the image orthicon tube has an important bearing upon the picture quality. The beam current, as it leaves the electron gun, is a direct current; *i.e.*, it contains no signal modulation. In the process of scanning, electrons are attracted to the target in sufficient quantities to neutralize the configuration of charges that are created on the target by reason of light falling on the photocathode. These are subtracted from the original scanning-beam current, thereby modulating the returning beam and forming the picture signal. This return beam, after considerable amplification by the electron-multiplier section of the tube, flows through an output resistor and makes available a video signal voltage.

It is evident, from consideration of this action, that in a black portion of a scene all the scanning-beam electrons come back to the multiplier. In the highlights, however, only a part of the electrons return as the others are removed from the beam to neutralize the charge on the target. Assume, for a moment, that for a given picture the beam current is deliberately increased to a value considerably larger than necessary to neutralize the highlight charge. For the black portions of the picture, all the scanning electrons return to the multiplier. In the highlights, only a small number of the total beam electrons are required for target discharge, the remainder returning to the multiplier. Under these circumstances the percentage modulation of the electron beam is low. On the other hand, since beam noise is proportional to the square root of the beam current, the noise will be relatively high. The net result is that, under these conditions of operation, the signal-to-noise ratio for the picture is poor.

The obvious procedure for obtaining the highest signal-to-noise ratio is to keep the beam current as low as possible consistent with providing enough electrons to neutralize the charge created by the brightest highlight in the scene. In practice, some allowance or safety factor must be provided, of course, to take care of some unusually bright, unexpected highlight that may be introduced during the action. Without this reserve

beam current, if an extra-bright highlight is encountered, it will result in white compression since the depth of beam modulation cannot be adequately increased. However, there is nothing to be gained and a great deal to be lost by the use of excessive beam current. There is considerable to be gained by proper adjustment of the beam current.

**"S" Distortion.** If a straight, horizontal line in the picture is curved like the letter "S" on its side, it is probable that the ratio of the photocathode voltage to image accelerator voltage (grid No. 6) of the image orthicon is incorrect. This distortion often may be corrected by adjustment of these two potentials only, although, under some circumstances, it may be necessary to change the focus-coil current also. If the latter is required, it will be necessary to repeat the entire series of camera and camera-control setup adjustments.

**Target-screen Potential.** In typical image orthicon tubes, when the target-screen potential is made a volt or two negative with respect to the cathode, a cutoff point is reached and no picture signal results. As the target-screen potential is made a few volts more positive than the cutoff value, the picture signal appears. The optimum target-screen potential depends to a great extent upon the average scene brightness. The effect of different values of target-screen potential on the gray-scale rendition of scenes of high- and low-average scene brightness is shown in Fig. 2-14. These curves are representative of the dynamic transfer characteristics of an image orthicon tube. They are seen to differ very radically from the typical static output curves of image orthicon tubes (Fig. 2-14*b*). These curves are adapted from data presented by Schade<sup>4</sup> and were calculated on the basis of the video gain and blanking being adjusted in each case for constant signal amplitude. The dynamic transfer characteristic of the image orthicon with a target-screen potential 1 volt more positive than cutoff is shown in Fig. 2-14*a*. Under these operating conditions, it is evident that with a scene of high average luminance (high-key scene), low and intermediate tones (the blacks and grays below a relative luminance of 0.2), will result in practically no discernible detail. In other words, these tones are completely suppressed. However, in a low-key scene, one having low average luminance, a brightness range of perhaps 10 to 1 can be handled. In actual practice, an adjustment which resulted in an operating condition as shown by this illustration would be intolerable. If a performer's face registered a relative luminance of 0.3 and he were to walk from in front of a low-key background to a second position in front of a high-key background, his face would change from white to black! Under these circumstances, as shown by the curves, when in front of the

<sup>4</sup> Schade, O., *Electro-optical Characteristics of Television Systems*, RCA Rev., Vol. IX, Nos. 1, 2, 3, and 4 (March, June, September, and December, 1948).

low-key background, the relative output voltage would be some 70 per cent; when in front of the high-key background, it becomes only 15 per cent.

The dynamic transfer characteristics of the image orthicon with the target screen adjusted to a potential 2 volts more positive than cutoff is

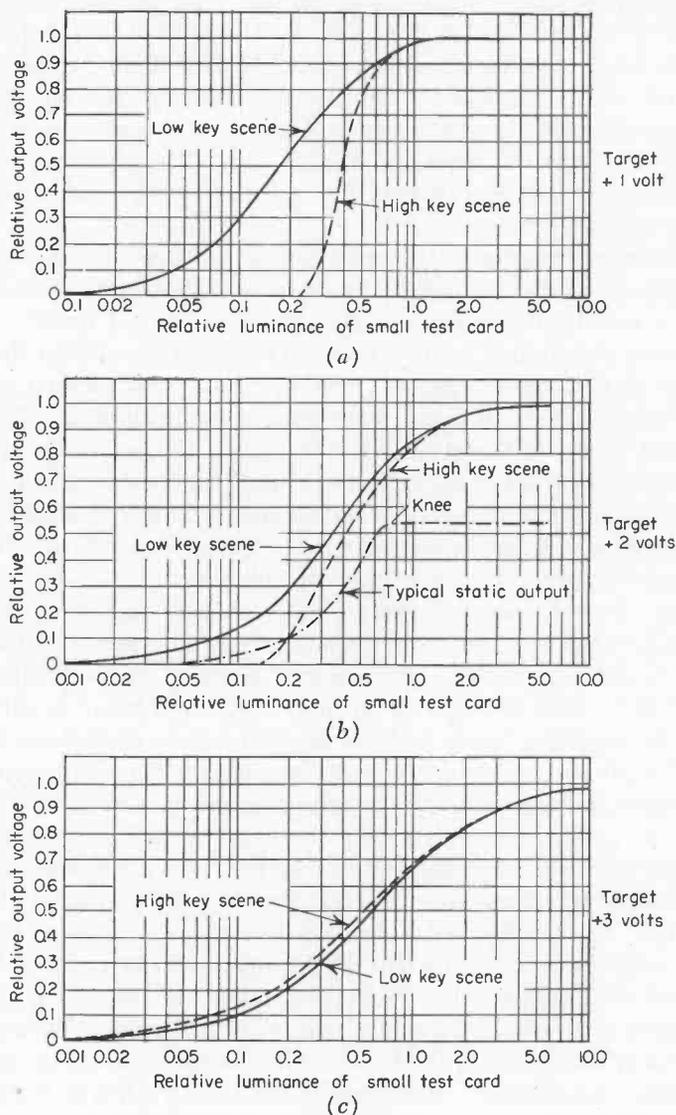


FIG. 2-14. Dynamic transfer characteristics of the 5820 image orthicon camera tube for three values of target-screen potential.

shown in Fig. 2-14*b*. Compared to the preceding condition, less severe suppression occurs for high-key scenes. Under these circumstances a brightness range of perhaps 20 to 1 can be accommodated (relative luminance from 3.0 to 0.15). In this illustration, for comparative purposes, there is presented a typical static output curve for the image orthicon. The great difference between the two curves is accounted for by the electron redistribution effects that take place on the target of the image orthicon.

When the target-screen potential is adjusted to a value 3 volts above cutoff, the transfer characteristic shown in Fig. 2-14*c* is obtained. Here the secondary electrons are prevented from landing on the target and filling in "black" areas by the relatively high screen-to-target potential. Instead, they are collected by the screen. As the target-screen potential is increased, a longer and more stable gray-scale or dynamic characteristic is obtained. However, the upper limit is set by signal-to-noise ratio considerations. Greater target-screen voltage requires higher beam current to discharge the highlights which (see Sec. 2-6, *Scanning of Target*, above) results in a lower signal-to-noise ratio. Experience indicates that target-screen potentials in the range between 1.6 and 2.2 volts above cutoff usually result in an optimum picture. Above these values, the signal-to-noise ratio is poorer than needs be; below them, it is often difficult to handle the shading. In addition, higher target voltages tend to emphasize small black spots which may be practically invisible when the tube is operated within normal voltage range.

The importance of properly adjusting the target-screen potential of all image orthicon cameras in order to obtain uniform transfer characteristics is evident from a study of Fig. 2-14. Unless the proper target-screen potential is used, there may be a very decided change in the contrast of the picture signal upon switching from the output of one camera to another. It is also apparent that both the target-screen potential and the beam current must be adjusted simultaneously to obtain the best signal-to-noise ratio.

**Photocathode Illumination.** The amount of light on the photocathode has considerable bearing upon the picture quality obtained from an image orthicon camera. For a given amount of illumination on the scene, the photocathode illumination is a function of the iris opening of the lens. In general, it is desirable to keep the lens stopped down (*i.e.*, larger  $f$  or smaller  $T$  numbers) as much as possible, consistent with other considerations, in order to obtain the maximum depth of focus. On the other hand, if the lens is stopped down too far, resolution in the image orthicon will be lost and the signal-to-noise ratio will decrease. In situations where insufficient illumination of the photocathode is experienced, even with

the lens iris wide open, some improvement of the picture quality may be obtained by slight readjustment of the target-screen potential and the beam current.

Where an adequate amount of lighting is available, it is customary to adjust the iris of the lens so that the highlights in the scene bring the signal output of the image orthicon slightly above the knee of the output signal curve. The knee is that point where the signal resulting from the highlights begins to drop appreciably as the lens opening is decreased in size. Operation at this point is especially important in studio operation (as discussed in greater detail in Chap. 7) in order to obtain the best gray scale in the picture and to reduce the possibility of image retention (see Sec. 2-6, *Retention of Scene*, above). Operation farther along the horizontal part of the curve may give pictures in which the subject has an overemphasized outline.

For outdoor scenes where a wide range of illumination may be encountered and where the best lens opening cannot always be selected for each scene, the best compromise is usually that wherein the highlights of the least illuminated part of the scene bring the signal just above the knee of the output signal curve.

## CHAPTER 3

# Field Television Equipment

ALMOST WITHOUT EXCEPTION television broadcasting stations commence their origination of "live" program material with transportable field pickup equipment. As a matter of fact, unlike aural broadcasting practice, some stations may never become equipped with permanent, studio-type television camera facilities. A number of factors contribute to this situation: First, some stations may begin operations with nothing more for program origination than a film projector, a slide projector, and a film camera chain. Second, if the station is fortunate enough to be on a video network route it will probably depend upon the television networks for the bulk of its program material. If the station is not so fortunately located, it may still rely upon the networks for most of its program material but, in this case, it will be obtained through the medium of television recordings (see Chap. 11). Third, when the station begins its local program originations, it will probably wish to broadcast public events, athletic contests, and other off-premise newsworthy and interesting programs. Program material of this kind is almost always of considerable interest to the television audience and usually requires the minimum of preparation on the part of the broadcaster. Finally, when the television broadcaster does go to the expense of fitting out his own studio, he usually already has available field pickup equipment which, if it is not assigned elsewhere, may be used to good advantage in making the studio pickup. As a matter of fact, because of their expense, it behooves him to schedule his programs so as to obtain the maximum use of available television camera chains. By scheduling network or film programs between live pickups, it is possible to employ one set of field pickup equipment for several live program originations during the course of a given program period.

**3-1. Field Pickup Systems.** Television field pickup facilities<sup>1</sup> consist of transportable equipment units and accessories that are capable of producing a composite picture signal, together with the associated audio sig-

<sup>1</sup> Roe, John H., New Television Field Pickup Equipment Employing the Image Orthicon, *Proc. IRE*, Vol. 35, No. 12, p. 1532 (December, 1947).

nal, from either a fixed or a mobile location in the field. The video portion of the system usually consists of (a) one or more cameras, associated view finders and control units, (b) a synchronizing waveform generator, (c) a switching and amplifying system which provides means for selecting for transmission the outputs of the various cameras, (d) picture and waveform monitors, and (e) the necessary power supplies. Tripods, friction heads, operating desks, shockmounts, and connecting cables are some of the accessories usually required to supplement the basic video equipment.

The audio portion of the system is often comprised of one or more microphones and a portable audio amplifier which incorporates (a) means for mixing the outputs of a number of microphones, (b) visual monitoring facilities, and (c) sufficient amplification to provide a signal of required level for transmission of the audio portion of the program to the main television studios or transmitter. In addition, aural monitoring means (usually headphones) are provided. Accessory audio equipment may include microphone stands, highly directional pickup microphones (for crowd or band pickup at athletic fields), connecting cables, and the required power supplies.

Other items that are often a part of a television field pickup unit include (a) especially designed cars or coaches for transporting the equipment, (b) gasoline-driven primary power supplies, (c) relay transmitters and receivers, and (d) portable lighting equipment.

An exceedingly vital part of any television field pickup system is the intercommunication system that is required to effect liaison between the various members of the field crew. Instantaneous telephonic communication must be available to cameramen, camera-control men, the video switcher, the audio man, the program director, the relay transmitter crew, and any others responsible for the production of the program.

A typical arrangement of the equipment that makes up a television field pickup system is shown in schematic form in Fig. 3-1. This illustration includes the camera equipment, necessary switching facilities, radio relay equipment, and a mobile unit. A simplified indication of the equipment interconnections is also shown.

The two upper-left blocks enclose the camera equipment required for a two-camera system. The block (dotted lines) in the lower left of the figure illustrates how other cameras, up to a total of four, may be added to the system. The equipment shown in the center and on the right of the illustration represents units that are common to the entire system, whether it is composed of two, three, or four cameras. The upper center block encloses the field-synchronizing waveform generator equipment. This may consist of a pulse-former unit and a pulse-shaper unit as shown or, in some instances, both functions are performed by a single unit. The

lower center block encloses the video switching equipment, a picture and waveform monitor unit, and the power supply for both. In some equipments, the switching and monitoring equipment are contained in a single unit.

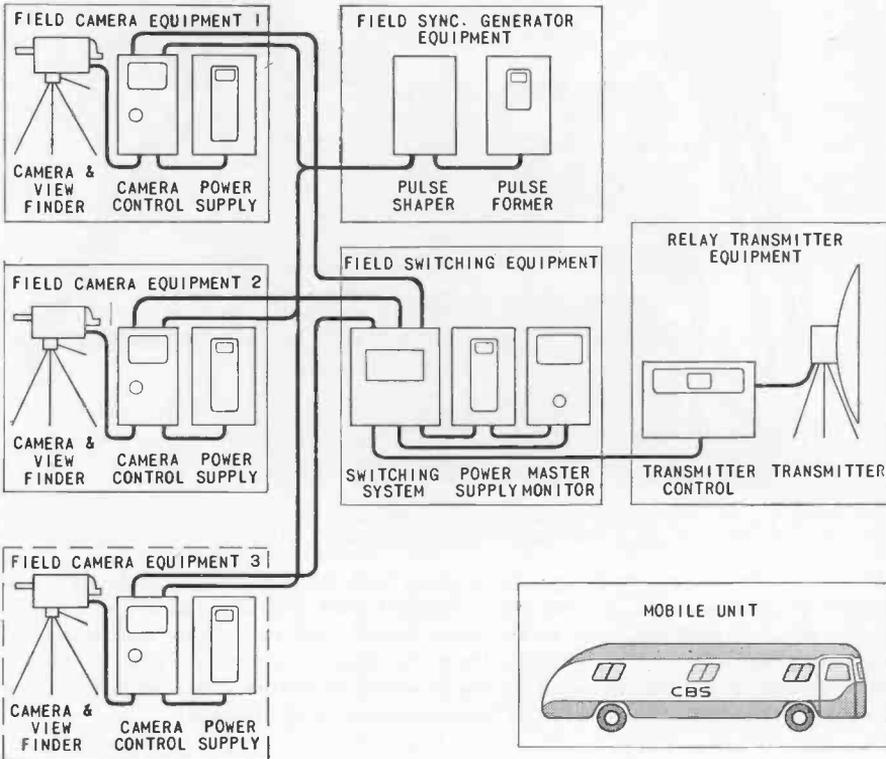


FIG. 3-1. The main equipment units of a multicamera field pickup system and the general plan of their interconnection.

The blocks to the right of Fig. 3-1 enclose the radio relay transmitting and receiving equipment which may or may not be needed for transmitting the television signal back to the main studio or transmitter plant. Where video circuits are available and used, this relay equipment is not required.

A two-camera chain of portable type is shown set up on a table in Fig. 3-2. The image orthicon camera, its associated control unit, and the technique of their use are described in Chap. 2. The remaining equipment employed for field applications, with the exception of the synchronizing waveform generator (see Chap. 5), is described in the following sections.

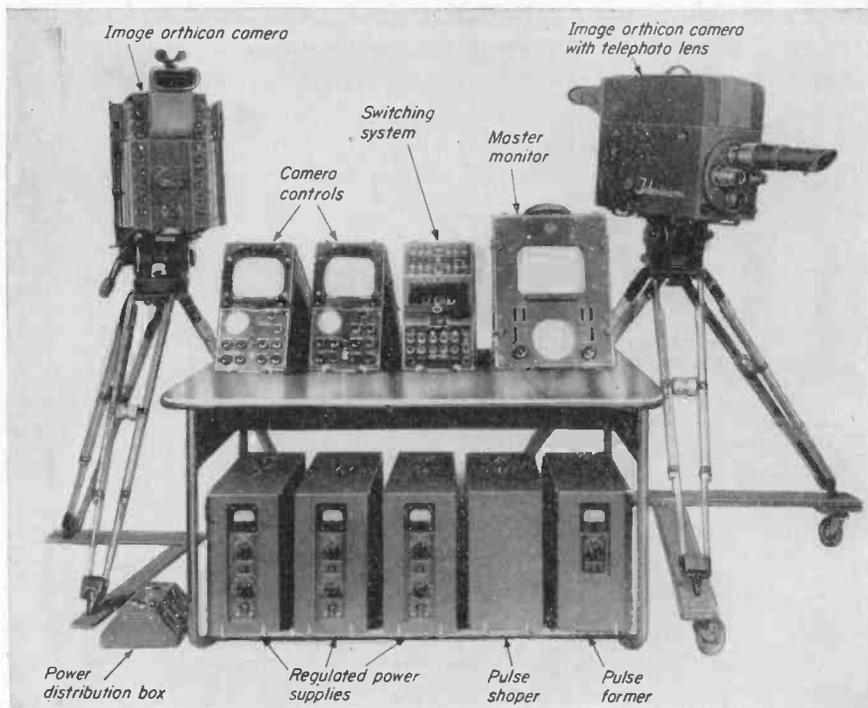


FIG. 3-2. The units comprising a two-camera field chain include, in addition to the tripod-mounted cameras, the two camera-control units shown at the left end of the table, the field switching unit to the right thereof, and the picture and waveform monitor at the right end of the table. Under the table there are three portable power-supply units, at the left, followed by synchronizing waveform generator pulse-shaper and pulse-former units. (Courtesy of Radio Corporation of America.)

**3-2. Video Mixer and Switching Units.** Except for the most elementary kind of television program production, two or more cameras are always used for pickup purposes. On the other hand, more than four units are seldom employed except on those special occasions where the action originates at such widely separated points that an unusually large number of cameras are necessary to cover all scenes of action. Facilities are therefore needed for selecting the output of the particular camera that is to be connected to the broadcasting transmission system at a given moment. Just as in an audio system, means should be provided both for instantaneously switching from one camera to another and for fading out the picture from one camera and fading in a scene from another source. Furthermore, provisions are frequently desired for creating a dissolve, *i.e.*, the momentary overlapping of pictures from two cameras and then the gradual fading

out of one. A variation of this technique is the superimposition, wherein the outputs of two picture channels are displayed at the same time, superimposed on each other.

The typical mixer amplifier and monitor unit shown in Fig. 3-3 has provisions for handling four incoming sources of picture signals and providing a single output signal. Four separate video amplifier channels are provided, one for each input, each with its own manual gain control and push-button switch. These controls provide, respectively, for (a) adjusting the gain and, therefore, the output level of each channel separately and (b) instantaneous electronic channel selection. In addition, a circuit is provided for automatic fades or dissolves, the choice of one or the other being made by means of a suitable switch. When an automatic fade or dissolve is made, any of three rates of change may be preselected by switch operation. These controls make it possible to (a) automatically fade to black at a preselected rate and then to fade in the next scene or (b) automatically dissolve from one scene directly into the next.



FIG. 3-3. A portable video switching unit that incorporates, in addition to the usual manual controls, automatic means for dissolving from one camera output to that of another. (Courtesy of Allen B. Du Mont Laboratories, Inc.)

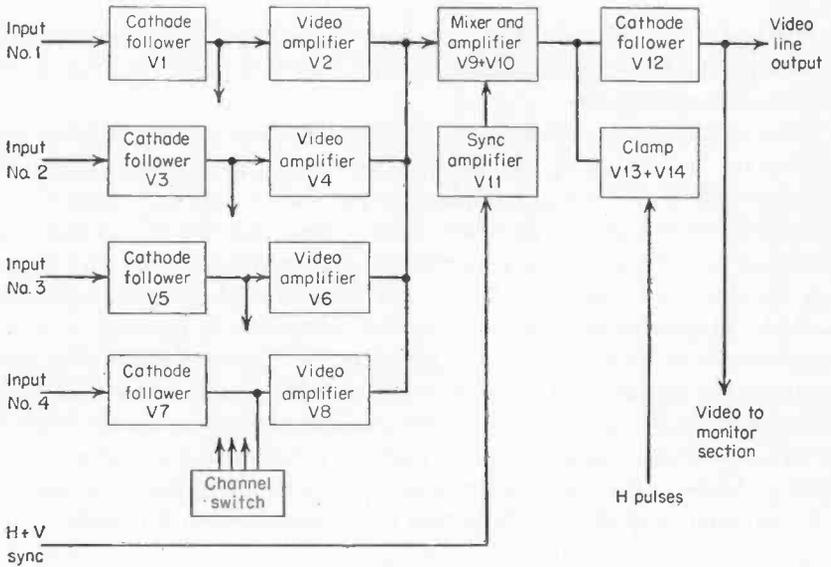


FIG. 3-4. Schematic block diagram of the mixer-amplifier section of the video switching unit shown in Fig. 3-3.

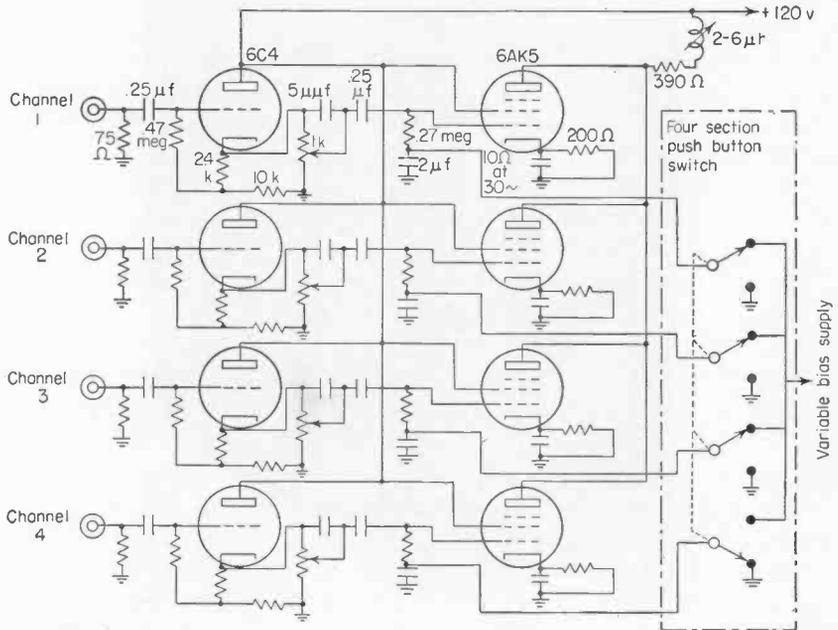


FIG. 3-5. Schematic circuit diagram of the automatic electronic mixer portion of the video switching unit shown in Fig. 3-4.

Video mixer units also incorporate synchronizing pulse-mixing circuits; in addition, the particular equipment illustrated contains a picture and a waveform monitor. These latter facilities are sometimes mounted in a separate assembly as is the case for the equipment shown in Fig. 3-2.

A block diagram of the mixer-amplifier section of the video mixer and switching unit of Fig. 3-3 is given in Fig. 3-4. A schematic wiring diagram for the automatic electronic mixer portion of the circuit is shown in Fig. 3-5. The operation of the unit is described in the following paragraphs.

**Video Mixer Circuits.** Each of the four incoming video signal channels consists of a cathode follower (V1, V3, V5, V7) and an associated voltage amplifier (V2, V4, V6, V8) having a gain of about two times. In accordance with standard practice, the input impedance of each channel is 75 ohms, and one side of the circuit is grounded. There are manual gain controls in the input of each channel which are physically located on the front panel of the unit (Fig. 3-3). In addition, between each cathode follower and its associated voltage amplifier there is an additional gain control. The purpose of this secondary control is to permit adjustment of the output level of all channels to the standard transmission level when the primary or manual gain controls are turned to their full-on positions.

When employed, automatic switching between channels is accomplished by individual adjustment of the grid bias of the four amplifier tubes. In switching from one channel to another, for instance, the negative bias on the channel that is to be turned off is gradually increased while that of the channel that is being turned on is gradually reduced to the correct value to permit the tube to function as a normal amplifier. Control of the rates of rise and fall of these bias voltages and, consequently, of the rate of fading is accomplished by the use of suitable resistor-capacitor networks in the bias supply.

By reducing the time constants of the bias circuits to a very low value, essentially instantaneous switching from channel to channel may be accomplished. However, the relatively rapid rate of change of plate current caused by turning off one tube and turning on another introduces an undesirable surge in the video circuit. This effect is eliminated, however, by the clamper, V13 and V14, which is connected across the input to the cathode follower that comprises the output stage of the unit.

**Video-signal Amplifier.** The output of the video mixer amplifiers is coupled by means of a suitable frequency-compensating network to parallel-connected amplifier tubes V9 and V10. This stage provides a voltage amplification of approximately four times. The output of this stage, again with the aid of frequency-compensating networks, drives the

cathode follower V12. This tube serves as the output stage and has an effective gain of about 0.4 times. It is capable of supplying a 2-volt peak-to-peak, black-negative video signal into a 75-ohm load. Being a directly coupled circuit, part of the cathode direct current flows through the load that is coupled to this amplifier.

**Synchronizing-signal Amplifier.** With single-camera operation, it is customary to add both blanking and synchronizing pulses to the picture signal in the camera-control unit (see Sec. 2-5, *Picture-signal Amplifier*). Accordingly, the output signal is of standard composite form ready for transmission to the remainder of the broadcasting system. No mixing or switching units need be employed under these circumstances.

On the other hand, when multiple-camera operation is practiced, only blanking signals are added in the camera-control units, and the several resulting video signals are then transmitted to the mixer and switching unit. The synchronizing signals are then added after all picture-signal mixing and switching operations take place. This avoids the possibility of losing the synchronizing information at any time during the switching processes. In other words, even though the picture should be faded to black, the correct synchronizing pulses will continue to be sent to the remainder of the transmission system (see also Sec. 6-5, *Remote Inputs*).

In the switching unit illustrated, horizontal and vertical synchronizing pulses from the synchronizing generator are amplified by tube V11. The output of this amplifier is added to the video signal by virtue of a plate load resistor that is common to the video amplifier tubes V9 and V10 and the synchronizing amplifier tube V11. The gain of the synchronizing signal amplifier is manually adjusted by means of a gain control in its input circuit. This control is mounted on the front panel of the mixer-amplifier unit and upon proper adjustment completes the formation of a standard composite television signal for transmission to the remainder of the broadcasting system.

**Clamper Circuits.** A clamper, consisting of tubes V13 and V14, is connected across the input of the cathode-follower output tube in order to maintain a constant black level in the composite output signal. In addition, the clamper improves the effective low-frequency response of the video amplifier, eliminates low-frequency pickup and the surges introduced by switching operations. Keying pulses for the line-to-line clamper tubes are derived from the horizontal blocking oscillator tube.

**3-3. Master Monitors.** In order to provide a means for evaluating both the picture composition and the quality, camera-control and video switching units must be accomplished by a picture monitor. It is customary for the unit employed for this purpose to display, at all times, the picture that is being transmitted to the outgoing broadcasting circuit. As already

noted (Sec. 2-5), each camera-control unit is normally equipped with a picture monitor. However, in order that all concerned may know which picture channel or combination of channels is being broadcast at a given instant, there is need for a "master" picture monitor connected across the outgoing circuit at a point as close to the line terminals as feasible. Thus, the results of all channel mixing, switching, gain adjustment, and other signal manipulation are visually displayed for monitoring purposes.

In addition to facilities for evaluating the picture content, there is need of means for monitoring the amplitude of the composite signal waveform. A cathode-ray oscilloscope is provided, therefore, in each camera-control unit. Again, however, an over-all or "master" waveform monitor is essential to ensure the transmission at all times of signals of standard amplitude and correct video-to-synchronizing signal ratios.

Some field pickup equipment systems employ a separate unit for the master picture and waveform monitors as, for example, that shown in Fig. 3-2. Other systems, such as shown in Fig. 3-3, incorporate the master monitoring facilities in the same unit with the mixing and switching equipment. Both arrangements have their advantages and disadvantages, and neither can be said to enjoy an outstanding superiority over the other. The separate unit type of assembly is also often used for studio installations; consequently, a description of this kind of picture and waveform monitor is given in Sec. 6-8 rather than here.

**3-4. Intercommunication Facilities.** In order to facilitate the establishment of intercommunication circuits among the various members of a television field pickup crew, it is customary to include telephone circuit jacks on various equipment units. In addition, the necessary wire circuits are usually included in the interconnecting cables that are an important part of the field pickup facilities. For example, field camera units almost always have at least one telephone outlet jack, and sometimes two, located on the camera head. Where only one jack is provided, it is used by the cameraman himself. If a second telephone circuit is available, it is sometimes used by a program director's (or production manager's) floor assistant, although a radio-frequency communication channel is generally preferable for this service (see Sec. 6-13, *Radio Cueing System*). On occasions where a camera dolly is used in the field and a special operator is required to manipulate it, this assistant may make use of the second telephone communication facility. Furthermore, a telephone circuit jack is sometimes, but not always, included as a part of the camera-control unit. In field practice, the camera-control units are often set up immediately adjacent to the position of the program director and the video switcher. Accordingly, satisfactory communication often can be effected without the need for telephone circuits and instruments. The program

director and the video switcher (who is also often the technical crew chief) have frequent need for communication to production assistants, to the cameramen, to the mobile unit (if in use), and back to the main studios or the transmitter. Telephone outlets and telephone circuit switching facilities must, therefore, be provided to meet these needs.

One manufacturer has incorporated the intercommunication switching circuits in the same unit that contains the video switching equipment (Fig. 3-2). The upper two-thirds of the front panel of this unit constitutes a small telephone switchboard.

An important part of the communication and cueing facilities is the system of signal or tally lights employed to indicate which camera is being used at a given moment for picture transmission purposes. It is customary to provide tally lights on the front or lens side of the television camera (see Fig. 14-12) and also on the back or operator's side of the unit. In the latter case, a large signal light is usually placed on the control panel surface of the camera and a very small one alongside the picture tube in the electronic finder. This ensures that the operator will be warned when his camera is switched on even though he may be looking into the hood that is often used to shield the view finder picture tube from ambient light. Signal lights are also included on the camera-control units so that the operators at this point will know which camera is on the air at any instant. The camera actually in use should, of course, receive the undivided attention of the camera-control man in order to ensure that the best possible picture signal is obtained. Finally, signal lights are usually included as a part of the camera switching and fading unit in order to indicate quickly to the video switcher the position of all controls.

**3-5. Camera Tripods and Friction Heads.** A substantial and firm mounting arrangement is essential to support the television camera, if images free from "jitter" are to be secured. In addition, a solid, vibration-free platform must be available for holding the camera support and the cameraman who is responsible for operation of the camera. When setups are made in the field, particular attention must be paid to the selection of the camera locations because of this latter requirement. Not infrequently at a ball park, sports arena, or convention hall, a very attractive site is found and a camera setup made prior to the start of the event to be broadcast. Then, when the spectators arrive, it is discovered to the dismay of those responsible for the television pickup that the activities of the crowd result in violent (or at least objectionable) vibration of the camera platform. Good judgment must obviously be used in the selection of camera positions during the preliminary setting up of the television facilities.

For field applications, tripods are almost universally used for camera supports. These units are built along the conventional lines of motion-

picture-camera tripods and are made of metal or of wood with metal fittings. A tripod of the former type is shown in Fig. 3-6. This particular unit consists of a structure of aluminum castings and tubular steel which results in a compact, lightweight, yet rugged design. It folds into a small unit which is easily transportable. When collapsed for carrying, the unit

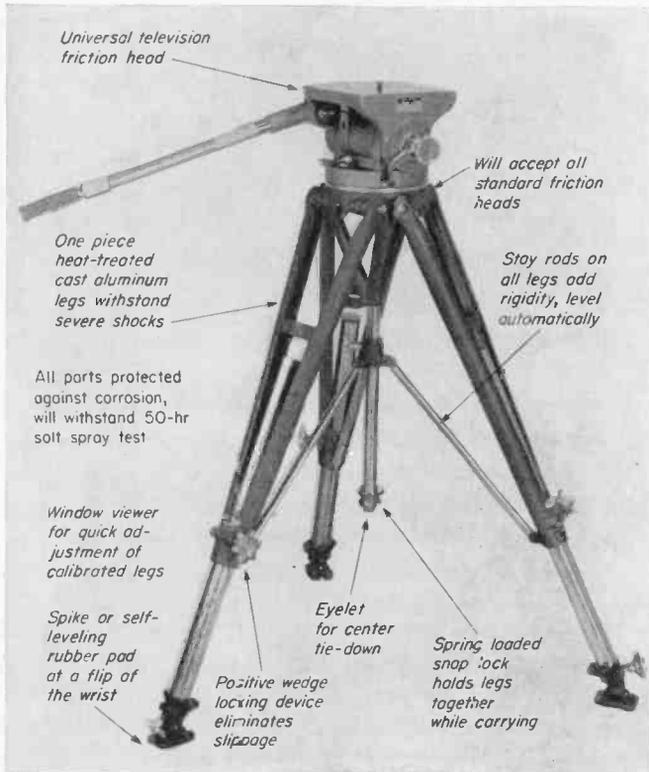


FIG. 3-6. A sturdy all-metal television-camera tripod that incorporates a number of desirable design features. (Courtesy of Radio Corporation of America.)

is about 32 in. long and 10 in. in diameter and weighs 25 lb. In operation, the tripod provides a working height ranging from approximately 25 to 42 in. Particularly valuable features of the unit shown are the individual tie rods which connect to and brace all tripod legs. These tie rods are coupled to a center stabilizing post and provide a stable rigid support.

The lower tubular portion of each leg is adjustable and slides within a long bearing which is held to close tolerances. Thus, minimum play and maximum rigidity are assured throughout the working range. When the tripod legs are adjusted for the desired height, they may be locked in posi-

tion by means of hand-operated clamp screws. The lower end of each leg is provided with a self-aligning universally mounted footing. On one side, this footing has a flat surface for use on level flooring; on the other side, it has a steel spike for use on rough surfaces. With the tripod legs fully extended, the feet may be placed upon the circumference of a circle having a maximum diameter of 70 in.



FIG. 3-7. A complete assembly consisting of an image orthicon camera, camera friction head, tripod, and tripod dolly primarily intended for field use but also satisfactory for some studio applications. (Courtesy of Houston-Fearless Corp.)

A tripod such as that just described more or less requires that the camera be set up in one place and remain there throughout the program. In those instances where a reasonably smooth surface is available, it is often advantageous to be able to wheel or dolly the camera to different positions. In studio applications, relatively heavy pedestals or camera dollies may be used for this purpose. For field applications, on the other hand, readily transportable equipment is required. A dolly suitable for use with the tripod just described is illustrated in Fig. 3-7. The unit consists of a lightweight (25-lb) triangular-shaped steel structure supported on three swivel wheels 5 in. in diameter. For convenience in transporting, the dolly folds into a self-locking package 8 by 14 by 29 in.

In order to provide a means for obtaining the smooth motion that is essential when the camera is turned and tilted to follow the action being televised, a camera friction head is used to couple the television camera to the tripod or other camera support. The typical camera friction head shown in Fig. 3-8 permits complete rotation in azimuth and ample tilt for any television camera applications. It is so designed that the camera may be swung and tilted in any direction with a minimum of effort and left in any position without the need for clamping unless it is desired to do so.

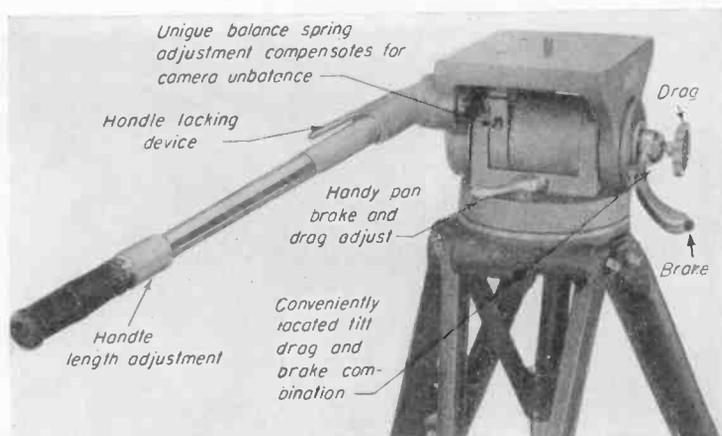


FIG. 3-8. This camera friction head is an ingenious spring-loaded ball-bearing device that permits a camera mounted thereon to be trained to the desired angle in azimuth and bearing and, by virtue of controlled friction, to hold the camera in the desired position without the need for clamps. (Courtesy of Radio Corporation of America.)

On the other hand, there are separate locking arrangements for both tilt and panning positions. That is, when one lock is applied, the camera can only be panned; when this is released and the other applied, the camera can only be tilted. When both are released, the camera can, of course, be panned and tilted simultaneously. A friction shoe permits adjustment of the tilting friction to suit the individual cameraman. Ball bearings in races on both ends of the tilt shaft and a large ball thrust bearing for panning assure smooth tilting and panning action. Ball thrust bearings and the afore-mentioned friction control adjustment provide for smooth panning and tilting action. Counterbalancing springs keep the camera in balance in any position of tilt. A detachable adjustable-length telescopic handle provides a means for tilting and panning the camera as desired.

**3-6. Portable Audio Facilities.** Audio facilities are an indispensable part of the equipment needed for producing a television program from a field location. For this application, it is customary to employ portable

equipment to amplify the exceedingly low output level of the pickup microphones, to combine or mix this program material in the desired proportions, to adjust the result to the proper transmission level, and to provide means for visually monitoring the outgoing program level and for aurally monitoring the program content. Various types of microphones are employed for field application, and there are a number of compact lightweight portable amplifier-mixer-monitor equipments available for this service. Representative components are described in the following paragraphs.



FIG. 3-9. A moving-coil-type microphone suitable for field applications. (Courtesy of Radio Corporation of America.)



FIG. 3-10. Microphones placed in parabolic reflectors are sometimes useful for picking up distant musical bands or cheering sections at outdoor athletic events.

**Microphones.** For the most part, the audio portions of a television pickup originating in the field consist of the voices of the commentators and the sounds that accompany the event, including those of the spectators and of the people and things that comprise the occurrence being broadcast. Usually this calls for two types of microphone pickup: First, there is the relatively close-talking pickup to accommodate the commentator and persons that may be interviewed. Second, there is the distant pickup of crowd noise, music, and other sounds.

Microphones for field use must be exceptionally rugged, weather-resistant, relatively immune to wind noise, and light in weight. One type of unit for commentator use is the moving-coil microphone (Fig. 3-9).

For picking up sounds associated with the event being broadcast, it is often desirable to make use of highly directional microphones. A simple parabolic reflector, with a microphone located at the focus, has often been used for this purpose (Fig. 3-10). However, in order to obtain an appreciable gain in sound pressure at the focus, the reflector must be large compared to the wavelength of the incident sound. The requirement of

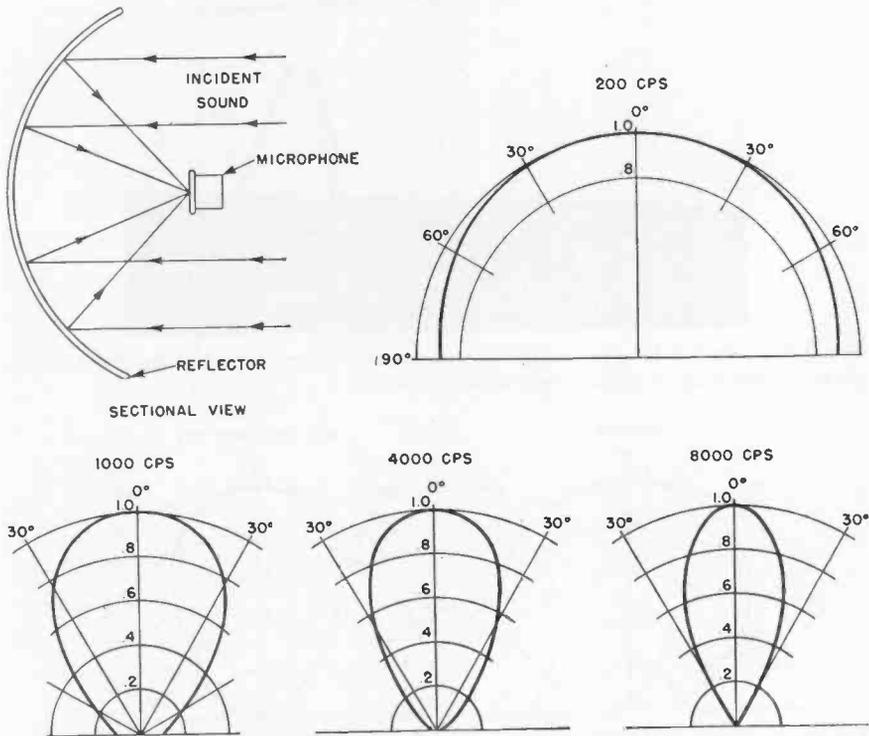


FIG. 3-11. Directional characteristics at various frequencies of the 3-ft-diameter parabolic reflector shown in Fig. 3-10.

size must also be satisfied in order to obtain sharp directional characteristics. If an effort is made to satisfy this condition at low frequencies, the size of the reflector becomes too large to handle with ease in the field. For example, the directional characteristics<sup>2</sup> of a 3-ft-diameter parabolic sound reflector are shown in Fig. 3-11. A reflector of this size is seen to be

<sup>2</sup> Olson, Harry F., "Elements of Acoustical Engineering," 2d ed., p. 277, D. Van Nostrand Company, Inc., New York, 1947.

essentially nondirectional at 200 cps and lower frequencies, but very directional at the high frequencies. When the microphone is located exactly at the focus of a parabolic reflector, the gain at the high frequencies is considerably greater than at the mid-frequency range. This accentuation of the high frequencies may be overcome by moving the microphone slightly out of focus. This expedient also tends to broaden the sharp directional characteristics at the high frequencies.

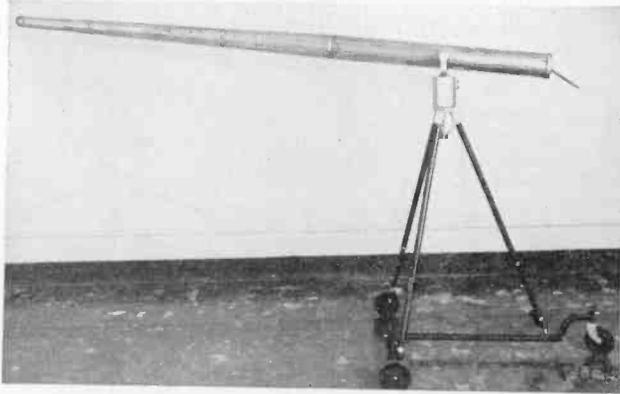


FIG. 3-12. An 8-ft-long acoustical line or "machine-gun" type of directional microphone. (Courtesy of Radio Corporation of America.)

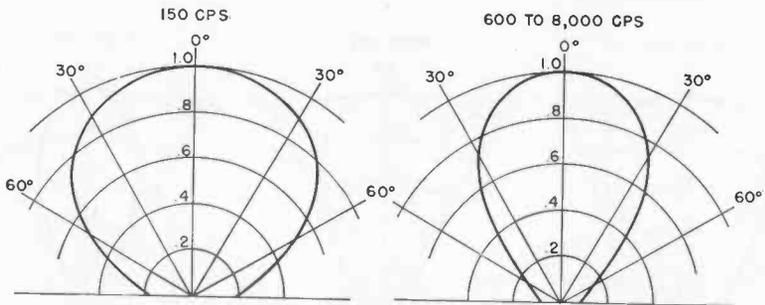


FIG. 3-13. Directional characteristics of the "machine-gun" type of microphone shown in Fig. 3-12.

Another type of directional microphone that has been employed is the line or "machine-gun" type of microphone (Fig. 3-12). This unit consists of a number of small tubes, the base ends of which are connected to a pickup microphone of one type or another. The open ends of the tubes serve as the pickup points. The lengths of the tubes vary in a systematic manner over a range of sizes that are a function of the desired directivity pattern. In this type of microphone also, the directivity pattern varies

with frequency. The directivity pattern of a line-type microphone having an over-all length of 8 ft is shown in Fig. 3-13 for a number of frequencies in the audio range.

**Audio Amplifiers.** A typical portable audio amplifier applicable to television field pickup service is illustrated in Fig. 3-14. The unit has provisions for handling four microphone or other low-level input circuits. Each input channel is provided with a preamplifier employing low-noise low-microphonic tubes. Inverse feedback is used in these amplifiers to reduce distortion should abnormally high input levels be encountered. The input transformers associated with each channel are tapped for source im-



FIG. 3-14. A portable audio amplifier suitable for television field applications which incorporates four preamplifiers, an equal number of associated mixers, a suitable program amplifier, headphone monitoring facilities, and a standard volume-indicator instrument. (Courtesy of General Electric Company.)

pedances of 30, 150, 250, and 600 ohms. The 30- and 250-ohm taps are provided to accommodate the older type of microphones, while the 150-ohm tap is for microphones having the established standard output impedance.<sup>3</sup> The 600-ohm tap matches the standard transmission-line impedance found (together with the standard 150 ohms) in audio practice.

The outputs of the four preamplifiers feed directly into a high-impedance mixing circuit, where the respective audio signals are adjusted to the desired relative levels and blended together as required. The audio output of the mixer network is amplified further by a booster, driver, and output stage. A master gain control precedes the driver stage and pro-

<sup>3</sup> RTMA Standard No. TR-105-B, "Audio Facilities for Radio Broadcasting Systems," November, 1949, Radio-Television Manufacturers Association, New York.

vides means for over-all adjustment of the output level of the amplifier. Inverse feedback voltage is obtained from a tertiary winding on the output transformer and applied to the input of the driver stage in order to minimize over-all distortion and noise. The amplifier may be adapted to operating into either of two standard line impedances, 150 or 600 ohms, by the operation of a load-impedance selector switch.

The amplitude of the outgoing signal is monitored by means of a panel-mounted volume indicator. However, the impedance of the program transmission line to which this type of amplifier is usually connected varies considerably with frequency. Consequently, in order to isolate the volume indicator and the output amplifier from these impedance variations, a resistance attenuation network is provided between the output of the amplifier and the program transmission-line load.

A unique feature of the portable amplifier illustrated is the inclusion of a 400-cps test oscillator for adjusting transmission levels. This source of tone provides a quick and accurate means for checking levels with the master control room or other point to which the transmissions are being sent.

**3-7. Mobile Units.** Considering the amount and the complexity of the equipment involved, the designers and the manufacturers of television broadcasting equipment have done a remarkable job of packaging the components of a complete field pickup system into compact, reasonably proportioned, transportable units. The general practice has been to break down the complete system into units, each one sufficiently small and light enough in weight so that, when necessary, they can be carried onto location by one man. A complete two- or three-camera chain, however, including camera tripods, audio facilities, and other accessories will amount to 20 or so pieces of equipment. Furthermore, with only a nominal amount of camera cable, the equipment will weigh, altogether, perhaps three-quarters of a ton (see Table 3-1). If, by chance, each camera is to be provided with the maximum length of cable with which it is normally designed to work (usually 1,000 ft) over 400 lb of additional weight would be added for *each* camera. It is evident, unlike the portable equipment used for aural-broadcasting field pickups, that television equipment cannot be readily transported from place to place by the use of taxicabs and passenger automobiles. At least station wagons, and preferably light trucks or buses, are obviously required for this service.

On the other hand, where time is of the essence, provisions for safely transporting television equipment in a ready-to-use condition (combined with space for an efficient working area and for transportation of the crew) are very important considerations. To provide sufficient space for a television installation in working condition and for operating the equip-

ment inside the vehicle itself, it is usually necessary to employ either a small truck, a school-type bus, or possibly a passenger-type coach. About the only upper limit on the size of vehicle that may be used in this service is the matter of convenience in handling on the road, the parking problem, and the cost.

TABLE 3-1. TYPICAL FIELD-EQUIPMENT WEIGHTS

Equipment	Unit weight (lb)	Two-camera chain		Three-camera chain	
		No. of units	Weight (lb)	No. of units	Weight (lb)
Camera and view finder . . . . .	100	2	200	3	300
Camera tripods . . . . .	25	2	50	3	75
Camera-control unit . . . . .	65	2	130	3	195
Power supply for above . . . . .	60	2	120	3	180
Camera cable, 200 ft . . . . .	80	2	160	3	240
Synchronizing generator (2 cases) . . . . .	130	2	130	2	130
Switching system . . . . .	70	1	70	1	70
Power Supply for above . . . . .	60	1	60	1	60
Picture and waveform monitors . . . . .	70	1	70	1	70
Audio amplifier, microphones, etc. . . . .	100	1	100	1	100
Subtotals . . . . .	...	16	1,090	21	1,420
Microwave transmitter . . . . .	40	1	40	1	40
Control unit for above . . . . .	40	1	40	1	40
Antenna and tripod . . . . .	60	1	60	1	60
Totals . . . . .	...	19	1,230	24	1,560

For broadcasting from any given location, the cameras and microphones must, of course, be taken from the mobile unit and set up in locations suitable for picking up the picture and the sound portions of the program. However, if the remaining equipment is set up and interconnected in the truck, it can serve as a mobile television control room. Under these circumstances, upon arrival at the site it is only necessary to run (a) video and audio cables to the cameras and microphones, respectively, (b) power cable to the source of primary power, if one is not contained within the mobile unit, and (c) cables to the facility that is used for transmitting the picture and the sound signals to the main station or transmitter location.

With an arrangement of this kind, the equipment can be moved from one location to another in a minimum of time. In addition to reducing the time required for setting up and taking down the facilities, this method of operation reduces wear and tear on the equipment. Furthermore, it

saves considerable manual labor that would otherwise be required for carrying the equipment from the delivery truck to the temporary control site and back again. Also, it is sometimes found that there is no suitable location for control equipment at the site of a proposed television pickup.

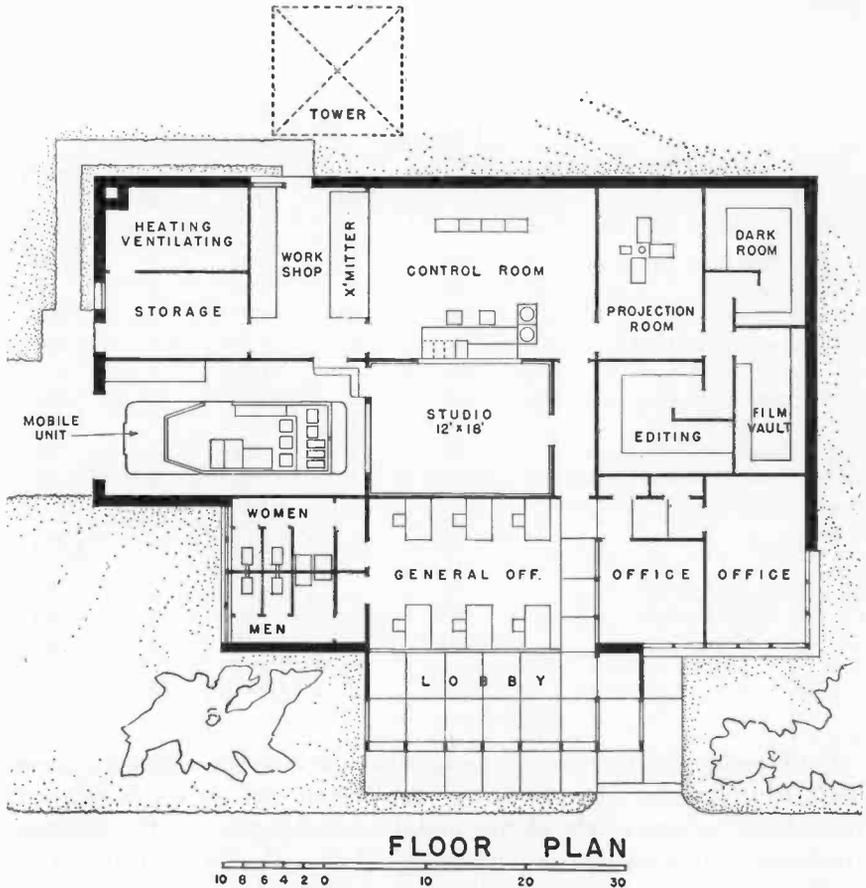


FIG. 3-15. Floor arrangement of a small, but complete, television station building that has been planned to permit the use of equipment installed in a mobile unit for local studio pickup purposes without the need for removing other than the cameras from the truck. (Courtesy of Brugnoli and Adler.)

Normally it is desirable to be able to set up this equipment in a relatively small, quiet room which can be somewhat darkened and from which unauthorized visitors can be excluded. While not absolutely essential, such control provisions are conducive to good program production, particularly if the alternative is to set up outdoors in inclement weather. A mobile

unit, if sufficiently large and carefully designed, can provide excellent control-room facilities in the field. As a matter of fact, by coordinating the design of a mobile unit and a permanent studio,<sup>4</sup> the equipment set up in the field unit may be used for studio pickup purposes, when it is not in use in the field, by parking the mobile unit adjacent to the studio and moving the cameras and microphones therein (Fig. 3-15).

**Station Wagons.** Station wagons are useful for transporting television pickup equipment and operating personnel. In addition, they offer several advantages over a small truck, even though their load-carrying capacity and space for equipment are limited. Station wagons can be operated over parkways and other restricted roads, and they are relatively easy to park and to handle in heavy traffic. Furthermore, they represent a relatively small investment as compared to a permanently equipped truck or bus. However, station wagons have a limited load-carrying capacity which varies with the size of the chassis, of course, and ranges from about 1,600 to 2,200 lb, including passengers. But station wagons are generally equipped with relatively soft passenger-type springs and shock absorbers and often with low-pressure cushion-type tires. Under these circumstances, if properly operated, the station wagon may subject equipment to somewhat less shock and vibration during transportation than will a small truck.

**Panel Trucks.** Conventional panel-type trucks, mounted on chassis having ratings of approximately 2,000 to 3,000 lb, are more spacious (from an equipment-transportation viewpoint) and can handle somewhat greater loads than can station wagons. They cannot, however, be operated over roads that are restricted to passenger automobiles. On the other hand, they can be constructed more ruggedly than station wagons and may stand up better under severe service conditions than a vehicle that is primarily designed for passenger and light luggage transportation. However, in choosing between these two types of vehicles for equipment transportation, consideration must also be given to the riding qualities of each. Neither the station wagon nor the small panel-type truck is sufficiently large to permit a permanent, ready-to-operate setup of television equipment.

**Bus-type Mobile Unit.** A one and one-half ton truck chassis is about the smallest that can be used for a mobile television unit in which the equipment is to be set up in a working arrangement and space provided for the operating personnel. Actually, a bus-type chassis is usually preferable to a truck chassis since the former usually has softer springs and other features that contribute to better riding qualities. A typical bus-type mobile

<sup>4</sup> Brugnani, R., and B. Adler, Facilities Housing for TV, *Broadcast News*, Vol. 50, p. 8 (August, 1948).

television unit is shown in Fig. 3-16. This particular vehicle has a 160-in. wheel base and is approximately 22½ ft long, 7 ft wide, and 9 ft high overall. The useful space inside the body is roughly 14 ft long, 7 ft wide, and 6 ft high. The weight of the vehicle without equipment is about 9,500 lb, and the maximum safe load is 4,000 lb, making the gross weight some 13,500 lb.



FIG. 3-16. A mobile television unit that has provisions for accommodating a two- or three-camera chain and a microwave relay-link transmitter (seen set up on the roof of the unit). (Courtesy of WTCN-TV, now WCCO-TV, Minneapolis.)

The design of the unit shown is such that the rear of the vehicle is used as a control room. Windows at the back and on the two sides provide an excellent view of the surroundings whenever the mobile unit can be located in a position where a view of the scene to be televised can be obtained. This window arrangement also facilitates use of the mobile unit as a control room for a fixed studio as already suggested. Curtains are provided for the windows in order to partially darken the control room, if desired, by covering those windows not in use. An additional draw curtain immediately back of the operating seats may be used to exclude light coming from the front windows of the unit.

The top of a mobile unit can often be used to advantage as a location for one or more of the television cameras. In addition, if the location of the mobile unit is favorable, a microwave relay transmitter may be set up on the roof of the unit to provide a means of sending the picture signals back to the main studios or transmitter plant. The roof is, therefore,

covered with a nonskid tread material and reinforced in order to support the weight of the equipment and the personnel necessary for its operation. Access to the roof of the mobile unit illustrated is gained by means of a roof hatch (measuring approximately 2 by 3 ft) and a ladder located inside the body.

The interior layout plan of the mobile unit described is shown in Fig. 3-17. The control desk extends across the rear of the unit and, as shown, provides space for a three-camera chain and associated audio facilities. Above the desk there is a shelf for auxiliary equipment that

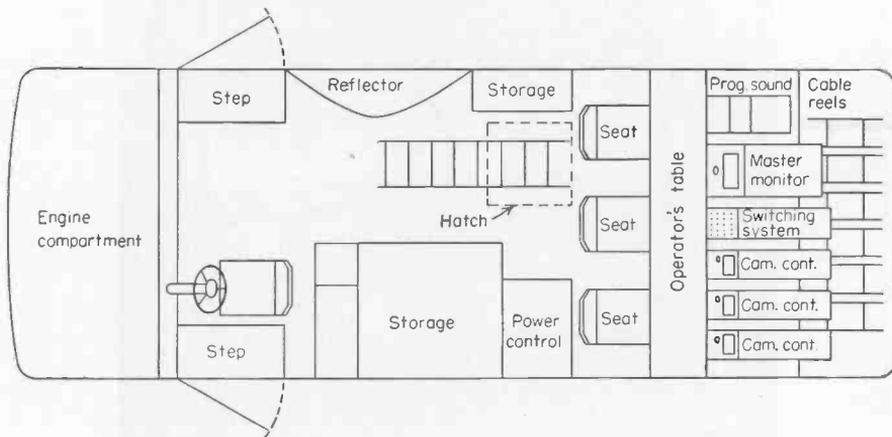


FIG. 3-17. Floor plan of the mobile unit shown in Fig. 3-16.

need not be within the immediate reach of the operating personnel. Under the desk there is ample space for the synchronizing waveform generator and power-supply units. All units are carried on shockmounts to minimize vibration during transportation.

The camera, microphone, and power cables that often become a major handling problem in the field are neatly accommodated in this mobile unit by reels located at the rear of the truck and accessible from the outside through two rear half doors (Fig. 3-18). A total of six cable reels are contained in this compartment. Each can accommodate 200 ft of 3/4-in.-diameter camera cable or proportionate amounts of cable of another size. Cable having several coaxial conductors and many single conductors (see Sec. 15-2) is commonly employed for camera connection and is, therefore, not amenable to any sliding contacting arrangement that would permit the inside end of the cable to be permanently connected to the associated equipment at all times. Instead, the end of the cable is terminated in a suitable connector and a short length passed through a

hole in the bottom of the reel (see Fig. 3-18). The remainder of the cable is then wound on the reel. In setting up for a broadcast, it is only necessary to unreel the desired length of cable and then remove the inner end of the cable from around the hub and connect it to the proper con-



FIG. 3-18. Cable reels for accommodating camera and other cables associated with the mobile unit are carried on reels that swing out from the back of the vehicle to make them more readily accessible. (Courtesy of Radio Corporation of America.)

trol unit. After all cables have been unreeled and their inner ends connected to their respective control units, the cable reels can be dropped back into their compartment and the rear doors of the mobile unit closed. A rubber astragal at the bottom of the doors permits the cables to go under the door without damage.

For comparison purposes, the layout of another mobile unit,<sup>5</sup> on approximately the same size chassis as that described above, is shown in Fig. 3-19. The scope of the facilities provided in this unit is generally similar to that of the mobile unit already described. The layout, however, is entirely different. It cannot be said that any particular arrangement

<sup>5</sup> Harvey, F. W., and E. D. Hilburn, The WMAL-TV Mobile TV Unit, *Communications*, Vol. 29, No. 3, p. 8 (March, 1949).

of the interior of a mobile unit offers outstanding advantages over all others. In any given application, the requirements peculiar to that situation will largely govern the manner in which a given mobile unit is planned. The two plans presented are those of mobile units that have been in active service for some periods of time and have proved themselves to be well adapted to their respective needs.

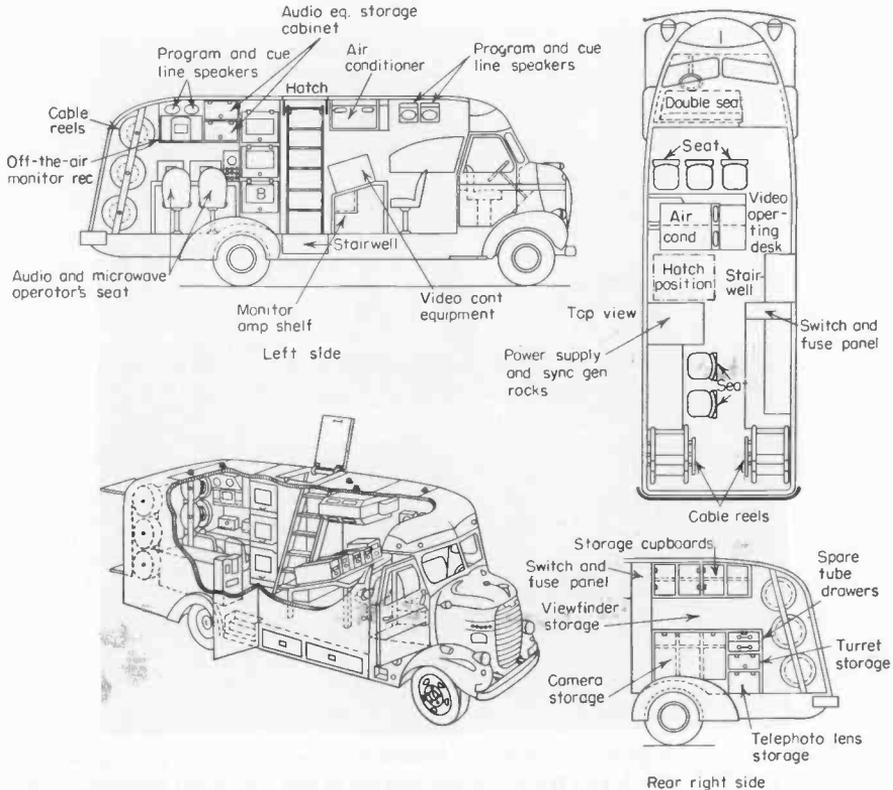


FIG. 3-19. Floor plan of another television mobile unit on a chassis of approximately the same size as the unit already illustrated. (Courtesy of WMAL-TV, Washington.)

**Coach-type Mobile Units.** The passenger-coach type of vehicle <sup>6</sup> (Fig. 3-20) unquestionably provides the most elegant kind of mobile television unit. Not only does a unit of this type provide enough working space for a full complement of operating personnel but, in addition, ample space for an announcer's booth and for transportation of the crew to and from the scene of the broadcast. The coach-type unit illustrated consists of a

<sup>6</sup> McCord, Willis, Simplified Handling of TV Remotes, *Tele-Tech*, Vol. 8, No. 6, p. 26 (June, 1949).

24-passenger bus chassis with a special body (*e.g.*, most of the windows are eliminated and two bulkheads are added to partition the interior into three compartments) on a 172-in. wheel-base chassis powered by a 144-hp engine. In over-all dimensions, the unit is approximately 30 ft long, 8 ft wide, and 9 ft high. A roof deck, 6 ft wide and 19 ft long, provides ample space for three camera or relay transmitter tripods and the personnel asso-



FIG. 3-20. A coach-type mobile unit that houses complete television pickup facilities which are installed, wired, and ready for use as soon as the associated cameras, microphones, and microwave transmitting antenna are set up on location. (*Courtesy of Allen B. Du Mont Laboratories, Inc.*)

ciated with their operation. Stabilizing jacks are used to nullify spring action when the vehicle is stationary and a broadcast is in progress. A demountable guard railing is erected when the platform is in use, as a safety measure for those on the roof. The ladder leading to the roof through a suitable hatch is located within the unit and thus provides control over those who have access to the roof area.

A plan of the interior of this coach-type mobile unit is shown in Fig. 3-21. The accommodations in the front compartment provide for the

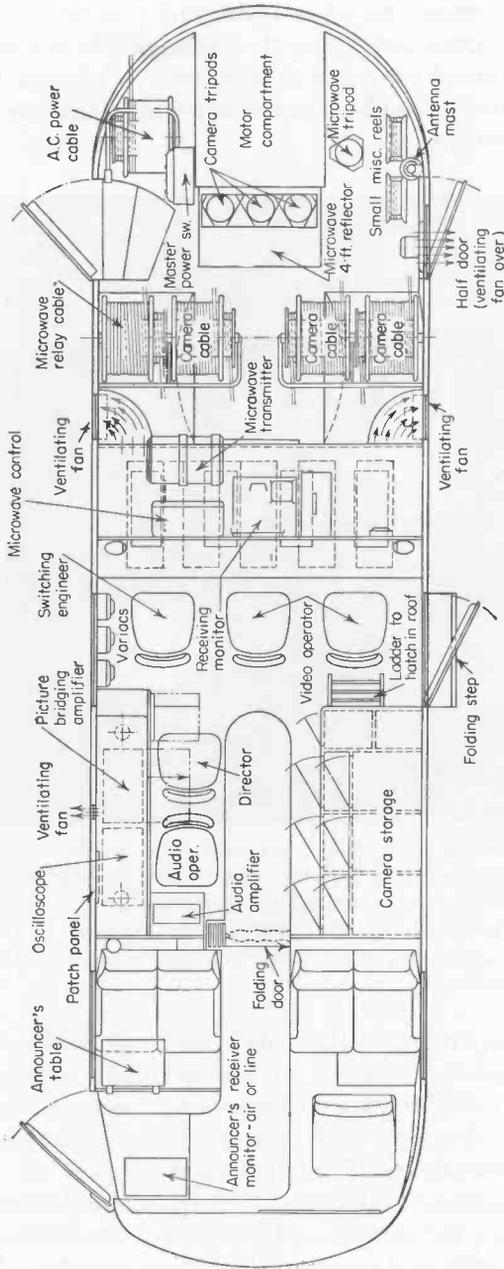


FIG. 3-21. Floor plan of a large coach-type mobile unit.

driver and four passengers, while additional passengers can be accommodated in the second compartment. When on the site of a broadcast, the front compartment can serve as an announcer's booth. For this purpose, a table is provided for his use, and a picture monitor is located where it can be readily viewed.

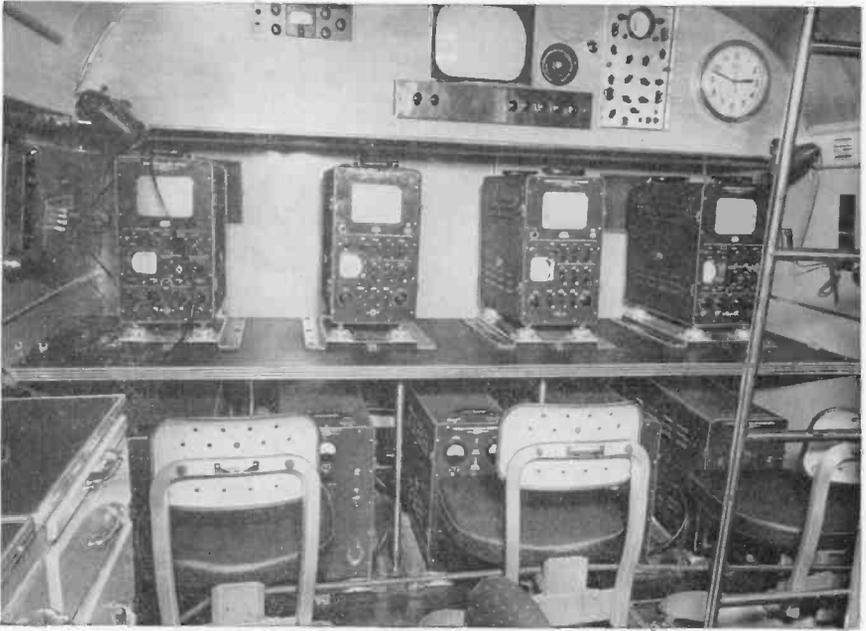


FIG. 3-22. The video operating position of a coach-type mobile unit. Camera-control and video mixer units occupy the desk top while a synchronizing waveform generator and power supplies (for all units) are located under the desk. On the overhead bulkhead, there is a control panel for a microwave transmitter at the left, a built-in television receiver in the center, and a test oscilloscope at the right. (Courtesy of Allen B. Du Mont Laboratories, Inc.)

The second compartment is the main control area and contains most of the technical facilities. Positions are provided here for the program director, the video switcher, two camera-control men, and the audio operator. Figure 3-22 shows the desk upon, over, and under which is located most of the permanently installed television equipment.

The rear compartment of the coach-type mobile unit contains the cable reels, storage space for camera and microwave transmitter tripods, the microwave transmitter, and its parabolic antenna reflector. In this mobile unit, the cable reels are completely inside the unit and out of the weather. The cables themselves are passed through ports in the rear of the unit at

roof level and from this high point are easily carried to the roof of the mobile unit or across sidewalks at a height that will not obstruct traffic. The gasoline engine that propels the unit is located in a compartment at the very rear of the coach.

**3-8. Microwave Relay Systems.** In order to transmit picture signals from field locations to the main television studios or transmitter, it is the general practice to make use of wire circuits or of radio relay links. Where the demand is sufficiently great to justify the facilities, video circuits (which may be either wire or radio) may often be leased from the local telephone company. Where such circuits are not available or where for some other reason it is desirable to establish one's own point-to-point circuit for the transmission of video signals, use can be made of microwave relay equipment. Three bands have been allocated in the radio-frequency spectrum by the Federal Communications Commission for this service. Microwave relay channel assignments for picture transmission are made to television broadcasters in the following bands:

1,990 to 2,110 Mc	(2,000-Mc band)
6,925 to 7,050 Mc	(7,000-Mc band)
13,025 to 13,200 Mc	(13,000-Mc band)

An additional band of frequencies, extending from 890.5 to 910.5 Mc, is available for transmission of the accompanying sound. In practice, however, wire circuits are almost always used for this purpose when they are available and, although not in extensive use, equipment has been developed for diplexing the sound on the microwave picture channel.<sup>7</sup>

Microwave equipment lends itself particularly well to television point-to-point relay service for several reasons. For instance, very high antenna gain can be obtained with relatively small and simple antenna systems. One frequently used form of directional microwave antenna is the parabolic reflector. The gain of an antenna of this type is a function of the frequency of operation and the diameter of the parabola. The power gain over an isotropic radiator of parabolic reflectors ranging in diameter from 2 to 8 ft and for frequencies of 2,000, 7,000, and 13,000 Mc is shown in Fig. 3-23. From this, it is seen that a 4-ft-diameter parabola operating at 7,000 Mc will provide a gain of 5,000 times. For fixed installations such as at the main studios or transmitter, larger parabolas having even more gain are, of course, entirely practical. For example, a 6-ft-diameter antenna at the same frequency has a gain of almost 11,500 times, while that of an 8-ft antenna exceeds 20,000 times. This high antenna

<sup>7</sup> Staschover, L., and H. G. Miller, TV Sound Diplexer for Studio-transmitter Links, *Tele-Tech*, Vol. 10, No. 3, p. 34 (March, 1951).

gain provides two distinct advantages: First, it makes possible relatively high equivalent radiated power with a relatively low actual power output from the transmitter. For example, a 7,000-Mc transmitter having an output power of only 0.1 watt when used with a 4-ft parabolic reflector

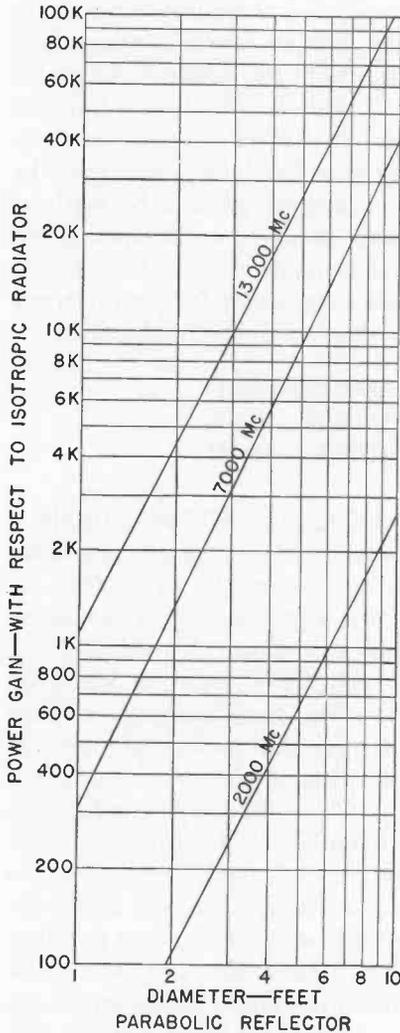


FIG. 3-23. Power gain (with respect to an isotropic radiator) of parabolic antenna reflectors as a function of reflector diameter for the three frequency bands available for microwave applications.

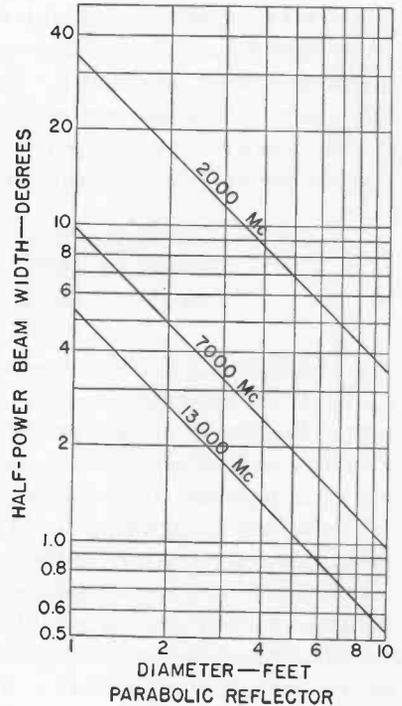


FIG. 3-24. The half-power beam width of parabolic antenna reflectors as a function of reflector diameter for the three microwave bands available for television relay applications.

antenna develops an equivalent radiated power of 500 watts. This makes it possible to employ small lightweight transmitters for field applications. A second and equally important advantage is that the transmitted power is concentrated along a very narrow beam.

As the diameter of a parabolic antenna increases, the width of its beam decreases. Likewise, for a given antenna, as the operating frequency increases, the beam width decreases. The manner in which the width of the beam at the half-power points varies with the diameter of a parabolic reflector and the frequency is shown in Fig. 3-24.

In addition to highly directional transmitting antennas, it is usually the practice to make use of equally sharp receiving antennas. As a result, when the transmitting and the receiving antennas are lined up on each other, an exceedingly selective transmission path is provided. In practice, this accomplishes the elimination of practically all difficulties from extraneous reflections whether from fixed or moving objects. The narrow reception angle, together with the negligible interference at the extremely high frequencies, results in practically noise-free transmission over line-of-sight paths of perhaps 25 miles with 4-ft-diameter antenna reflectors and upwards of 40 miles with 6-ft reflectors when operating in the 7,000-Mc band and with transmitter output powers of about 0.1 watt.

Although three bands of frequencies in the microwave region have been made available for the relay of television signals, only the 2,000- and the 7,000-Mc bands are in extensive use. The 2,000-Mc equipment features higher output power than the 7,000-Mc apparatus, but the lower frequency transmitter is correspondingly heavier and larger. As a result, it is better suited to fixed point-to-point service as from a television studio to the transmitter plant than for portable field use. On the other hand, the higher powered, 2,000-Mc transmitter may sometimes be used to advantage to cover longer paths than can be handled by the lower powered, higher frequency equipment normally used for field pickup work. However, the higher frequency, more portable equipment can be adapted to long courses by the expedient of using two or more sets of equipment and establishing intermediate repeater points.

**3-9. Microwave Relay Transmitter.** A representative 7,000-Mc relay transmitter intended for field applications is shown in Fig. 3-25. The several units of which it is composed have been made as light and as readily transportable as possible. The system consists of four units: (*a*) a narrow-beam antenna, (*b*) an antenna mounting capable of azimuth and elevation adjustment, (*c*) a transmitter (all of which are shown), and (*d*) a transmitter control unit.

The antenna shown is a 4-ft-diameter metal parabola which focuses into a narrow beam the radio-frequency power fed to its focal point by a hook-

shaped waveguide. For applications where additional antenna gain is required, a 6-ft-diameter parabola may be used. The power gain of these antennas is 5,000 and 11,500 times, respectively, at the 7,000-Mc operating frequency. The waveguide is simply a hollow metal pipe whose rectangular cross section measures  $\frac{3}{4}$  by  $1\frac{1}{2}$  in.



FIG. 3-25. A 4-ft-diameter parabolic reflector excited by means of a hook-shaped waveguide which, in turn, is fed by a microwave transmitter contained in a weatherproof cylindrical case mounted on the back of the reflector. (Courtesy of Radio Corporation of America.)

Because of the extremely sharp beam of radiation from the transmitting antenna, it must be oriented very accurately toward the receiving point. For supporting the antenna in field applications, it is customary to make use of a tripod mount fitted with a special head that permits tilt and azimuth adjustments. The tripod may be one of the same type used for camera applications (but without the friction head), provided a sturdy unit is employed. Where the antenna is likely to be exposed to severe weather conditions, a more rugged tripod than commonly used for camera work is advisable. This is particularly the case where large-diameter antennas are used or where strong gusts of wind are likely to strike the antenna. To facilitate lining up the transmitting antenna on the receiving site, the tilt and azimuth head that fastens the antenna to the tripod is usually fitted with scales, graduated in degrees, to show the elevation and the direction in which the antenna is pointed. Sep-

arate, positive locking handles are also required for the tilt and the azimuth adjustments. Either adjustment may then be made independently of the other.

For very short courses, the gain and narrow beam widths afforded by 4-ft or larger diameter antenna reflectors are often unnecessary. As a matter of fact, the very sharp beam widths may be more of a nuisance than help where the path is very short. Very stable antenna mounts must be provided under these circumstances for both the transmitting and the receiving antennas to keep them from vibrating and causing a flutter in

the resulting signal. Smaller sized parabolic reflectors can be used, of course, but electromagnetic horn antennas are even more convenient for applications of this type.<sup>8</sup> An antenna of this latter type, having a rectangular mouth opening of roughly 8 by 10 in. and an over-all length of 14 in. is shown in Fig. 3-26 attached to the same transmitter shown in Fig. 3-25. This horn antenna has a horizontal beam width of approximately 50 degrees and a power gain of about 200 when operating at 7,000 Mc.



FIG. 3-26. For transmission over short distances, a conveniently small horn antenna of this type may provide all the directivity and gain required for satisfactory operation. (Courtesy of WMAL-TV, Washington.)

The microwave transmitter itself is contained in a cylindrical weather-proof housing which is rigidly attached directly to the rear of the antenna, as shown in Figs. 3-25 and 3-26. This arrangement results in a very short waveguide transmission line between the transmitter and the antenna thereby eliminating the matching and loss problems that may be encountered when a transmitter and an antenna are located at appreciable distances from each other. The transmitter chassis (Fig. 3-27) contains the oscillator and modulator circuits, a monitor, and wavemeter. All connec-

<sup>8</sup> Hilburn, E. D., TV Microwave Relay Equipment Operation, *Television Eng.*, Vol. 1, No. 3, p. 8 (March, 1950).

tions from the associated control unit to the transmitter are made by means of a single plug-in connector. In addition to the circuits required for the operation of the transmitter, there is included an intercommunication circuit for conversation to the control point during setup and orientation of the antenna. In addition there is an a-c convenience outlet for supplying power to a piece of test equipment, a soldering iron, or a droplight.

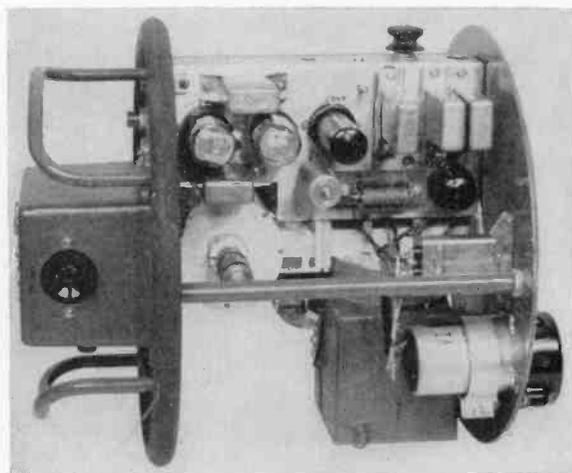


FIG. 3-27. A microwave transmitter chassis removed from its protective case. A klystron oscillator is contained in the small square case at the lower right. A self-contained wavemeter is enclosed in the round compartment just left of center. (Courtesy of Radio Corporation of America.)

To facilitate maintenance and replacement in an emergency, the entire transmitter chassis may be removed from the case after three wing nuts are removed. A klystron oscillator is used and is mounted in the shielded temperature-controlled compartment that may be seen at the lower right of Fig. 3-27. The base of the klystron extends directly into the waveguide that carries the output of the oscillator to the antenna. The oscillator has a power output of approximately 100 mw and is capable of operating over a frequency range of approximately 6,500 to 7,050 Mc.

The oscillator is *frequency-modulated* by varying the reflector voltage at video frequency. The normal frequency deviation is 12 Mc, and the polarity is such that a picture signal in the white direction produces an increase in the transmitter frequency. The modulator tube receives its input signal from one of the coaxial lines in the connecting cable. The frequency characteristic of the over-all transmission system is flat from approximately 60 cycles to 6 Mc.

**3-10. Microwave Relay Receiver.** The microwave relay receiving system that is the companion of the transmitting system described above consists of (a) a highly directional antenna, (b) an antenna mount that may be adjusted for azimuth and elevation, (c) an FM video receiver, (d) a receiver control unit, and (e) a regulated power-supply unit. The antenna may employ either the 4- or the 6-ft parabolic reflectors described in the preceding paragraphs. If the receiving site is a fixed location, such

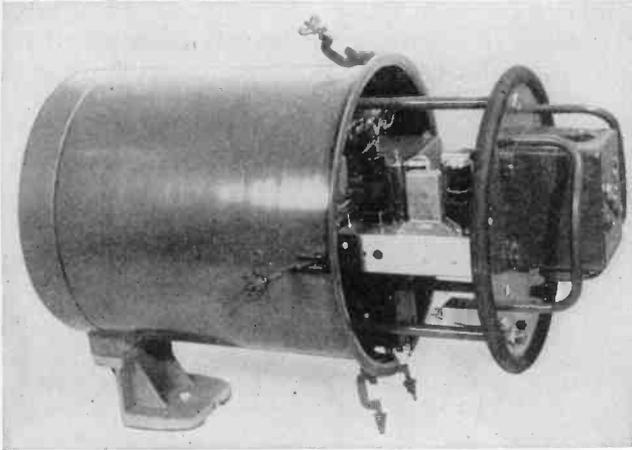


FIG. 3-28. An FM microwave receiver chassis that may be mounted on the back of a receiving antenna in a manner analogous to that employed for the associated transmitter (see Fig. 3-25). (Courtesy of Radio Corporation of America.)

as at the main studio or transmitter, the antenna may be more or less permanently installed. Under these circumstances the question of portability is not a factor, and the larger reflector with its higher gain, but narrower beam, may be used. In any event, a firm antenna support with both azimuth and tilt adjustments is essential. Antenna mounts, with scales to show the direction of orientation and the amount of tilt, are usually employed for this service just as for the transmitter. The signal is fed from the antenna into the receiver by means of a waveguide.

The FM receiver chassis itself mounts in a cylindrical can (Fig. 3-28) that fits on the back of the receiver parabola just as does the transmitter. The receiver chassis contains a first detector, a heterodyne oscillator, and five intermediate-frequency amplifier stages. The heterodyne oscillator is a klystron tube designed for operation in the 6,500- to 7,050-Mc band. The first detector is a crystal which mixes the output of the oscillator with the incoming signal to produce an intermediate frequency centered about 129 Mc. This signal is amplified by the five-stage intermediate-frequency

amplifier and produces an output signal of about 50 Mv. This signal is fed over a coaxial line in the interconnecting cable to the receiver control unit. Jacks are provided on the receiver chassis so that the crystal detector current and the grid current of the intermediate-frequency limiter stage in the receiver control unit may be metered. By reducing the intermediate-frequency amplifier gain (a knob adjustment on the receiver control unit) until the grid current of the limiter stage is reduced to one-half its normal value, the setting of the gain control may be used to indicate the relative strength of the input signal. Thus, by observing this current at the antenna location (using the receiver-chassis jack mentioned above), it is possible to orient the reflector for maximum received signal.



FIG. 3-29. This control chassis for the microwave receiver can be on either a rack or in a carrying case and located an appreciable distance from the microwave receiver and antenna assembly. (Courtesy of Radio Corporation of America.)

The receiver control unit (Fig. 3-29) contains an additional seven stages of 129-Mc intermediate-frequency amplification, the limiter and discriminator stages, and an automatic-frequency-control system. There are two separate discriminator channels fed from the output of the intermediate-frequency amplifier. Each channel contains a limiter circuit, a balancing circuit, and the discriminator circuit proper. One channel supplies the video signal to the video amplifier which, in turn, also has two outputs. One of these is generally used for supplying a 1.4-volt peak-to-peak, black-negative picture signal to the main studio or transmitter and the other for monitoring purposes. The second discriminator channel is used to generate a control voltage for the automatic-frequency-control amplifier. The output of this amplifier is used to control the frequency of the heterodyne oscillator. It operates in such a way that the peaks of the syn-

chronizing signal appear at the same point on the discriminator characteristic (within 1 Mc) regardless of the picture content.

The automatic-frequency-control amplifier is a special type of d-c amplifier which takes a d-c signal varying at a relatively slow rate and amplifies it to supply a control voltage to the heterodyne oscillator. This control system will keep the receiver in tune with the transmitter for a change in transmitter frequency of  $\pm 20$  Mc. The output voltage of the automatic-frequency-control amplifier is the main determinant of the heterodyne oscillator frequency and, therefore, the tuning of the receiver.

**3-11. Primary Power Supplies.** A reliable source of primary power for the operation of television pickup equipment is often a major problem in the field. So much so, in fact, that some field pickup crews include an electrician among their number whose prime responsibility is to obtain and maintain an adequate source of a-c power at all times. Depending upon the number of auxiliaries that are in use, a field pickup setup may require from 5 to 15 kw of a-c power. Where possible, connection to a commercial source of power is to be preferred over the use of a small gasoline-engine-driven generator. The advantages of the former practice include the ability to lock the synchronizing waveform generator to the power-line frequency as is normal studio practice (see Sec. 5-3, *Frequency-control Circuits*). Under these circumstances, relatively simple practices can be followed to ensure against disturbance of the receiver synchronizing circuits when switching from a remote program to a studio origination, or vice versa (see Chap. 5). Furthermore, if all equipment is operated from the same source of power, there will be a minimum of annoying degradation to the received picture because of nonsynchronous hum pickup. With this method of operation, the pattern or shading introduced by hum will be stationary on the picture, whereas if different sources of primary power (that drift in frequency with respect to each other) are used, the hum bars move up and down in the picture area.

It is also necessary in field pickup work to be in a position to make use of any source of primary power whether it be single-phase two-wire, single-phase three-wire, three-phase three-wire, three-phase four-wire, or some other arrangement peculiar to the section of the country involved. Furthermore, it is advisable to be prepared to handle potentials ranging from 100 to 130 volts and from 200 to 240 volts.

**Gasoline-engine-driven Power Supplies.** Where no commercial source of primary power is available, resort must be made to gasoline-engine-driven a-c power supplies. Units ranging from 3 to 15 kw are frequently employed for television service. The smaller types of permanently equipped mobile units do not afford the space for installing a gasoline-engine-driven generator of the size needed for this application. Under

these circumstances, it is generally necessary to install the generator unit in a two-wheel trailer which can be fastened to the rear of the mobile unit. An alternate arrangement is to mount the gasoline-engine-driven generator in a station wagon or other vehicle and transport it separately. Either of these arrangements affords the opportunity on the broadcasting site of setting up the gasoline-engine-driven generator at a distance from the mobile unit in order to minimize the noise and vibration that generators of this type produce. However, where a bulkhead intervenes between the operating area and a storage area, as in the coach-type mobile unit shown in Figs. 3-20 and 3-21, it may be entirely feasible to install a gasoline-engine-driven generator in the mobile unit. This was done for the mobile unit illustrated, a 5-kw unit being installed in the rear storage compartment. The a-c line frequency of gasoline-engine-driven alternators is not likely to be particularly stable nor accurately maintained at 60 cps. Therefore, when primary power sources of this type are used, it is generally advisable to operate the synchronizing waveform generator with crystal control rather than locked to the power line as is the common practice where commercial power is available. This will ensure generation of accurately timed synchronizing pulses regardless of the power-line frequency.

## CHAPTER 4

# Field Pickup Techniques

NO MATTER HOW PERFECT the equipment that is available for making television pickups, in the final analysis the quality of the program that is broadcast is a reflection of the skills and the experience of those responsible for its production. Each member of a television field crew has a specialized function and, given time, each crew member may be expected to acquire a thorough knowledge of his responsibilities. However, as a guide to the approach to the problem, the experience of others is informative. Furthermore, data concerning typical situations that are met in the field are useful for reference purposes. With this in mind, this chapter is devoted to a description of field pickup techniques and the presentation of information concerning field conditions that time has proved to be both useful and reliable.

**4-1. Technical Operating Personnel.** The technical personnel required for the operation of a two-camera television field chain may, typically, consist of the following:

- 2 cameramen
- 1 video control man
- 1 video switcher
- 1 audio control man
- 1 relay transmitter operator
- 1 electrician (optional)
- 1 program director

The functions of these operating personnel are described in the following sections.

**Cameraman.** One cameraman is required for the operation of each camera. Consequently for a three- or four-camera setup an equal number of cameramen are required; under these circumstances, the size of the typical crew listed above would be increased accordingly. The responsibility of the cameraman is to cover the scene called for by the program

director. In order to do this, he must not only bring the camera to bear on the scene but he must also select the proper focal-length lens and adjust the focus and the iris opening for an optimum picture. (In some instances remote-control facilities are employed to relieve the cameraman of some or all of the last three responsibilities.) Instructions for the selection of the field of view are usually given verbally by interphone equipment since the cameraman and his equipment are often located remotely from the program director's position.

**Video Control Man.** One video or camera-control operator, if skilled in his profession, can usually handle two camera-control units. As a result, if the above-mentioned two-camera chain is increased to three or even four cameras, it is usually necessary to add only one additional video control man. The responsibilities of the video operator include the monitoring and adjustment of the video and blanking level of the cameras under his jurisdiction. Further, he is concerned with obtaining optimum electronic focus and beam current for the pickup tube in the camera. Added responsibilities may include the selection of camera lenses and the adjustment of the iris opening and focus thereof, all by remote control. All these and certain other adjustments of the electronic portion of the camera are made at the camera-control unit which is normally located remotely from the camera itself, perhaps as much as 1,000 ft away.

**Video Switcher.** One video switcher operator can normally handle as many cameras as are used on a given pickup. His function is to select, upon instructions from the program director, the camera that is placed on the air at a given moment. The video switcher is responsible for switching, lapping, and dissolving from one camera to another. In addition it is his responsibility to monitor the outgoing picture quality and signal level to ensure the transmission of matched pictures from all cameras. In a fast-moving program involving a large number of cameras, frequent switching, lapping, and dissolving, the video switcher is an exceedingly busy individual. Usually his location is immediately adjacent to the program director who gives instructions to him orally.

**Audio Control Man.** One audio control operator can usually handle the field audio pickup problem without assistance, regardless of the number of camera chains employed. His responsibilities consist of mixing and switching the audio program material from all pickup sources employed and adjusting the over-all level to a value suitable for transmission. In the most simple case, the audio operator need concern himself only with the microphone of a commentator describing the event being broadcast. In more complex situations, it may be required that he switch from one microphone to another in synchronism with the switching of camera outputs.

**Relay-transmitter Operator.** If a relay transmitter is used, a government-licensed transmitter operator must be present to supervise its operation. Where a transmitter is located in a mobile unit together with the audio and video control equipment, this function may be performed by one of the technical operators already described. However, if all equipment except the transmitter is removed from the mobile unit for temporary setup elsewhere, as is often the case, then an operator must remain at the transmitter. The reverse may occur where the transmitter is removed from the mobile unit and located at a high point while the audio and video control equipment remains in the truck. In this instance too, a special transmitter operator may be required.

**Electrician.** The primary power requirement of field pickup equipment is often an appreciable item. Failure of the a-c supply would, of course, result in loss of the program. As a result, it has sometimes been found advisable to include a competent electrician in the field crew, particularly when setups must be made hurriedly in unfamiliar locations. His responsibilities are to obtain adequate and reliable sources of primary power, run temporary power lines to all equipment requiring alternating current, and otherwise accept responsibility for the primary power circuits being in accordance with local ordinances.

**Program Director.** Program directing is not primarily a technical function. However, since the program director is so closely associated with technical operations, his functions are briefly described here. He is responsible for proper coverage of the event from a program-production viewpoint. His directions to attain this end are translated into technical operations by the technical personnel. In some instances, in the interests of economy, the functions of program director and video switcher have been combined in one person. Although this may be an acceptable arrangement for the very simple slow-moving events, experience indicates that top-flight program production cannot generally be achieved in this manner.

**4-2. Field Equipment Application.** As compared to an aural broadcasting pickup, a television remote pickup is a very complex operation. Because of this, all remote operations should be planned very carefully in advance. In order to determine intelligently the equipment required for a given pickup, it is necessary to have an intimate knowledge of how and where it is to be used. It is instructive, therefore, to become acquainted with the way the equipment is set up and used for a typical field pickup.

By all odds, athletic events of one kind or another make up the bulk of all nonstudio television program originations. These include baseball, football, basketball, hockey, tennis, golf, all kinds of racing, boxing, wrestling, roller derbies, bowling, and swimming meets. Each of these

events requires different setup arrangements and, of course, there is not complete unanimity of opinion as to what camera angles are most successful for any given kind of event. Some popular arrangements are described, however, as a guide to coping with any specific pickup problem.

The basic arrangement of technical facilities for televising a field event is fairly well standardized. Microphone and cameras are located at vantage spots in the stands or elsewhere around the field. Camera and microphone cables run from these locations to the camera-control equipment which is installed in a mobile unit, often parked adjacent to the stands. The video control operator, video switcher, audio control operator, and program director operate from the mobile unit. Instructions to the cameramen and commentators in the stands are given by interphone. From the mobile unit, television signals are often fed to the main transmitter location by microwave relay—the transmitting antenna ordinarily being mounted on the roof of the grandstand or on one of the field lighting towers, and the receiving antenna on the main television transmitting antenna tower. Occasionally, there are variations from this standard setup along the following lines: (a) some stations place the control equipment in a room under the stands, (b) some send the microwave signal to the master control-room location rather than directly to the transmitter, and (c) some use coaxial circuits between the field location and the master control room.

**4-3. Baseball.** Without doubt, in the United States, baseball is the most popular spectator sport. Consequently, baseball pickup techniques are described at some length, particularly since many of the principles presented apply equally well to any other field pickup problem.

In the majority of cases, three cameras are used for televising baseball games. It is true that where a skilled crew is available successful productions are put on with a two-camera chain. However, where the equipment and personnel are available, there is no question but that a three-camera chain makes the program director's task easier, makes possible better camera angles, and provides insurance against having to produce a show with only one working camera as would be the case with a two-camera chain should one unit fail.

The selection of camera locations is an exceedingly important task. In many instances the restrictions imposed by the construction of the stands, the size of the field, the direction of the sun, or the inevitable limitations of space, time, and cost sometimes make it impossible to obtain the locations that would provide the best possible coverage.

Based upon country-wide experience, it is now the accepted practice in baseball pickups to locate camera No. 1 so as to obtain the best possible "standard" or "cover" shot, *i.e.*, the shot used as the pitcher winds up and

throws the ball (Fig. 4-1). This scene is usually on the air for more of the total time than any other single shot. The consensus as to the best position for camera No. 1 is that it be placed 60 to 75 ft back of home plate and about 20 to 30 ft above the surface of the field, as shown in Fig. 4-2. This permits the viewer to see the home-plate umpire, the catcher, the batter, and the pitcher, all at the same time.

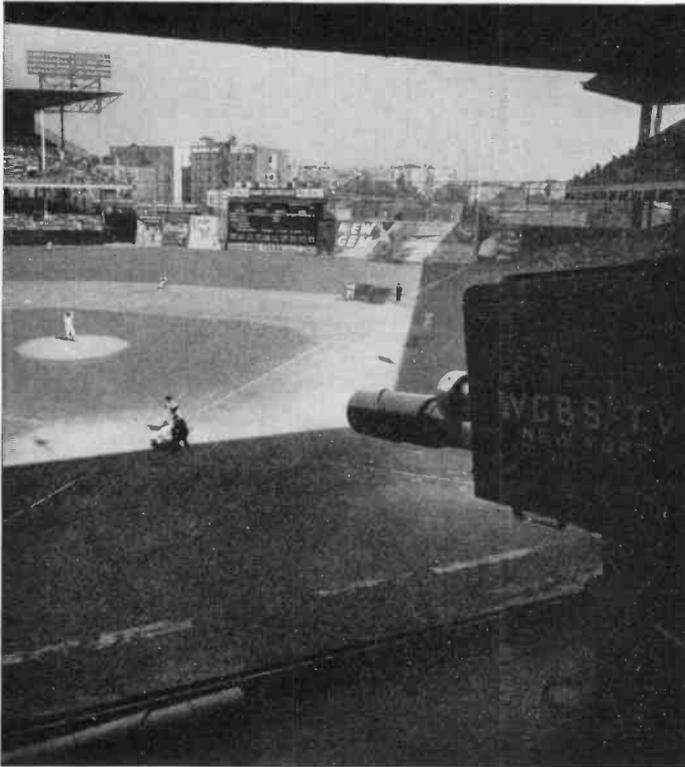
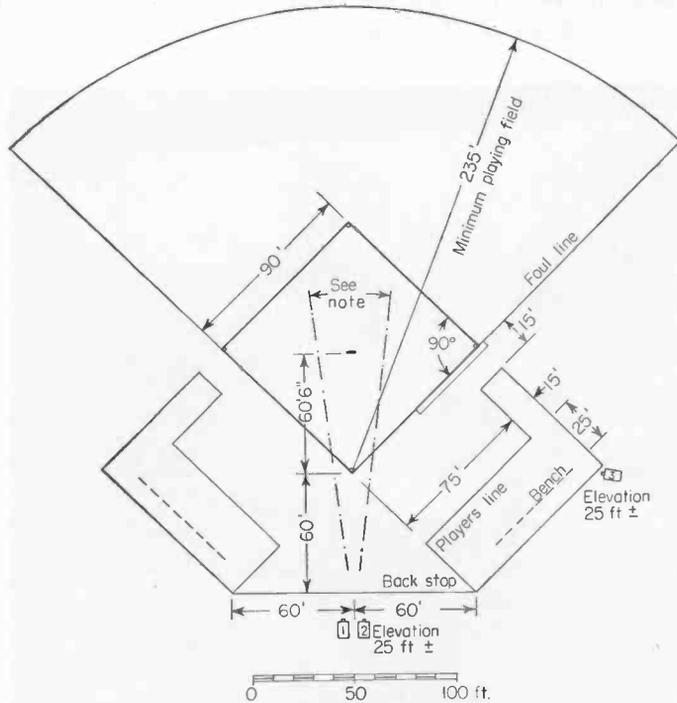


FIG. 4-1. In baseball pickups, the most popular camera position is this one, back of home plate and 20 to 30 ft above the field. From it, both the pitcher's box and the home plate may be covered simultaneously.

It is possible, of course, to get a combined picture of the umpire, catcher, batter, and pitcher from almost any location in the stands. However, from any position except that directly behind home plate, a fairly wide-angle lens (usually 50 mm) is required. When such a lens is used in a situation like this, the players may look foreshortened. On the other hand, a camera behind home plate sees all four figures nearly in line; hence a lens of relatively narrow angle (usually 135 mm) may be used,

provided the camera is not located so high that the vertical angle becomes the limiting factor. In this instance, also, a wide-angle lens would have to be used in order to obtain the desired field of view in the vertical dimension. Again, an undesirable visual foreshortening would result.



Note: Field of view of 135 mm lens with camera 75 feet back of home plate

FIG. 4-2. The essential dimensions of a baseball diamond drawn to scale and the popular positions and elevations for one, two, or three television cameras.

Another important advantage in the behind-home-plate camera position is the reduced amount of panning that is required to follow the action. For example, to follow a ball hit to the outfield, a camera back of third base would have to pan through an angle of approximately 135 degrees. On the other hand, a camera behind home plate can follow the ball to any point on the field without panning more than 30 degrees from the batter-pitcher center line. Swinging the camera quickly through wide angles is confusing to the viewer, to say the least.

The location of the second and the third camera is less critical, and, consequently, there is not a unanimity of opinion as to the best locations. However, one favorite position for the second camera is directly alongside

the first camera. This location offers the advantages of not changing the viewing angle markedly when switching from camera No. 1 (which may be transmitting the cover shot) to No. 2 which, with a telephoto lens, may be viewing a close-up of some interesting field action. Further, this position for camera No. 2 presents a normal view of the field as a spectator would see it. Finally, this position results in an alternate camera being immediately available in the event that camera No. 1 should fail.



FIG. 4-3. It is sometimes necessary to construct special booths in order to gain a vantage point for television cameras and to ensure against obstruction of the line of sight. (Courtesy of KGO-TV, San Francisco.)

Another favored spot for camera No. 2 is also behind the home plate but higher than the No. 1. This gives a good view of the field, provides some change in scene, and generally does not confuse the viewer on switching from camera No. 1 to No. 2. If more change of view is desired and only a two-camera chain is in use, camera No. 2 can be located at any height, from medium to high, along either the first- or the third-base line. It must be reasonably high, however, to get the desired view of the outfield. The first-base side has the advantage of more action (at close range), but the direction of the sun may rule against this location.

In three-camera setups, camera No. 3 is usually, although not always, associated with one or the other of the first two cameras (assuming they are not already being used together). Camera No. 3 is almost always used for "local-color" shots, close-ups of interesting action on the field, in the crowd, or around the ball park.

In choosing any location, it is important that it be high enough so that people or vehicles do not pass in front of the camera (Figs. 4-3 and 4-4).

On the other hand, as already mentioned, it must not be so high that the persons being televised look abnormally foreshortened. With the aid of Fig. 4-2, which shows the standard dimensions for major league baseball diamonds and a knowledge of the location of the stands at specific ball parks, preferred camera positions and lens sizes can be determined in advance of actually coming on the site for a television broadcast.



FIG. 4-4. This especially constructed camera platform, on one face of a steel column, provides a camera position at a vantage point that otherwise would not have been available. The crow's-nest appearance is created by the installation of netting to catch any objects that might be dropped accidentally. (Courtesy of WEWS, Cleveland.)

**4-4. Boxing and Wrestling.** Many of the basic principles that apply to television camera location in field pickup of sporting events are detailed in the preceding section. Consequently, in this and succeeding sections dealing with other types of field pickups, the discussion will be limited to those special considerations that are peculiar to the type of pickup being analyzed. In each case, however, a sketch is presented giving the essential dimensions of the area within which the sporting event takes place. These sketches are useful for reference purposes since they permit advanced planning of camera angles, lens sizes, and other pertinent factors.

The dimensions of a standard boxing and wrestling ring are shown in Fig. 4-5. The over-all dimensions of the platform are 24 by 24 ft, but the roped-off section is only 20 ft square. Three ropes, located 2, 3, and 4 ft above the surface of the ring, are standard features. There is no standard elevation for the height of the ring above the spectator's floor.

Two television cameras, located side by side, usually suffice for pickups of this type. With cameras located as suggested in Fig. 4-5, a 50-mm lens provides a sufficiently wide angle of coverage to take in the entire ring with the camera trained in a single direction. However, a 90-mm lens, which requires some panning to follow the action around the ring, is a better choice since it provides a better viewing angle and also larger images of those in the ring. For close-ups of action in the ring, a 7- or 8½-in. lens will be found very satisfactory. Where lens turrets are in use and, therefore, are available for rapid and frequent switching of lenses, all the sizes mentioned may well be employed together with even longer focal-length lenses for shots of action in the crowd, or elsewhere, more distant from the cameras than is the ring or normal center of attraction.

When two or more cameras are employed for pickups of this type, it is exceedingly important that they all be located on the same side of the ring, preferably side by side as suggested in Fig. 4-5. If the cameras were to be placed on opposite sides of the ring, the relative location of all persons and objects in view would be reversed upon switching from one camera to another. This sudden shifting of one's viewpoint from one location to an entirely different one is not a natural experience and, consequently, is both confusing and difficult to accept. Furthermore, since the viewpoint is reversed, objects and persons on the right shift over to the left, and vice versa. The only advantage that might be achieved by having cameras on more than one side of the ring is to obviate the possibility of having some interesting action blocked by an unfortunate position of the participants or the referee. The disadvantages of the arrangement, however, far outweigh this possibility, and the practice is to be avoided.

In general, the elevation of the cameras above the ring should be as low as consistent with clearing any person or object that might come between the camera and the ring. If the cameras are located too high, the camera angle is an unnatural one from the viewer's standpoint and the composition of the picture becomes undesirable. On the other hand, the camera must be high enough so that the ropes surrounding the ring do not interfere with the line of sight.

Where it is not possible to locate the cameras as close to the ring as recommended, they may be placed farther away and use made of lenses having longer focal lengths. It might be thought that long-focal-length lenses would make it possible to locate the cameras at almost any reason-

able distance from the ring. Unfortunately this is not the case since the perspective becomes unduly distorted when they are employed. The general effect is to make the ring look abnormally shallow with all action taking place in a single plane at right angles to the line of sight. In other words the ability to judge depth in the two-dimensional picture is almost

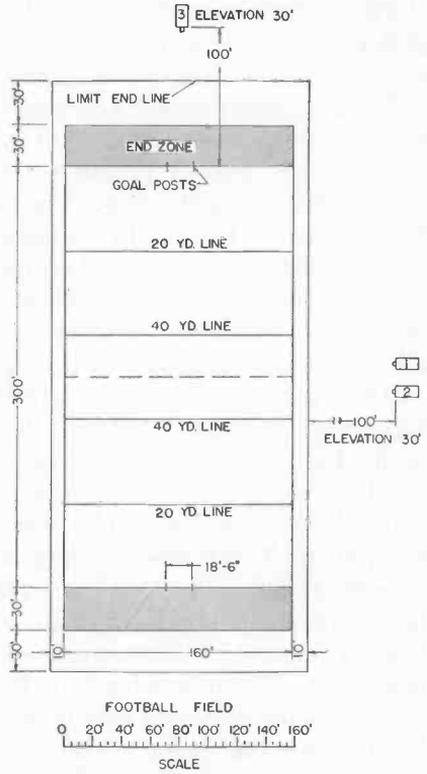
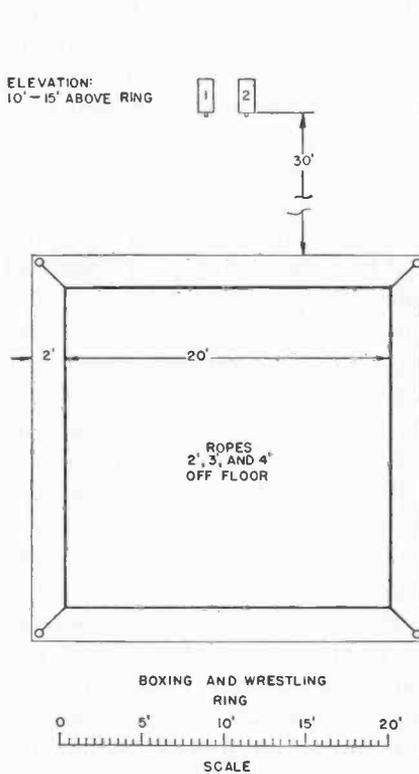


FIG. 4-5. The dimensions of a standard boxing or wrestling ring drawn to scale, together with suggested positions for one or two cameras.

FIG. 4-6. This scale drawing of a standard football field may be used in planning camera locations and for determining the coverage of lenses of various focal lengths. Suggested locations for one, two, or three television cameras are shown.

totally lost. However, regardless of the location of the pickup cameras, with the aid of the scale drawing of Fig. 4-5 and the data on television camera lenses given in Table 2-1, it is an easy matter to determine the lens complement required for a given set of circumstances.

**4-5. Football.** Football games are among the most popular of the sporting events that are regularly televised; in some respects, the television

viewer is able to see the game better than a spectator at the field. This stems from the fact that the television cameras are almost always located on, or at least very close to, the fifty-yard line, and their elevation above the field is chosen as carefully as possible. Furthermore, when more than one camera is used, it is possible to switch back and forth from long shots to close-ups and thereby make visible not only the broad aspects of the play but also the details. The basic principles of camera location, as discussed in preceding sections, apply equally well here.

The dimensions of a standard football field are given in Fig. 4-6, together with suggested locations for one, two, or three cameras. If there is a choice as to the side or end, it is preferable, of course, to avoid having to face the cameras into the sun, which, on a fall afternoon is at a relatively low elevation.

The range of action on a football field, coupled with the size of the field and the surrounding stands or stadium, calls for the use of lenses of all sizes, from wide-angle types having a focal length of only 50 mm to those having focal lengths of 20 in. or more. For the most part, however, the 50-mm, 90-mm, 135-mm, 8½-in., and 13-in. lenses will be most useful for football pickup work.

As with all other pickups, perspective is important in football broadcasts. The truest perspective, for this and other pickups, is obtained with a lens having an angular field of view of about 15 degrees. A 135-mm lens for the image orthicon, or similar diameter camera tube, meets this requirement and this, no doubt, contributes to the popularity of this lens for many pickup problems.

**4-6. Basketball.** A scale drawing of a standard basketball court is shown in Fig. 4-7, together with suggested locations for two cameras. Because of the size of a basketball court, and in the light of the basic camera location principles detailed in preceding sections, there is little need for more than two cameras for basketball pickups, except as spare units.

Unlike the sports previously described, basketball pickups may present some problems in so far as lighting of the court is concerned. Both base-

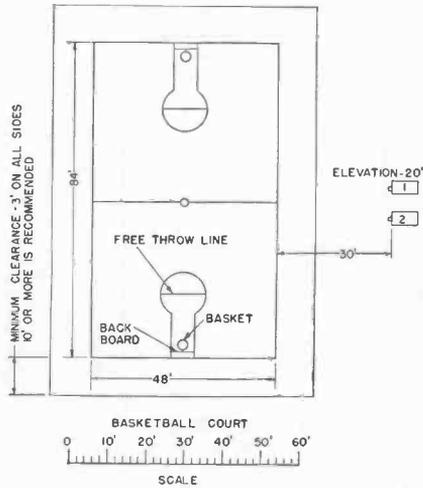


FIG. 4-7. The official dimensions of a standard basketball court drawn to scale, together with suggested locations for one or two cameras.

ball and football are played outdoors under daylight conditions (except for games that run over into dusk), or if a night game is involved, brilliant lighting of uniform coverage is usually provided. Likewise, the boxing or wrestling ring is usually intensely illuminated and presents no lighting problem of any consequence. Basketball courts, on the other hand, are

usually indoors and are not always so well illuminated as desired; it is, therefore, good practice to check the intensity of the incident light under actual operating conditions.

**4-7. Ice Hockey.** Ice hockey is probably the fastest sport of all that are regularly televised not only because a relatively large area must be covered but also because the participants skate about the rink at considerable speed. In addition, the action is often long sustained, and the center of interest is a relatively small puck that can easily be lost from sight because of its size, coloring, and the speed with which it travels across the ice and through the air. This sport requires the utmost skill on the part of those responsible for camera pickup and switching if the material is to be presented in a manner that is both interesting and easy to follow.

Perhaps more so than in any other sporting pickup, it is important in ice-hockey pickups to group at least two if not all three

cameras (if as many as three are in use) as closely together as possible. As a general rule, it has been found that a grouping of this kind, coupled with judicious switching between cameras (in order to effect appropriate changes in the focal length of the lens trained upon the center of interest), results in the easiest viewing on the part of the television audience. Ideally, the viewer should be completely unaware of the switching of

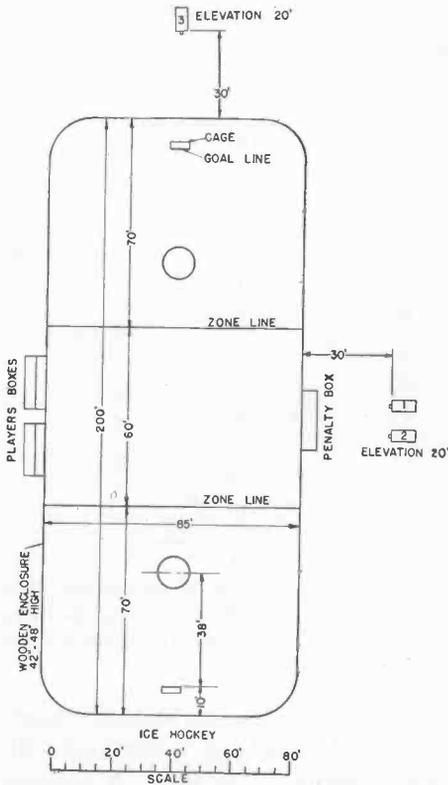


FIG. 4-8. The dimensions of the regulation ice-hockey rink drawn to scale with suggested locations for one to three television cameras.



If only one camera is available, it is best employed by locating it at the side of the court approximately 30 ft from the side line, in the plane of the tennis net, and about 20 ft above the surface of the court.

Where a second camera is available, it is suggested that it be located at one end of the court, about 30 ft back of the base line and approximately 20 ft above the court. This is the first instance where it has been suggested that a second camera be placed at a location other than alongside the first. However, because of the fast flight of the ball from one side of the net to the other, it is generally not desirable to attempt to follow the game by rapid back-and-forth panning of camera No. 1. Instead, it is suggested that a camera be placed at the end of the court and employed to observe the general play. Under these circumstances, the camera in position No. 1 may be reserved for following the service of the ball at the beginning of play, action at the net during play, and for general use around the court between actual plays. This example illustrates the basic principle of endeavoring to locate cameras in positions that will provide the most interesting and informative view of the action with the least amount of camera movement.

If a third camera is provided for a tennis pickup, it may be located alongside the first. This provides an opportunity to employ lenses of different focal lengths in the two cameras and avoids the possibility of this location being uncovered if camera No. 1 should fail during a broadcast.

The lens sizes most useful for tennis matches will depend, of course, upon the exact positions selected for the cameras. For cameras located as shown in Fig. 4-9, it will be found that for camera positions Nos. 1 and 3, a 7-in. lens will be useful for watching the ball being served and 50- and 90-mm lenses for pickup of general action on the court. Camera No. 2, on the other hand, can usually make good use of 90- and 135-mm lenses for general shots and 7- or 8½-in. lenses for close-ups.

**4-9. Bowling.** Bowling is perhaps the one sport where pickup cameras may be located opposite to each other with reasonable success. The arrangement is not employed by preference, however, but rather as a practical working arrangement. As shown in Fig. 4-10, one camera may be located 5 to 10 ft back of the approach area of the alley and the other at the opposite end of the alley back of the pins. Camera No. 1 is usually employed to televise delivery of the bowling ball and to follow its travel down the alley almost to the pins. At this point, a quick switch is usually made to the second camera to show the result of the ball hitting the pins. This arrangement is simply an expedient to obtain a close-up of the pin action and, from the television audience's viewpoint, is completely unnatural since the scene presented is that from the pin boy's side of the alley rather than from that of the spectators. However, probably because

of the relatively simple geometry of the situation, viewers adjust themselves to the situation easily and, after a short period of indoctrination, accept the presentation without protest.

Televising the action on a bowling alley presents some problems from the viewpoint of lens selection. Because of the narrow field of interest on a bowling alley, lenses of rather long focal length may be used to advantage. For instance, the camera in position No. 1 in Fig. 4-10 can usually employ lenses having focal lengths ranging from 8½ to 17 in. for following the ball down the alley. However, with a lens of this focal length, the field of view in a vertical direction is such that it is impossible to get even a half-length view of the bowler during delivery of the ball. For this latter purpose, a 50-mm lens is usually required. If the pickup can afford two cameras at location No. 1, both short- and long-focal-length lenses may be used; otherwise, a compromise must be made between a lens that provides an acceptable view of the bowler and of the ball.

The camera in position No. 2 is not subject to this handicap, since its assignment is primarily to cover the field of interest at the pit end of the alley—primarily, the area occupied by the tenpins. A 90- or 135-mm lens usually serves this purpose satisfactorily.

**4-10. Camera Location Principles.** In the foregoing examples of typical field pickup arrangements, the basic principles of site selection for the cameras have been presented by specific illustrations, all in the sports field. However, since these principles are applicable to public events and outside pickups other than those explicitly mentioned, the fundamental tenets are summarized here. In selecting camera positions for televising events in the field, the following principles, where relevant, should be followed:

- a. Choose a position that will provide the most interesting and informative view of the scene with the least camera motion.

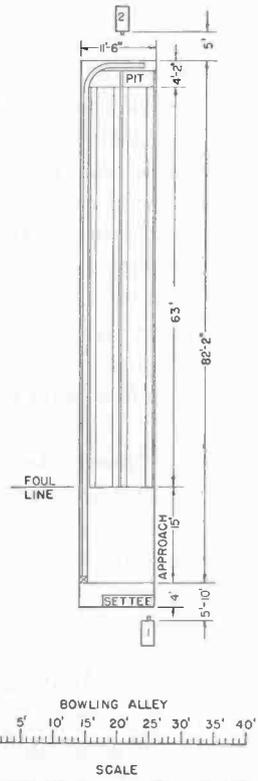


FIG. 4-10. Study of this dimensional sketch of a bowling alley will show the difficult pickup problem that this sport presents. This is about the only instance where cameras can be used at opposite ends of a playing area with any degree of success.

- b. To avoid confusion in the minds of the viewer, do not locate cameras on the opposite sides of a field (bowling is an exception).
- c. Choose a location that is sufficiently well elevated to avoid interference from persons or vehicles that pass between the camera and the action being televised but not so high that persons appear foreshortened.
- d. Avoid locations that permit a pillar, post, pole, or other obstruction to come in front of the camera as it is panned to follow the action.
- e. As a rule, if more than one camera is used, the second should be located alongside the first (tennis matches are an exception).
- f. Avoid facing the sun unless some special circumstances make such locations mandatory.
- g. The problem of keeping the camera in focus with the action at all times should be kept in mind when a location is chosen.
- h. Choose a location that will provide correct perspective of the scene that is viewed for the majority of the time.

**4-11. Camera Lenses for Field Pickups.** In the preceding sections a number of examples are given of the focal lengths of the lenses that are suitable for use at specific sporting events. Since correct lens selection is important for every pickup, the principles that serve as a guide are reviewed here. In addition, certain lens problems peculiar to field pickup operation are discussed in detail.

Six lens sizes, 50 mm, 90 mm, 135 mm, 7 in., 13 in., and 17 in. (Fig. 4-11), are used extensively for field pickup work. (Detailed quantitative information covering these lenses is given in Table 2-1.) The 50-mm lens is used for wide-angle opening and closing shots of an athletic field, of a crowd, or of the general scene of a broadcast. The 90-mm is used where a fairly large field of view is required, as in a baseball game when a man is on base and it is desired to cover the area from second base to home plate. (For the standard baseball shot, however, covering just the pitcher to home-plate area, the 135-mm lens is almost always used.) The 17-in. lens is used for medium or group close-ups of people on the field. The 13- and the 17-in. lenses, on the other hand, are used mostly for individual close-ups and crowd shots in the far stands. Lenses larger than 17 in. are seldom used for three reasons: (a) They are hard to pan without causing a picture jitter, (b) their field of view is so limited that if a fast-moving object is being followed it may be lost, and (c) their long barrels tend to get into the field of view of the shorter lenses if the latter are also included on the lens turret.

Although the six lenses mentioned above fulfill most requirements, some in-between sizes are used in special cases where the available camera

locations are such that the sizes mentioned result in either too small or too large a field of view. The alternate sizes found in television use include focal lengths of 8½, 15, 20, and 25 in. Details of typical lenses of these sizes are given in Table 2-1.

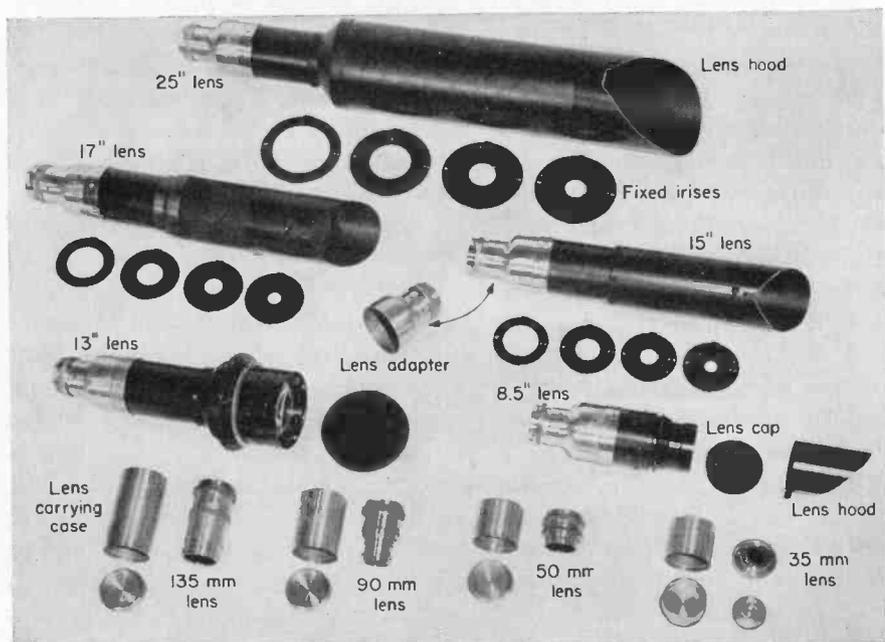


FIG. 4-11. The long-focal-length lenses shown at the top of this illustration are equipped with hoods and make use of the fixed irises shown. Shorter focal-length lenses that afford adjustable irises, which are much to be preferred, are shown at the bottom. The adapter in the center is used on the long-focal-length lenses, as illustrated in order to accommodate them to a standard lens turret. (Courtesy of Radio Corporation of America.)

The Zoomar lens (see Sec. 2-2) is a special type that affords certain advantages because its focal length is continuously adjustable from 3 to 22 in. For example, if there is adequate light, a camera equipped with a Zoomar lens can do almost anything a camera equipped with the lens sizes bracketed can do. In addition, the Zoomar has the advantage that it can change smoothly and almost instantaneously from one focal length to another.

However, the Zoomar has its disadvantages. It usually ties up one camera completely because it generally cannot be mounted on a standard turret; rather, it requires a special attachment. In addition it usually has

more aberration than standard lenses; consequently, there is loss of detail particularly around the edges of the scene. Further, it is not intended for producing maximum picture definition under poor light conditions. One type, for example, is limited to a speed of  $f/5.6$  for focal lengths of less than 12 in. and to  $f/8$  for greater focal lengths.

In operation, it is recommended that the Zoomar be panned to follow the action in the usual way and that the zoom action be manipulated slowly and only when necessary. Too much zooming will defeat its purpose and distract attention from the subject matter being televised. It is particularly important that the beginning and the end of the zoom be slow and hardly perceptible. If a visual impact designed to startle the audience is desired, a fast zoom is permissible. However, like background music, the less one is conscious of the camera work, the more the program material is likely to be enjoyed.

The Video Reflectar lens (see also Sec. 2-2 and Fig. 2-4) having a focal length of 40 in. is another special type of lens that proves useful in certain field pickup situations. However, because of the relatively small field of view of a lens of this focal length, a very accurate optical sighting arrangement is needed if even moderately fast-moving action in the distance is to be followed.

Nevertheless, there are undoubtedly situations where the use of a lens of this type will be indispensable as, for example, where conditions are such that the television cameras cannot be located as close as desired to the scene of action. A ceremony taking place on a distant platform, an event on the far side of a body of water, or some hazardous operation that cannot be too closely approached are all instances where an extremely long-focus telephoto lens may be used to advantage. As noted heretofore, however, perspective is badly distorted by the use of long-focal-length lenses and, where this is important, they should be considered only where circumstances make their use imperative.

In planning for a field pickup, it is important to realize that the camera location makes a big difference in the size of the field covered with any particular size of lens. When available, scale drawings (both in plan and in elevation) of the site of the broadcast are very helpful. With the proposed camera positions spotted on these drawings, the field of view which the various lenses cover can be studied. A series of transparent triangles, having angles corresponding to the different lenses, are very useful in quickly visualizing the possible fields of view. Alternately, one large transparent angle, corresponding to the widest angle lens available, can be used with the lesser angles of other lens inscribed on its surface. Where the action to be televised ranges in some depth, it is necessary also to check the vertical angle limitations. This problem is accentuated by

the fact that the 3 by 4 aspect ratio makes the vertical field of view 25 per cent less than the horizontal.

When outdoor pickups are made on very bright days, it may be impossible to stop the lens down far enough to reduce the highlight illumination on the photocathode of the camera tube to a value near the knee of the transfer characteristic (see Sec. 2-7, *Photocathode Illumination*). When this condition is encountered, it may be corrected by the use of a neutral

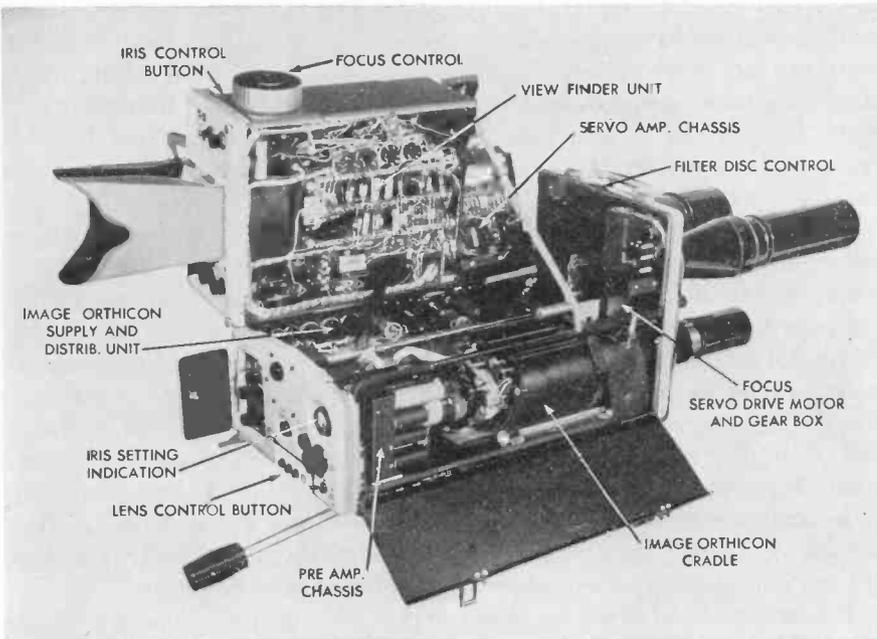


FIG. 4-12. Among other features this camera includes an internally mounted light-filter holder that permits instantaneous choice of any one of four color or neutral density filters. In addition, it incorporates means for remotely controlling lens selection and iris opening. (Courtesy of General Precision Laboratory, Inc.)

density filter of the proper transmission value to give the required reduction in illumination. Usually two filters, one having a transmission of 1 per cent and the other 10 per cent, will give the required amount of control. Filters of this type are normally mounted in lens adapter rings that either slip or screw onto the lens. In one instance, however (see Fig. 4-12), provisions have been made for accommodating neutral density and other optical filters on a filter wheel which is located immediately back of the lens turret. The filter disk that rotates independently of the lens turret may be turned manually until the desired filter (or a clear opening) is in

front of the camera tube face. The filter that is selected in this manner remains in place, regardless of which of the lenses on the turret is in use, until another filter is moved into place by rotation of the filter disk.

Some makes of longer focal-length lenses do not have adjustable irises. Under these circumstances, however, inconvenient use can be made of removable fixed stops such as shown in Fig. 4-11. In this instance, it might be thought that under extremely bright lighting conditions, there would be no need for neutral density filters since as small an iris opening as needed could be used. Unfortunately, this is not the case since it is seldom possible to use a lens stop smaller than about  $f/22$  because of the resulting loss of resolution. As a matter of fact, lenses often exhibit maximum resolution at approximately one stop opening smaller than the maximum for the lens in question. Maximum resolution should not be confused with maximum depth of focus, however. This latter characteristic increases with decreasing stop openings.

It is important, under practically all conditions of operation, to make use of sunshades or lens hoods on the camera lenses. Their use will prevent stray light from striking the surface of the lens and causing loss of contrast and general degradation of the optical image. The appearance of typical lens hoods is shown in Fig. 4-11. Lens hoods and other accessories should be securely fastened to their lenses in order to avoid their loss during severe outdoor operating conditions. Furthermore, because of the possibility of accidental collision of lenses with the supporting columns or pillars when operating in the field from balconies and platforms, it is advisable to secure at least the longer lenses by a chain or other means. If a lens is then knocked loose accidentally, the chain will prevent it from falling on anyone or anything that happens to be below.

It is advisable to avoid, as much as possible, the removal and replacement of lenses from the lens turret to prevent damage to the threads on the lens barrel. These barrels are often made of brass (although some are of stainless steel) and are relatively soft. The threads of the lens turret, on the other hand, are usually stainless steel; consequently, no force should be used at any time when attaching lenses to the turret. Lenses employing bayonet and similar types of couplings are not susceptible to this type of damage, of course.

On the other hand, when a camera is being transported, it is advantageous to remove the lenses and carry them in a separate container in order to protect the lenses and to make the camera lighter for carrying. Lenses having bayonet-type couplings may be readily removed and suitable covers substituted in their place on the lens turret. However, since lenses employing thread-type mounts are prone to having their threads damaged by frequent removal and subsequent reinstallation of the indi-

vidual lenses, it is advisable to remove the entire turret and lens assembly, as a unit, and to substitute a dummy turret in its place in order to protect the face of the image orthicon and other internal parts of the camera.

**4-12. Field Surveys.** Before a commitment can be made as to the feasibility of originating a television program from a particular field location, it is desirable that representatives of both the program and the technical departments make a survey of the proposed scene of action. During this survey, information may be obtained as to the availability of (*a*) suitable camera locations, (*b*) commentator vantage points, (*c*) primary power supply, (*d*) lighting facilities, (*e*) microwave transmitter sites, (*f*) parking space for mobile units, (*g*) camera-control and audio-equipment positions, (*h*) video, audio, and telephone circuits, and (*i*) other facilities necessary to the successful production of a television program. In addition to data pertaining to the physical layout, it is also useful to obtain information as to (*a*) the names and telephone numbers of the persons that may be contacted for assistance at the field location, (*b*) the shipping address to which the equipment should be directed, (*c*) the route through the premises over which the equipment will have to be taken to reach its final location, (*d*) the time of day when access to the premises may be had for setting up the equipment, (*e*) the opportunity that will be afforded for testing the setup and rehearsing the proposed program pickup, (*f*) the strength of any disturbing magnetic or electrical fields at camera locations, and (*g*) the other factors that must be given consideration in preparing for a television origination from a field location.

In all survey work it is important that the conditions recorded be representative of those at the time of the day and the season of the year when the broadcast is to take place. Furthermore, the data should reflect the conditions that exist when any crowds that are involved are present and when all ventilating, air-conditioning, lighting, elevator, and other equipment is in operation. More than once the unwary have been surprised to find that conditions at the time of the broadcast sometimes bear little resemblance to those existing when a survey was made during a period that was not representative of the scheduled program time. The presence of large crowds of people may cause building-structure vibration at camera locations, they may unexpectedly obstruct the field of view of a camera, or they may create so much noise that the commentator's remarks are seriously masked. The load thrown on the power lines by equipment essential to the operation of the facilities connected with the site of the pickup may reduce the line voltage to unusable levels, or the circuits may be inadequate to supply the additional power demands of the television equipment. The contractors employed for the operation of elevators or of other machinery may cause serious interference to the audio and video

circuits. Instances have been known where a single piece of office equipment, such as an adding machine or an electric typewriter, located in an adjacent building and many floors away, has created enough interference to ruin a television program completely, simply because its presence was not detected at the time of the original survey and a full-scale test was not made prior to the broadcast. In still another case, although a satisfactory rehearsal was conducted in the afternoon, the air show (which was scheduled during the evening transportation rush hour) had to be canceled because of the exceedingly strong magnetic fields set up by the almost continuous passage of subway trains in an adjoining tunnel and which made camera operation impossible.

Because of the extent of the information that should be compiled concerning the origination site of a field program, a field survey form is almost a necessity; its use will certainly speed the survey and guard against any important data being overlooked. Furthermore, a survey serves to place in the file information concerning the pickup point and makes it unnecessary to rely upon a particular person's memory as to the length of camera cables required, whom to contact, what kind of power is available, and the myriad of other details that may be readily recorded for future reference. The need for a systematic means of keeping records of field conditions is equally great in both large and small organizations. In the former, a survey form ensures that all reports are made in a uniform manner, and no matter who is finally sent to undertake the pickup, he will have access to full information concerning conditions at the site. In a small organization, even though one person may make all the surveys, he may be ill or unexpectedly out of town when a broadcast is scheduled. With the information in the file, those who act in his absence are fully prepared to carry on without loss of time.

In addition to a systematic method of reporting field survey information, an invaluable aid for field pickup work is a check list of the equipment required for a given program or location. An equipment check list serves not only to bring to mind every equipment component that is available but to act as a "packing slip" when it comes to assembling the equipment for a given pickup. Finally, when the equipment check list has once been filled out and corrected for any errors or omissions, it can be used over and over again for subsequent programs of a similar nature from the particular location which it covers. Thus on repetitive shows it is not necessary to make completely new lists each time a pickup is to be made.

**4-13. Microwave Relay Site Selection.** Communication at microwave frequencies is dependent upon ground wave transmission with the added complication that, at receiving sites below the line of sight, tropospheric reflections may be of importance. Consequently, microwave relay trans-

mitter and receiver site locations should be selected so that there is an unobstructed line-of-sight communication between the two units, preferably with terrain clearance of 100 ft. or more. If the terrain clearances are limited, there may be large variations in signal levels at various times of the day and seasons of the year. On occasion the minimum signal may become inadequate to sustain limiting action in the FM receiver that is used in microwave point-to-point television relay systems. Picture quality is usually unsatisfactory under these conditions because the signal-to-noise ratio becomes poor, and the signal intensity may become so low that the control circuits beyond the receiver may not be able to function properly because of degradation of synchronizing waveforms.

**Microwave Propagation.** From a radio wave propagation viewpoint a receiver site is considered to be above the line of sight to a transmitter if it is possible for a direct ray to pass from the transmitter to the receiving point without being intercepted by the bulge in the earth's surface, *taking into account* the effect of the variation with height of the refractive index of the earth's atmosphere upon the wave's propagation. The reduction in dielectric constant with height causes the path of the direct ray to be curved slightly in the same direction as the curvature of the earth's surface but to a lesser extent. Under these circumstances the radio line-of-sight condition exists slightly beyond the horizon as determined on the basis of a geometrical straight-line path. This effect can be taken into account by assuming that the space waves propagate along straight-line paths and that the earth has an effective radius slightly larger than its actual radius.<sup>1</sup> In practice this phenomenon may be provided for by assuming the earth's effective radius to be approximately 1.33 times its actual radius. Under these circumstances, the distance  $d_0$  to the radio horizon for an antenna height  $h$ , as illustrated in Fig. 4-13, is

$$d_0 = \sqrt{2h}$$

where  $d_0$  is in miles and  $h$  is in feet. The result of this equation is plotted in the figure.

When both the transmitting and the receiving sites are elevated a distance  $h_1$  and  $h_2$ , respectively, the maximum distance  $d_L$  over which a wave can propagate between them, without being intercepted by the earth, is

$$d_L = \sqrt{2h_1} + \sqrt{2h_2}$$

where  $d_L$  is in miles and  $h_1$  and  $h_2$  are in feet. Figure 4-13 may also be used to determine the results of the above equation by using the chart first to find the distance from the transmitting site to the radio horizon,

<sup>1</sup> Terman, F. E., "Radio Engineer's Handbook," p. 683, McGraw-Hill Book Company, Inc., New York, 1943.

doing the same for the receiving site, and then adding the two results. The above formulas and chart are useful for estimating propagation results over an essentially smooth earth, bearing in mind the recommendation that for reliable transmission it is advisable to allow for a terrain clearance of 100 ft or more.

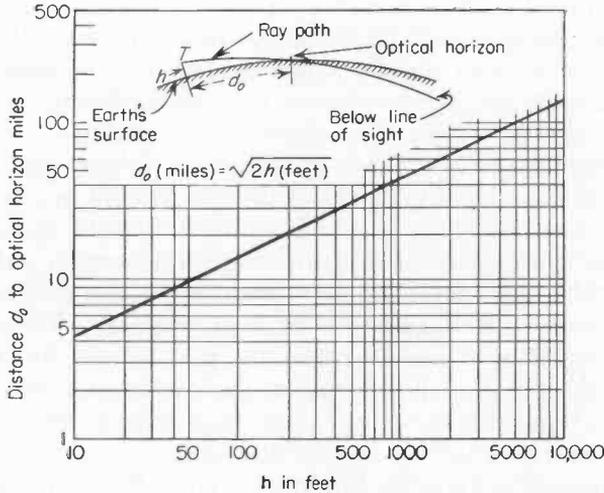


FIG. 4-13. Distance to "radio" horizon as a function of antenna height. (After Terman.)

For propagation in hilly or mountainous country or where man-made obstructions loom large, it is generally necessary to resort to plotting the proposed path of transmission on a chart such as shown in Fig. 4-14. This profile graph paper (which can be readily prepared as a tracing from which blue line prints may be obtained for use in practice) is based upon a fictitious earth having an enlarged radius 1.33 times the earth's true radius ( $3,963 \times 1.33 = 5,284$  miles) to take into account the refractive phenomenon explained above. On this type of profile graph paper, the radio rays may be drawn as straight lines. The abscissas and the ordinates of this graph can, of course, be changed to provide absolute values more in keeping with any particular application. It is to be noted, however, that a square relation exists between the two scales. Consequently, if the distance in miles is divided by 2 (or multiplied by 2), then the height in feet must be divided by 4 (or multiplied by 4).

Ground contours, for plotting on this graph paper, may be determined by reference to topographical maps of the terrain along the proposed transmission path. In making use of these maps, it should be remembered that, as a rule, they do not show the heights of man-made structures

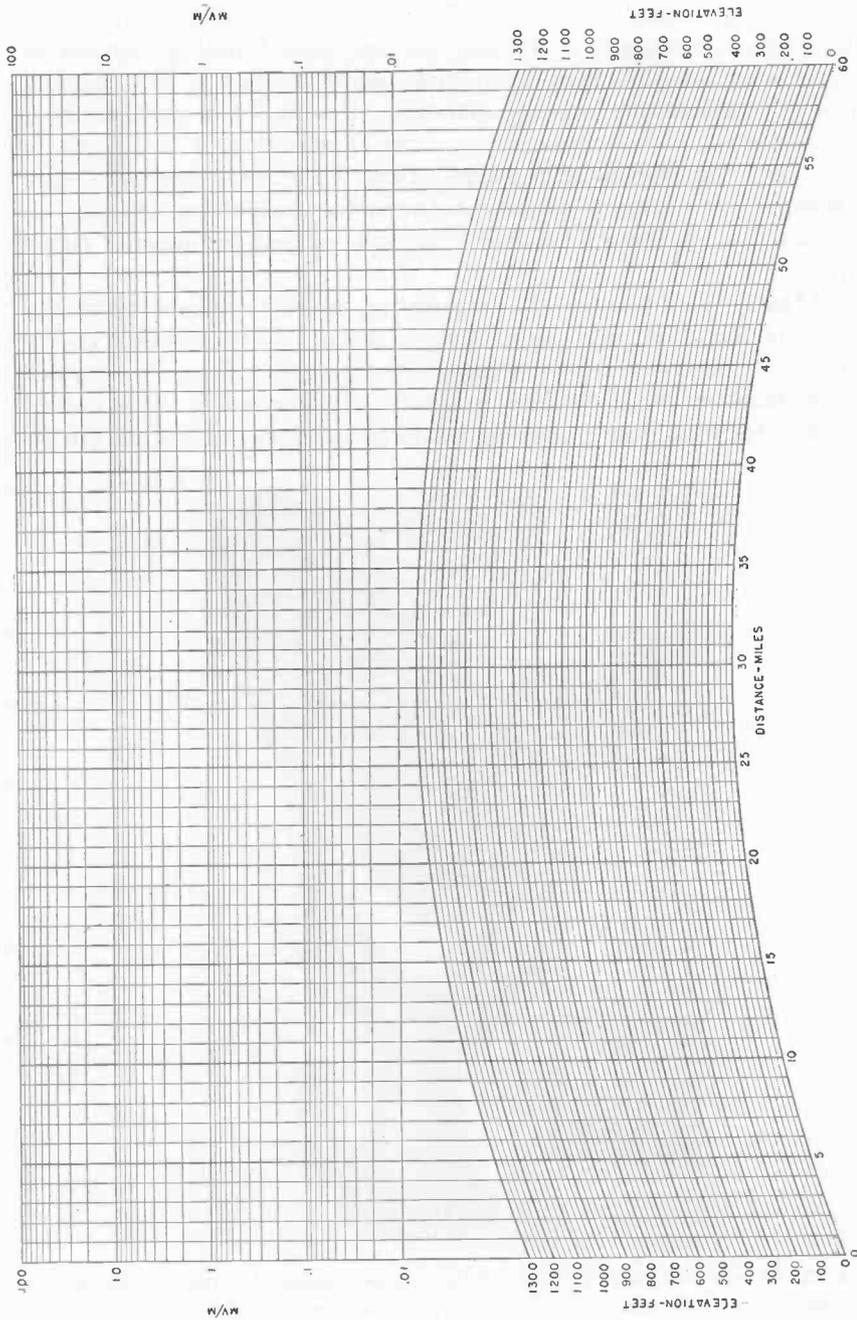


Fig. 4-14. Profile paper is useful for plotting the elevation of the terrain between proposed transmitting and receiving sites. The upper portion of the chart provides a space for plotting measured or calculated field intensities.

or botanical growths; rather they show the contour of the land itself. Under these circumstances, if there are any high buildings, groves of trees, or other nongeological obstructions along the line of transmission, they must be taken into account separately. If such obstructions are near the transmission path (either below or to either side), it is difficult to predict their exact influence on propagation. In general, they will cause less difficulty at locations midway between the transmitter and the receiver and become more of a factor as their location approaches either antenna.

**Field Tests.** To determine the propagation limitations of any particular path completely, it is advisable actually to install relay equipment and to make test transmissions. This is especially true where large buildings or other obstructions are in the line of sight or just to one side. Not only is it possible for such obstructions to create ghosts, but in addition the re-

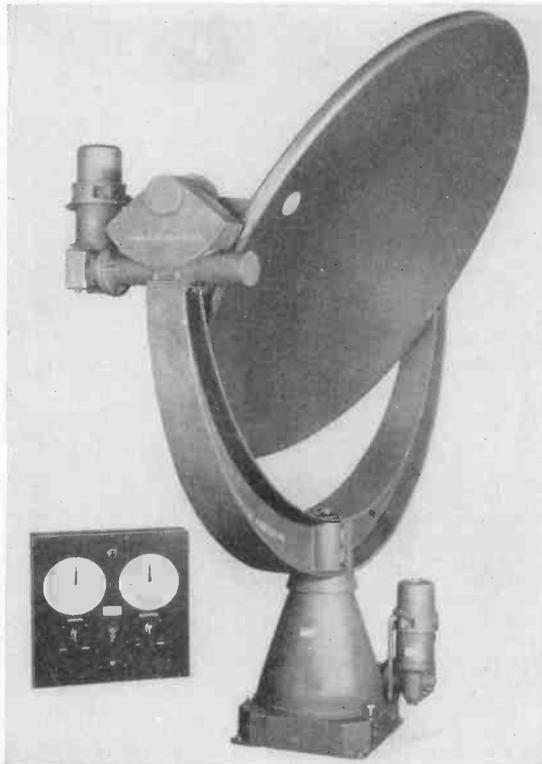


FIG. 4-15. A remotely controlled microwave antenna mount that permits adjustment of the antenna in both azimuth and bearing. The antenna reflector shown is six feet in diameter. (Courtesy of Radio Corporation of America.)

ceiving antenna may be directed toward a strong reflected signal rather than along the direct path. The direct signal always has greater strength and, of course, is preferred for best operation. On the other hand, where a direct signal cannot be obtained, it may be possible to operate satisfactorily by means of a strong reflected signal from some large object. In this instance, both the transmitting and the receiving antennas must be oriented to take advantage of the reflecting properties of the surface being used. For direct-line transmission, mirrors for reflecting the sun have been found useful (under proper conditions) for visually determining the direction from one site to the other. With the direction established in this manner, or with the aid of a compass, the final adjustment of the transmitting and the receiving antennas may be made by observing the amplitude of the received signal as outlined in Sec. 3-10. Parabolic reflectors produce very narrow beams which result in very high antenna

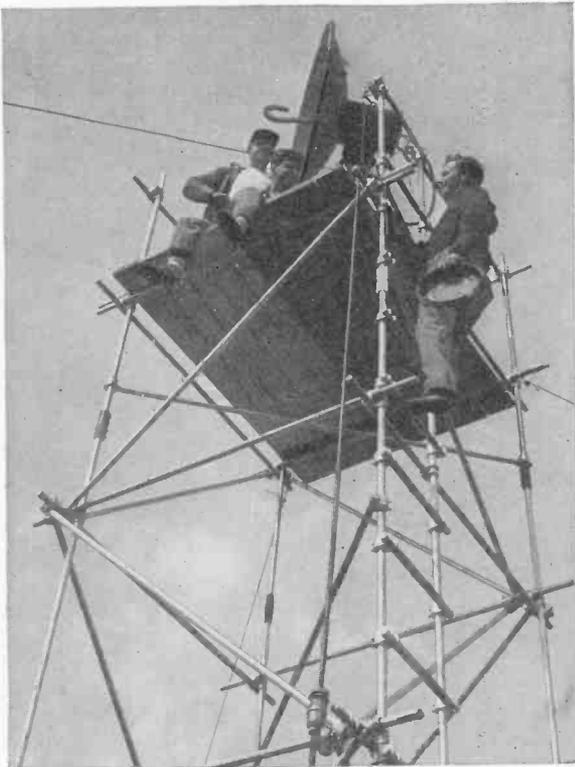


FIG. 4-16. Steel-pipe scaffolding of the type frequently erected for temporary use may be employed for the construction of antenna towers required on a transitory basis. (Courtesy of WEWS-TV, Cleveland.)

gains (5,000 times for a 4-ft reflector). The half-power beam width of a 4-ft reflector operating at 7,000 Mc is only 3 degrees. This means that a  $1\frac{1}{2}$ -degree error in *either azimuth or elevation of either antenna* will result in a 50 per cent reduction in received power. For a 6-ft-diameter reflector, the half-power beam width is somewhat less than 2 degrees so that a 1-degree error in either transmitting or receiving antenna orientation will result in reduction of the received signal to one-half its possible value.

**Central Receiver Sites.** Television stations sometimes find it advantageous to locate a microwave receiving antenna at some high central point that will afford good reception from field pickup points scattered over a wide area. For example, a receiving antenna may be located high up on the tower that supports the television station's main transmitter or, perhaps, on the top of some favorably situated high building which can serve as a main reception point for field pickups. Such locations are sometimes relatively inaccessible, particularly in inclement weather. Remotely



FIG. 4-17. Each tier of this aluminum-alloy scaffold can be reduced to a package only  $6\frac{1}{2}$  in. thick and weighing less than 60 lb. (Courtesy of Up-Right, Inc.)

controlled mechanisms (such as shown in Fig. 4-15) can be installed, of course, to permit adjustment of the antenna in both azimuth and elevation.

**Temporary Towers.** The use of temporary type of steel-pipe scaffolding to create temporary towers, as illustrated in Fig. 4-16, is an excellent method of obtaining necessary height for microwave relay transmitters and receivers when no other means are at hand. A tower of this type can be erected or knocked down in a matter of hours, the time depending upon the height of the structure. In most parts of the country structures of this type can be obtained on a rental basis from companies that deliver the required materials to the site, erect the tower, and subsequently dismantle and remove it. Often, very reasonable rates may be obtained for this service, particularly if the television station is in a position to contract with a particular erection company to supply all the needs of the broadcasting station. Because of the custom-built nature of the structure, the tower height and size may be individually determined for each installation thereby providing the maximum possible degree of flexibility. As is shown by the photograph, the structure consists of metal pipe fastened together with patented clamps. The diameter and the length of the pipe sections are chosen to fit the particular needs of the project in hand. Where the pipe is made of aluminum alloy, the individual sections are light enough to be carried readily. As shown in Fig. 4-17, each section of the scaffold illustrated folds into a flat package that is only  $6\frac{1}{2}$  in. thick and weighs about 60 lb.

## Synchronizing Waveform Generators

THE ROLE OF THE SYNCHRONIZING WAVEFORM GENERATOR in a television broadcasting system is all important since the purpose of this unit is the generation of the accurately timed and precisely shaped waveforms that are essential to the operation of the television transmitting and receiving system as a whole. In some respects its function may be likened to that of the heart since both are concerned with the pulse rate of the systems they serve. In another sense, it is similar to the brain since it is a nerve center that aids in coordinating the actions of the apparatus under its jurisdiction. In any event, because of its prominent place in the generation of a standard television signal, the synchronizing waveform generator is one of the most important single pieces of apparatus in the television broadcasting station.

**5-1. Function of Synchronizing Generator.** The primary purpose of a synchronizing waveform generator is to furnish the timing pulses necessary for proper operation of the television field, studio and film cameras, monoscopes, flying-spot scanners, and other video signal sources. In addition, it is employed for the generation of the government-specified standard synchronizing and blanking waveforms (see Sec. 1-7). Its output does not consist simply of one waveform but several, all properly synchronized to produce a television picture signal in accordance with prevailing standards. The output waveforms available from a synchronizing waveform generator include (*a*) a vertical driving signal, (*b*) a horizontal driving signal, (*c*) a composite synchronizing signal, and (*d*) a blanking signal. The frequency, the waveshape, and the timing of all these signals must be suitable for the intended purpose. A description of each of the signals is given in the following paragraphs. In all instances where numerical examples are given, the figures apply to 525-line 60-field 30-frame 2-to-1 interlaced monochrome transmission.

**Vertical Driving Signal.** The vertical driving signal consists of a square-wave pulse having a repetition rate of 60 cps, the vertical scanning rate. These pulses are used to control or trigger the saw-tooth generators which

supply vertical scanning voltages for camera and picture tubes. In addition, they are used for the generation of vertical blanking pulses (e.g., see Secs. 2-3 and 2-5).

**Horizontal Driving Signal.** The horizontal driving signal is also a square-wave pulse but of relatively short duration. The repetition rate of these pulses conforms to the horizontal scanning frequency or 15.75 kc. These pulses are used for the generation of horizontal scanning and blanking waveforms for camera and picture tubes.

**Composite Synchronizing Signal.** The composite synchronizing waveform is the signal that must be added to the television-camera picture signal in order to form (together with the blanking signal) the standard composite video signal in accordance with governmental standards (see Sec. 1-7). These synchronizing signals are employed by the television receiver to synchronize its scanning and blanking action with that of the television camera. The composite synchronizing signal consists of (a) short-duration, horizontal synchronizing pulses at 15.75 kc, (b) longer-duration vertical synchronizing pulses of the serrated type at 60 cps, and (c) a series of six short-duration equalizing pulses preceding each vertical pulse and six more following it.

**Blanking Signal.** A blanking signal is added to the transmitted video signal in order to extinguish the return traces on picture tubes. It consists of square-wave pulses at both horizontal scanning frequency (15.75 kc) and vertical scanning frequency (60 cps). These pulses are of longer duration than the corresponding synchronizing pulses and are transmitted at a "blacker-than-black" level so as to ensure complete blanking out of both the horizontal and the vertical return traces.

**5-2. Characteristics of Output Waveforms.** To a degree, the shapes of the output waveforms of synchronizing generators are determined by the governmental standards covering television transmissions. However, although these standards detail the shape of the synchronizing and blanking pulses that are finally transmitted, in addition to their *relative* amplitude, they do not cover *absolute* amplitudes of the synchronizing generator output waveforms, the load impedance for the various outputs, nor the shape and amplitude of the vertical and horizontal driving pulses. Government standards covering these details are unnecessary since several types of synchronizing generator waveforms can be used in pickup equipments and still generate a standard composite picture signal for broadcasting purposes. However, they are of importance to the broadcaster who is interested in the interchangeability of equipment and in the possibility of operating together television pickup equipment of various makes. Therefore, in order to facilitate the mixture of apparatus of different manufacture, industry recommendations have been formulated cov-

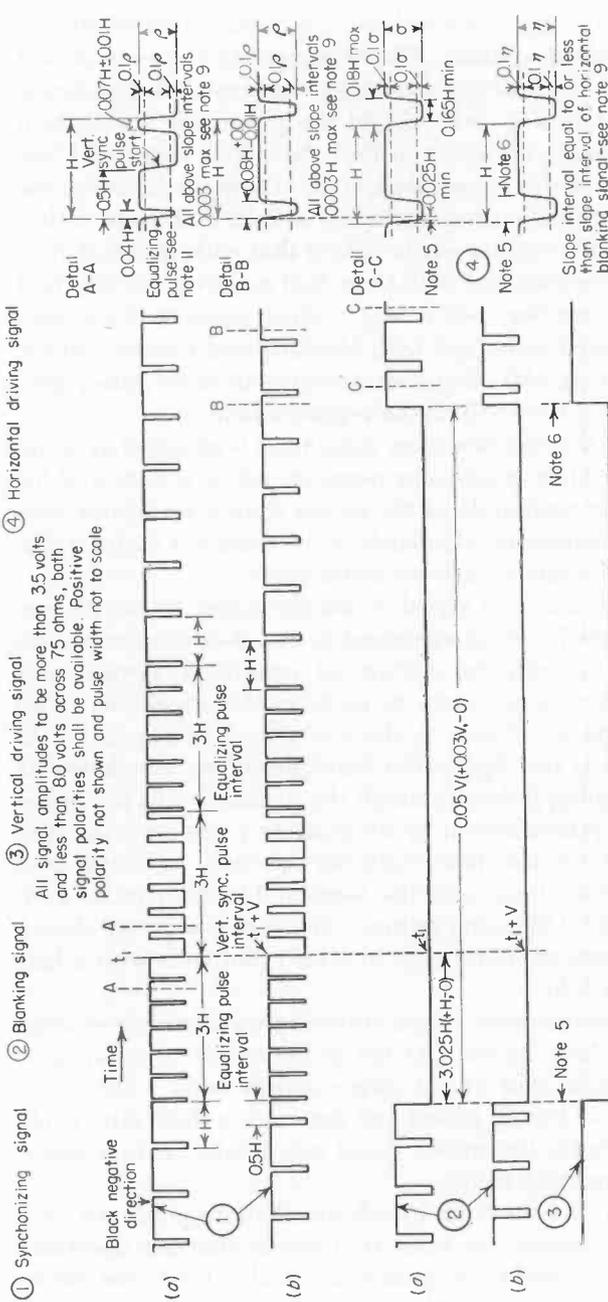
ering the items enumerated above pertaining to the characteristics of synchronizing waveform-generator output waveforms, amplitudes, impedances, signal polarities, and other pertinent details.<sup>1</sup> The characteristics of particular interest to the broadcasting engineer are presented in the following paragraphs.

**Vertical Driving Signals.** The standard shape for the vertical driving signal is shown by waveform No. 3 in Fig. 5-1. In this drawing the usual convention is followed of presenting negative-going signals in a downward direction. Therefore, the vertical driving signal is shown in this illustration as a negative-going pulse; consequently, its base line is represented by the upper horizontal lines at the left and right extremities of waveform No. 3, the pulse itself going in a downward direction from this base line. The duration of the vertical driving pulse is specified as being adjustable from  $\frac{1}{2}$  to 1 times the width of the standard vertical blanking pulse. The duration of this latter pulse is standardized as being between 5 and 8 per cent of the duration of a complete field, or between 833 and 1,333 microseconds in length (see Sec. 1-8, *Vertical Blanking Pulses*). Thus, the duration of the vertical driving pulse should be adjustable between the limits of 415 and 1,333 microseconds (one-half the lower and one times the upper limits). The output signal polarity is specified as being available both negative, as shown, and positive. The amplitude of the signal may be any value between 3.5 and 8 volts across a 75-ohm one-side-grounded load.

**Horizontal Driving Signals.** The standard shape for horizontal driving signals is shown by waveform No. 4 in Fig. 5-1. Again, a negative-going signal is illustrated although the standard calls for the availability of signals of either polarity. In any event, in waveform No. 4 the upper horizontal line represents the base line; consequently, two complete downward-going horizontal driving pulses are shown. The duration of these pulses is specified as being adjustable between the limits represented by  $\frac{1}{2}$  to 1 times the duration of standard horizontal blanking pulses. Since the duration of a horizontal blanking pulse is 11.4 microseconds (see Sec. 1-8, *Horizontal Blanking Pulses*), horizontal driving signals must be adjustable between the limits from 5.7 to 11.4 microseconds. The output amplitude of horizontal driving pulses is specified as being between 3.5 and 8 volts across a 75-ohm one-side-grounded load.

**Composite Synchronizing Signal.** For the reasons explained elsewhere (see Sec. 3-2, *Synchronizing-signal Amplifier*, and Sec. 6-5), synchronizing pulses are added to the combined picture and blanking signal after all mixing and fading of the various picture-signal sources are undertaken.

<sup>1</sup> RTMA Standards Proposal No. 378, "Electrical Performance Standards for Television Studio Facilities," Radio-Television Manufacturers Association, New York.



1. H = Time from start of one line to start of next
2. V = Time from start of one field to start of next
3. Leading and trailing edges of vertical driving and vertical blanking signals should be complete in 0.1H
4. All tolerances and limits shown in this drawing apply for long time variations and not for successive cycles
5. Timing adjustment, if any must include this condition
6. Horizontal and vertical driving pulse widths are adjustable from one half to one times their respective blanking pulse widths
7. The time relationship and waveform of the blanking and synchronizing signals shall be such that their addition will result in a standard RMA signal. The time relationship may be adjustable but must include this condition
8. The standard RMA values of frequency and rate of change of frequency for the horizontal components of the synchronizing signal at the output of the picture line amplifier shall also apply to the horizontal components of the output signals from the recommended sync. generator
9. All slope intervals to be measured between 0.1 and 0.9 amplitude reference lines
10. The time of occurrence of the leading edge of any horizontal pulse 'N' of any group of twenty horizontal pulses appearing on any of the output signals from a recommended synchronizing generator shall not differ from 'NH' by more than 0.0008H where H is the average interval between the leading edges of the pulses as determined by an averaging process carried out over a period of not less than 20 nor more than 100 lines
11. Equalizing pulse area shall be between 0.45 and 0.5 of the area of a horizontal sync pulse
12. The overshoot on any of the pulses must not exceed 2%

Fig. 5-1. Synchronizing generator output waveforms recommended as standard for the television industry. (Courtesy of Radio-Television Manufacturers Association.)

For this reason a train of composite synchronizing pulses is required as a part of each television pickup system. The configuration of the combined horizontal synchronizing, vertical synchronizing, and equalizing pulses is shown as diagram No. 1 in Fig. 5-1. Again the pulses are shown in a negative or downward-going direction so that the upper horizontal line represents the base line for the pulses illustrated. Diagram 1a shows the series of synchronizing pulses corresponding to a field that ends with a full line, while diagram 1b corresponds to a field that ends in a half line. These waveforms are commensurate with those that make up the standard composite video signal (see Sec. 1-7, *et seq.*) which consists of the synchronizing signal illustrated combined with blanking and picture signals. Since the function, duration, and other characteristics of these pulses have been described heretofore, they will not be repeated here.

The output polarity of the synchronizing pulse train is specified as being available in the form of either positive or negative pulses as required for a given installation. The amplitude of the pulses from a waveform generator meeting the recommended standards is between 3.5 and 8 volts, peak to peak, across a 75-ohm one-side-grounded load.

**Blanking Signal.** The blanking signal is usually added to the picture signal in the camera-control unit, as explained in Sec. 2-5, *Blanking-pulse Shaper and Clipper*. Accordingly, a train of combined vertical and horizontal blanking pulses is necessary to perform this operation. The recommended waveforms are shown by diagram No. 2 in Fig. 5-1. As with all other diagrams in this figure, the blanking pulses are shown as downward or negative-going pulses although the standard calls for pulses of either polarity. The pulses shown by diagram 2a represent, from left to right, the blanking pulses associated with the last three lines of a field that ends with a complete line, next the vertical blanking pulse and, finally, two more horizontal blanking pulses. The series of pulses shown in diagram 2b are the corresponding ones in a field that ends with a half line at the bottom of the field.

**5-3. Basic Circuit Arrangements.** Synchronizing waveform generators usually consist of three basic parts: (a) the pulse-former or timer unit, (b) the pulse-shaper unit, and (c) a power-supply unit. The pulse former generates the basic timing pulses and determines their rate, while the pulse shaper converts the accurately timed pulses into the four waveforms detailed in the foregoing section.

**Basic Frequencies.** A review of the waveforms that are produced by a synchronizing generator reveals the basic frequencies that are necessary to synthesize the complex trains of pulses involved. First, for example, there are vertical synchronizing, blanking, and driving signals that all occur at a 60-cps rate. Second, there are the horizontal synchronizing,

blanking, and driving pulses that occur at a 15,750-cps rate. Finally, there are the equalizing pulses and the serrations in the vertical synchronizing pulse, both of which occur at a 31,500-cps rate. Various admixtures of properly shaped and properly timed pulses of these three frequencies are therefore used to generate the synchronizing waveforms required.

The three basic frequencies required for the creation of the synchronizing pulses may be obtained in a number of ways. However, all of them must bear a fixed relation to one another and, in addition, the individual frequencies must be accurately determined and very stable. In practice, at least two basically different methods have been successfully employed to obtain the desired relation between the three basic frequencies. One method employs *pulse-counter* circuits, while the other makes use of *binary scalars*. Multivibrator circuits have also been employed for the purpose but are generally considered inferior to the two methods mentioned.

**Frequency-control Circuits.** In all cases, uniformity of timing is achieved by deriving the basic timing pulses from a master oscillator whose frequency may be stabilized by a crystal oscillator or by lock-in with an external frequency source such as the a-c power-supply line or a remotely located source (*e.g.*, another synchronizing waveform generator). The normal method employed for controlling the frequency of synchronizing waveform generators, particularly those used in fixed locations, is to lock the master oscillator circuit to the a-c power line. This type of operation has been adopted largely because of the need for operating motion-picture film projectors in step with the synchronizing generator as explained in Sec. 9-6, *Projector Synchronizing*. Although this method of operation is not mandatory for all types of film projectors, it is one of the easiest ways to operate the equipment and requires the minimum of associated electronic equipment.

Another reason for locking the synchronizing generator to the a-c power line is to minimize hum problems in home receivers and in picture monitoring equipment in the broadcasting station. Any residual hum in the video amplifiers or the deflection systems of these equipments will manifest itself as beam (brightness) modulation or picture displacement, respectively. However, television receivers and picture monitors connected to the same a-c power system as is used to control the frequency of the synchronizing generator will avoid the movement of these spurious signals over the picture display. Where the power source used to operate the receiver is not the same as that used to control the synchronizing generator, any spurious signals that exist will drift upward or downward through the picture at a rate determined by the difference in frequency of the two power supplies. With well-designed receivers this is not a major problem, however, and the primary reason for locking synchronous

generators to the power-supply frequency is, therefore, in connection with the operation of film projection equipment.

In practice, synchronizing waveform generators employed in fixed installations are seldom operated with crystal control because of the advantages (just enumerated) of operating with the unit locked in with the a-c power line. On the other hand, crystal control may be used, on occasion, in field setups where film projectors are not in use and where the power-supply frequency (which may be from a portable unit) is unstable.

Control of the basic frequencies of synchronizing waveform generators by a remotely located source of frequency is practiced where it is necessary to fade or lap dissolve from a remote program origination to a local one, or vice versa. Such control poses a problem, however, in the operation of the local motion-picture projectors which must also be synchronized with the remotely located source of frequency. This may be accomplished with the aid of auxiliary equipment, at the expense of a somewhat more complicated method of operation (see Sec. 5-6).

**Pulse Generators.** For the most part, multivibrators are used in synchronizing waveform generators for the formation of the various rectangular pulses that are required either for the creation of the various output waveforms or for control functions incidental to the generation of these output waveforms. Several general types of multivibrator circuits are employed for the purpose. In some instances, conventional astable or "free-running" multivibrator circuits are employed, their frequency of oscillation being controlled by the application of accurately timed pulses of the proper polarity. In other cases, monostable or "flip-flop" multivibrators, which produce one complete cycle of operation upon the application of each control pulse, are employed. In still other instances, bistable multivibrator circuits are used; *i.e.*, multivibrators that have two conditions of stability, one wherein one tube remains in a conducting state while the other is cut off until a control pulse applied to one tube causes the condition to be reversed. The new condition of operation is then maintained until a second control pulse is applied to the opposite tube. In the latter type of multivibrator, the length of the resulting output pulses is determined by the delay between the starting and the stopping pulses.

**Delay Lines.** Delay lines are used extensively in synchronizing waveform generators in order to obtain control pulses that are correctly timed with respect to each other. The construction of the delay lines is quite conventional, employing inductors and capacitors in the usual artificial line configuration. Depending upon the amount of delay required for any given application, the delay lines may employ 30 to 60 or even more sections, each consisting of an inductor and a capacitor. Taps are brought

out from the junction between sections in order that the timing intervals may be accurately adjusted to precisely the amount required.

**5-4. Binary Scaler-type Generator.** A portable synchronizing waveform generator employing binary scaler counters is shown in Fig. 5-2. The small size, light weight, and compactness of this type of synchronizing generator permit the entire unit, consisting of a frequency generator, a pulse shaper, and the necessary power supplies, to be contained in a single unit. The size of the carrying case is approximately 10 by 17 by 26 in., and its weight is 75 lb.

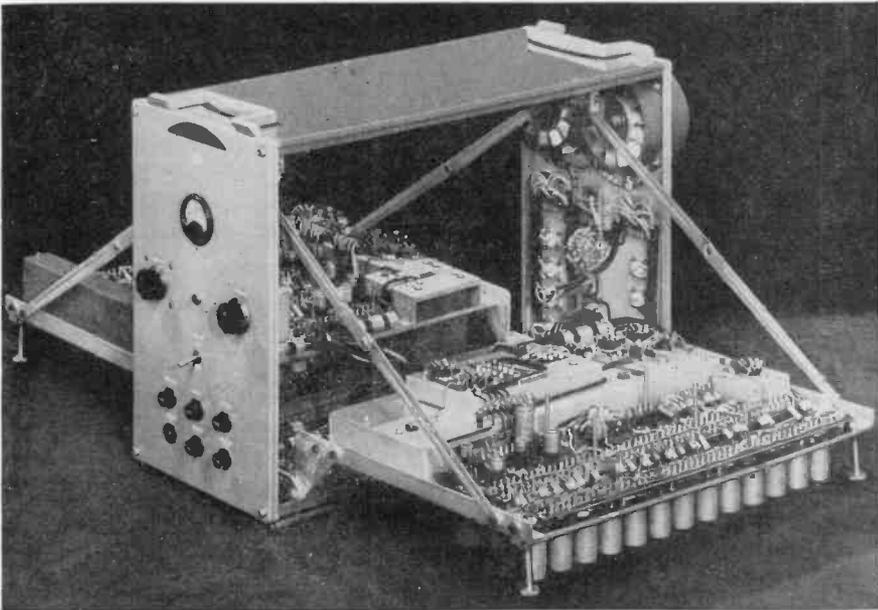


FIG. 5-2. A portable synchronizing waveform generator employing binary scaler-type counter circuits. A pulse generator, a pulse shaper, and the necessary power-supply circuits are all contained in one unit. (Courtesy of General Precision Laboratory, Inc.)

A rack-mounted synchronizing waveform generator employing binary counters is shown in Fig. 5-3. The chassis at the top comprises the timer or frequency-generating unit, and the one immediately below it is the pulse-shaper unit. Block schematic diagrams of the circuits employed in this synchronizing waveform generator are shown in Figs. 5-4, and 5-9 to 5-12. The functions and the manner of operation of the various circuits are described in the following paragraphs.

**Frequency-generating Circuits.** In order to create the output waveforms required of a synchronizing waveform generator, accurately timed

pulses are necessary at frequencies of 60, 15,750, and 31,500 cps. In the binary scaler type of generator, a master oscillator operating at the highest required frequency (31,500 cps) provides the basic source of energy, the lower frequency components then being obtained by frequency division undertaken with the aid of binary scaler counter circuits. To obtain the

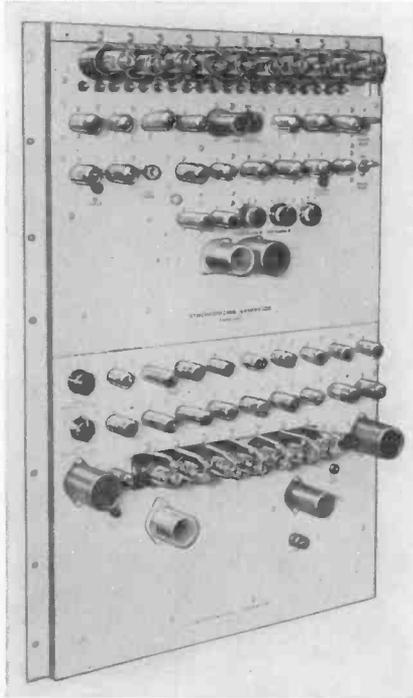


FIG. 5-3. In this rack-mounted synchronizing waveform generator, which employs binary scaler counter circuits, the pulse-former or timing unit is at the top, and the pulse-shaper unit is at the bottom of the assembly. (Courtesy of General Electric Company.)

the output of the binary chain via buffer tube V15B. These pulses are at field frequency rate which is nominally 60 cps although the exact frequency is a function of the frequency of the master oscillator from which they are derived. If the gating pulse arrives exactly when the instantaneous 60-cps a-c line voltage that is applied to the input of the gated tube is passing through zero, there will be no correction voltage applied to the master oscillator control tube V15A. If the gating pulse

horizontal and vertical scanning frequencies of 15,750 and 60 cps, the required frequency divisions are 2 to 1 and 525 to 1, respectively.

In Fig. 5-4 the master oscillator V17 is a 31,500-cps astable or free-running multivibrator employing the two diode sections of V18 as stabilizers. The frequency of this oscillator may be controlled by any one of three methods. Crystal control may be employed with the aid of the crystal-controlled oscillator V16, which operates at three times the frequency of the master oscillator frequency, or at 94,500 cps.

A second (and most common) method of control is to lock the master oscillator to the power-line frequency. This is accomplished by the automatic-frequency-control circuit consisting of power-line sine-wave amplifier tube V13A, dual-triode a-f-c tube V14, and master oscillator control tube V15A. A sample of the a-c power-line frequency is applied, via V13A, to the input of the dual triode V14 which is gated by pulses obtained from

arrives at any other time, a correction voltage will be applied to the frequency control tube, and the master oscillator frequency will be automatically changed. Correction of the master oscillator frequency will take place until, finally, each gating pulse arrives exactly at the moment the instantaneous a-c line voltage passes through zero. When once locked to the a-c line frequency, the master oscillator will continue to remain

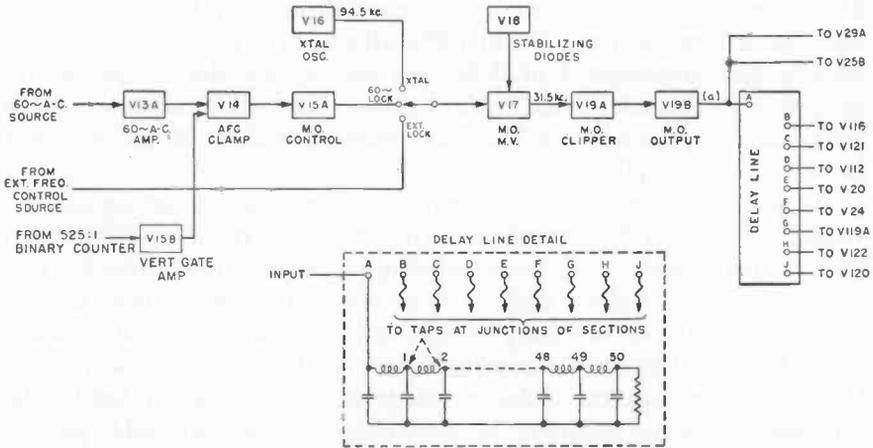


FIG. 5-4. Schematic block diagram of the frequency control circuits of a synchronizing waveform generator that incorporates provisions for locking the master oscillator to any one of three frequency sources. Details of an associated delay line are also shown.

synchronized to this reference frequency, since any tendency to wander off frequency will cause a correction voltage to be generated which, via the master oscillator control tube V15A, will bring the oscillator back into step. In order that the phase of the output of the synchronizing waveform generator may be in keeping with the requirements of associated equipment, the phase relationship between the power-line frequency and the locked-in master oscillator tube is continuously variable.

The third, and final, method of frequency control that is provided in the synchronizing generator illustrated permits locking the master oscillator to an external source such as a remotely located synchronizing waveform generator, as explained in Sec. 5-6.

The 31,500-cps output of the master oscillator, whatever its controlling source, is differentiated and then applied to the grid of a clipper tube, V19A, which sharpens and amplifies the differentiated pulses. The resulting pulses, which are of positive polarity and of twice horizontal scanning frequency, are then applied to a delay-line driver tube, V19B. The output of this tube is fed to three points: (a) a delay line (see Fig. 5-4), (b) a

horizontal-gate trigger amplifier, V25B, and (c) a binary-chain trigger amplifier, V29A (see Fig. 5-11).

**Delay Line.** The delay line, to which a portion of the master oscillator output amplifier is applied, consists of 50 individual pi sections, each consisting of a series inductance and a shunt capacitance, as shown in the delay-line detail of Fig. 5-4. A tap is brought out from the junction of each section of the line in order to provide means for obtaining a source of 31,500-cps pulses with any desired amount of delay up to the maximum obtainable from the line. The first 20 sections of the line provide approximately 0.33 microsecond of delay per section and the remainder approximately 0.22 microsecond per section. Thus the maximum delay obtainable is in the order of 13.2 microseconds, or about 20 per cent of a horizontal line, *i.e.*,  $0.2H$ .

The output of the delay line is employed to control the starting and the stopping of multivibrators which form (a) the vertical and horizontal synchronizing pulses, (b) the equalizing pulses, (c) the horizontal and vertical blanking pulses, and (d) the horizontal and vertical driving pulses. The taps on the delay line provide a means for obtaining accurately timed pulses for performing these operations. Thus, the relative timing and the duration of the various pulses that are generated by the synchronizing pulse generator are determined by the very stable passive components that are employed for creating the delay line.

The various taps on the delay line (Fig. 5-4) are employed for driving circuits that perform the following functions:

- a. Width of horizontal synchronizing pulses (the start is determined by position of tap G, the end by tap J).
- b. Width of vertical synchronizing pulses (start by tap G and end by tap C).
- c. Width of equalizing pulses (start by tap G and end by tap H).
- d. Width of front porch (start by tap F and end by tap G).
- e. Width of serrations in vertical synchronizing pulse (start by tap C and end by tap G).
- f. Timing of counters that determine the number and the positions of equalizing pulses and serrated pulses (taps D and E).
- g. Start of horizontal driving pulse (tap B).

The details of the circuits employed for the formation of the pulses enumerated above are explained below, following an explanation of the operation of the binary-counter type of frequency divider.

**Binary-counter Circuits.** Frequency division of the 31,500-cps output of the delay line is undertaken with the aid of binary counters in order to obtain accurately timed 60- and 15,750-cps pulses. Basically, the binary

scaler counter is a heavily biased relaxation oscillator consisting of two triode sections directly coupled to each other, as shown in Fig. 5-5. The circuit has two stable conditions: one in which the first triode is conducting and the second is cut off, and one wherein the reverse condition prevails. This bistable or "flip-flop" action provides the basis for a scale-of-two or binary-counter circuit.

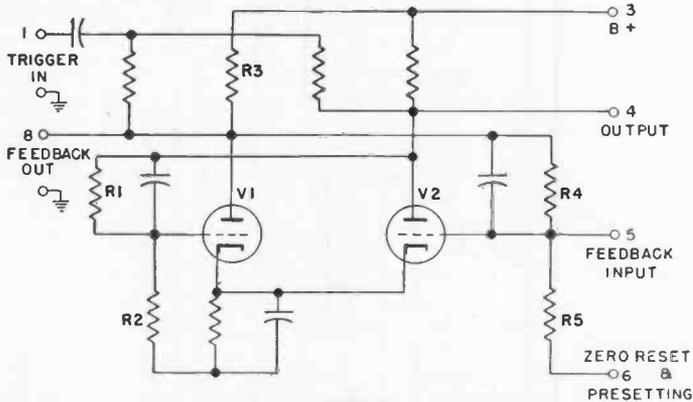


FIG. 5-5. The schematic circuit of a counter that, by reason of its bistable action, provides the basis for a scale-of-two or binary-counter circuit.

The sequence of operation may be explained by starting with the assumption that one tube is conducting, say V2. The triggering pulse, which is negative in polarity, is applied to the grids of both tubes through the input network shown. This pulse has no effect upon the cutoff tube V1, but it does cause the plate current of the conducting tube V2 to decrease, thus creating a rise in plate voltage on this tube. However, the grid of the cutoff tube V1 is directly coupled to the plate of V2, via the voltage divider consisting of resistors R1 and R2 in series. Consequently, the rise in plate voltage of V2 is reflected on the grid of V1 and causes the tube to begin to conduct. This causes the plate voltage of V1 to be lowered because of the voltage drop in its plate resistor R3. This voltage drop, in turn, is applied to the grid of the tube that was originally conducting, V2, via the voltage divider consisting of resistors R4 and R5. This drop in voltage augments the negative pulse that started the action, and the cumulative effect results in tube V2 becoming completely cut off and V1 conducting. A second trigger pulse, of the same polarity as the first, will reverse the action and return the scaler circuit to the initial set of conditions that existed before the first of the two triggering pulses was applied. Thus the binary scaler circuit goes through *one* complete cycle of operation upon the application of *two* triggering pulses. Accordingly a 2-to-1 frequency division is effected by the binary scaler circuit.

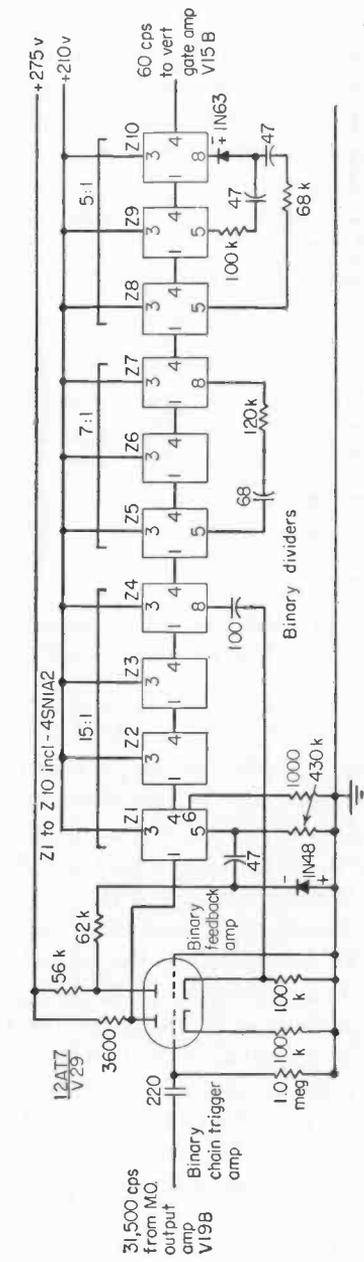


Fig. 5-6. The binary-counter portion of a synchronizing waveform generator wherein, by virtue of suitable feedback circuits, 15-to-1, 7-to-1, and 5-to-1 divisions are obtained from the basically scale-of-two counters. Details of the circuits of the binary counters Z1 to Z10 are given in Fig. 5-5 and details of the waveforms in Fig. 5-7.

The output of each scaler is a square wave having one positive- and one negative-going pulse *per cycle* of operation. However, only the negative-going pulse will trigger a binary scaler. Therefore, when the output of one binary scaler is directly connected to the input of a second unit, the second scaler will be triggered only once for each complete cycle of operation of the first unit. Thus, the second unit will not complete a cycle of operation until the first unit has gone through two cycles of operation. This requires the application of four triggering pulses to the input of the first unit. Therefore, a series of binary scalers connected in cascade yield total divisions that are integral powers of 2. For example, five cascaded scalers will result in a total division of  $2^5$  or 32.

On the other hand, both decade and odd-number divisions are often required, *e.g.*, 525 to 1. This type of operation may be obtained from a binary-counter chain by the application of feedback loops. For example, in Fig. 5-6 there is shown the binary-counter portion of the synchronizing waveform generator being described. In this circuit, binary scalers Z5, Z6, and Z7 are three cascaded units that would ordinarily produce a  $2^3$  or an 8-to-1 division. However, this action may be altered by application of a feedback loop from the output of one scaler in the group to the input of another. By inserting a small amount of delay in this loop, extra pulses from the output may be applied to the input and thereby modify the effective frequency division of the group as a whole.

For example, in the group of three scalers mentioned, a feedback loop is applied from the output of the third scaler to the input of the first unit. Therefore, immediately after the third scaler produces an output pulse (*i.e.*, after the application of eight pulses to the first scaler in the group), a pulse will be fed back to the input of the first scaler in the chain. This pulse serves as the first of the next group of eight that are required to actuate the chain; consequently, after only seven pulses have been applied from the normal sources of triggering signals, the last counter will again trigger and the cycle is repeated. Thus, this group of three binary scalers produces a 7-to-1 division rather than the normal 8-to-1 division which results when there is no feedback loop present.

The action of a chain of binary counters of any given number of units, with a feedback loop applied from the last unit to any preceding one in the chain, may be generalized by the following formula:

$$\text{Total division} = 2^n - 2^p$$

where  $n$  = total number of binary scalers.

$p$  = order number of scaler to which feedback (from output scaler) is applied; *i.e.*, if at input of first scaler,  $p = 0$ ; if at output of first scaler,  $p = 1$ ; if at output of second scaler,  $p = 2$ ; etc.

Applying this formula to the Z5, Z6, Z7 chain shown in Fig. 5-6,  $n = 3$ , and  $p = 0$ , since the feedback is applied to the input of the first scaler; therefore, the total division is

$$2^3 - 2^0 = 8 - 1 = 7$$

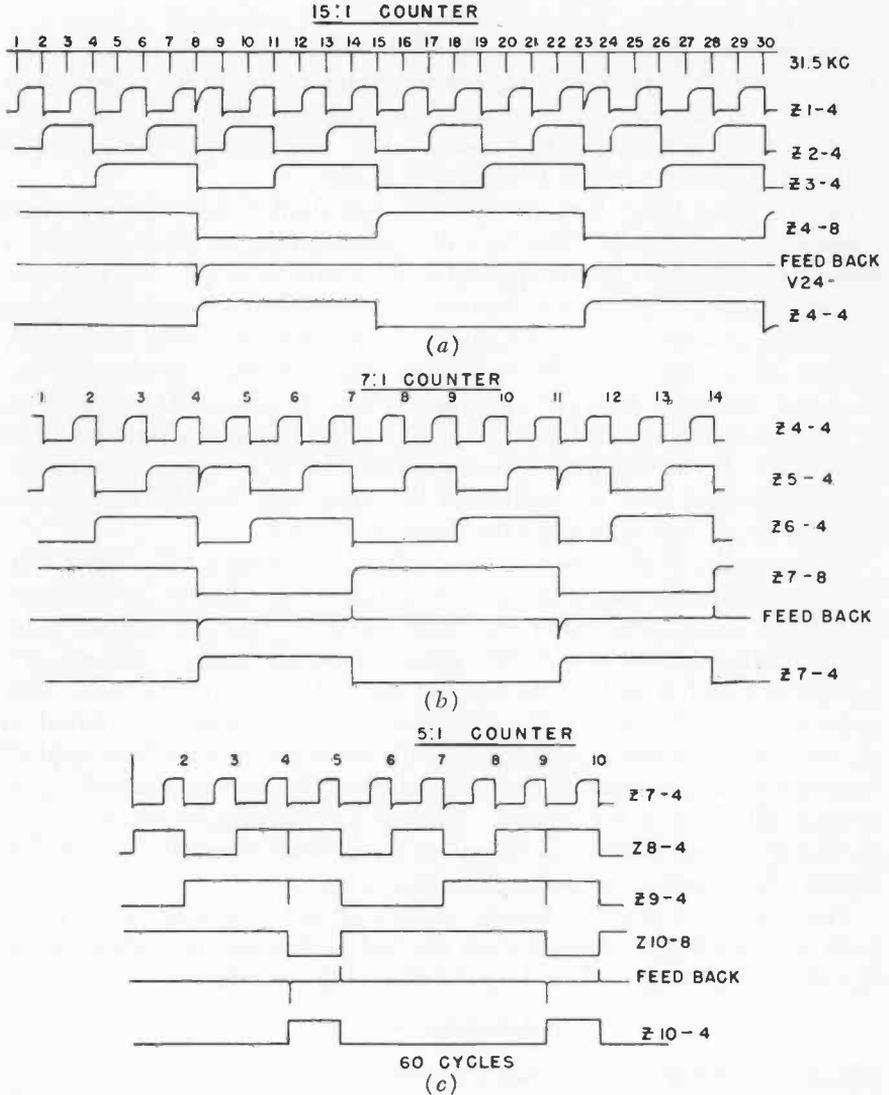


FIG. 5-7. The waveforms produced at various points in the binary-counter chain shown in Fig. 5-6. The nomenclature Z1-4 (and similarly) signifies the output of binary counter Z1 at terminal No. 4.

In the synchronizing waveform generator illustrated, the 525-to-1 frequency division required is obtained by three chains of binary counters providing divisions of 15 to 1, 7 to 1, and 5 to 1, respectively, or a total of  $15 \times 7 \times 5 = 525$  times. The first group of scalers, Z1 to Z4 inclusive, has a feedback loop applied from the last scaler to the input of the first scaler. A grounded-grid amplifier, V29B, is used in the feedback loop to obtain the proper amplitude relation between the feedback pulse and the regular triggering pulses that are obtained from V29A. The waveforms for this group of binary counters are shown in Fig. 5-7a. The first line of this illustration represents the triggering pips; the second line shows the output of scaler Z1; the third line, the output of Z2; etc. The next to last line shows the feedback pulse and the last line the output of Z4. Here it is seen that there is one negative-going stroke after every 15 input pulses.

The second group of scalers, consisting of Z5 to Z7 inclusive, has already been described. The waveforms associated with this group are shown in Fig. 5-7b. The third group, comprising Z8 to Z10 inclusive, has two feedback loops; one from the last scaler Z10 to the input of the first scaler in the chain Z8, and another feedback loop also from the last scaler Z10 to the second unit in the chain Z9. This combination of feedback loops applied to a three-unit chain results in a net division of 5 to 1. The manner in which this operation is obtained may be seen from the waveforms presented in Fig. 5-7c.

The binary scaler units used in the synchronizing waveform generator described are self-contained interchangeable plug-in units (Fig. 5-8) that reduce maintenance time to a minimum. The dual-triode tube that is a part of the binary scaler is also a conventional plug-in unit so that either the tube or the scaler circuit itself may be immediately replaced in the event of failure.

**Pulse-shaper Circuits.** The standard synchronizing signal (Fig. 5-1), may be thought of as consisting of horizontal synchronizing pulses at all times except during the first portion of the vertical blanking interval. At this time, nine of the horizontal synchronizing pulses are replaced by other types of pulses. For the remainder of the vertical blanking interval and throughout the following field, horizontal synchronizing pulses exist.



FIG. 5-8. This completely self-contained, plug-in binary scaler unit is only 1 $\frac{3}{8}$  in. in diameter and 3 $\frac{7}{8}$  in. high, including the tube that is plugged into the top of the device.



In the synchronizing waveform generator described, the output waveform is produced by starting and stopping a multivibrator with accurately timed triggering pulses which are applied in the correct sequence to produce directly the complex series of pulses that comprise the standard synchronizing signal. Separate triggering pulses are used to start and to stop the multivibrator and, consequently, the width of the resulting output waveforms may be controlled by the delay in time between the starting trigger and the stopping trigger.

As mentioned previously, the leading edge of all the pulses that make up the standard synchronizing waveform may be timed by a 31,500-cps source of frequency. Accordingly, the starting triggers are simply produced at this rate by circuits that are synchronized with the 31,500-cps master oscillator in the frequency-generating portion of the synchronizing waveform generator. The stopping triggers, on the other hand, must be delayed by prescribed amounts with respect to the starting trigger in order to produce output pulses of the specified duration. Furthermore, the sequence in which the variously delayed stopping triggers are presented must be accurately controlled. This is accomplished by the use of gating circuits which determine the number and the position of each type of pulse in the final signal. The pulses that control the gating circuits are also derived from the frequency-generating portion of the synchronizing generator with the aid of series of binary counters, over and above those used in the frequency-generating unit already described.

Alternate 31,500-cps pulses must be removed except during the two equalizing pulse intervals and the vertical synchronizing signal interval. This, too, is accomplished with the aid of a gating circuit which is controlled by a combination of pulses obtained from the master oscillator via a 2-to-1 counter and from the second binary-counter chain. Details of the process can be presented with the aid of Fig. 5-9. The multivibrator which receives the starting and stopping pulses to form the synchronizing signal employs two tubes, V123 and V124. The circuit values are such that this multivibrator will remain in a stable condition, with one tube conducting and the other cut off, until a triggering pulse is received that reverses the state of equilibrium. Starting triggers are applied to one tube and stopping triggers to the other. Each of the tubes contains two control grids, one of which is employed for the triggering function and the other for the usual multivibrator circuit connections. As a result, starting triggering pulses may be applied to one tube without affecting the action of the other, except through the resulting multivibrator action.

The triggers, waveform ( $k$ ) in Fig. 5-10, are of negative polarity, and when they are applied to a tube that is conducting, the reduction in plate current causes the plate voltage on the tube to rise. This action, by rea-

son of the usual multivibrator circuit connections, causes the other tube (which was cut off) to become conducting. The rise in plate voltage on the first tube constitutes the start of a synchronizing waveform of positive polarity. This pulse continues in time duration until a negative stopping trigger, waveform (*j*), applied to the second tube (which is conducting) to cut it off, reverses the action, thus terminating the pulse.

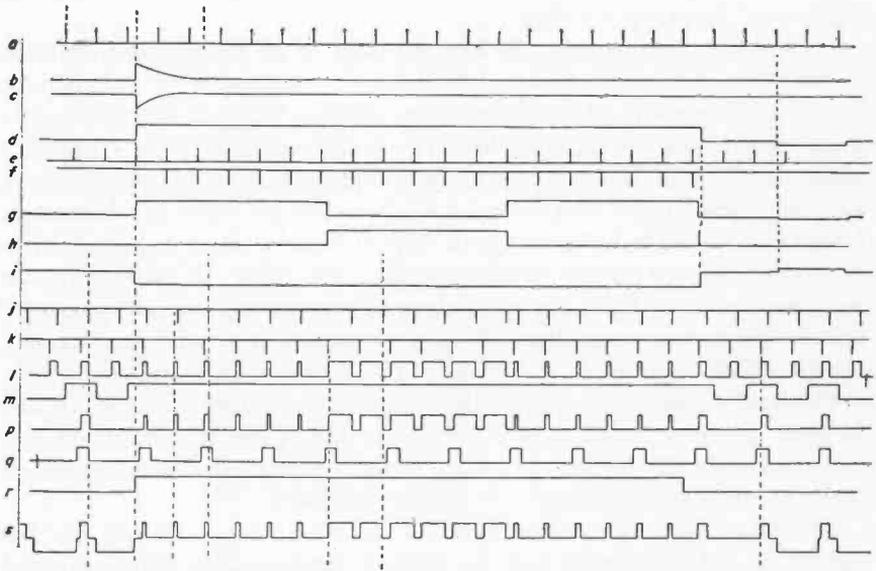


FIG. 5-10. The waveforms existing at various points in the synchronizing pulse synthesis circuits shown in Figs. 5-9, 5-11, and 5-12.

The starting triggers (*k*) are obtained from a tap *G* on the delay line to which a portion of the 31,500-cps output (*a*) of the frequency-generating circuit is applied. This delay line output is applied first to a starting-trigger amplifier V119A and then to the synchronizing signal-generating multivibrator V123, V124.

The formation of the stopping triggers is considerably more complex because of the various amounts of delay and the gating action that is required in order to achieve the complicated sequence of presentation required to form the standard synchronizing signal. The train of stopping triggers is produced by combining three separate trigger formations which, individually, determine the trailing edges of (*a*) the horizontal synchronizing pulses, (*b*) the vertical synchronizing pulses, and (*c*) the equalizing pulses. However, before the formation of these three sets of signals is described, the generation of the associated gating pulses will be explained.

**Gating-pulse Formation.** Three kinds of gating pulses are required to turn on and to turn off the three types of stopping-trigger pulses enumerated above. The gating pulses are rectangular pulses accurately timed with respect to the other signals employed in the synchronizing waveform generator. They are derived from the master oscillator with the aid of a series of binary counters and associated amplifiers as shown in Fig. 5-9.

The input for the binary-counter chains waveform (*e*) (Fig. 5-10) is obtained from tap *D* on the delay line (Fig. 5-4) associated with the 31,500-cps output of the frequency-generating portion of the synchronizing waveform generator. A gating amplifier, V112 (Fig. 5-9), is employed to control the flow of pulses (*f*) from the delay line to the first counter in the chain.

The binary counters are arranged to provide four different frequency divisions which, in various combinations, are employed to form the gating pulses. Binary counters Z101, Z102, and Z103 are connected in cascade, with a feedback loop from Z103 to Z102, and produce a 6-to-1 frequency division. The output of this chain is applied to binary-counter amplifier V113A and thence to counters Z105 and Z106 which are connected in cascade with a feedback loop from the output to the input, thus providing an additional 3-to-1 division. The output of this counter chain is used to drive a single counter Z107 which provides a 2-to-1 division. Thus, the output of the chain of six counters just mentioned provides an over-all division of 36 to 1.

The first of the three gating pulses created with the aid of the output from the binary-counter chains is a rectangular pulse (*i*) having a duration equal to nine times the horizontal synchronizing-pulse interval. It is employed during the first portion of the vertical blanking period to prevent the formation of horizontal synchronizing pulses during this interval. As shown by Fig. 5-1, there are no horizontal synchronizing pulses present during an interval, totaling  $9H$  in duration (where  $H$  equals the horizontal scanning interval) which commences at the beginning of vertical blanking.

The beginning of the  $9H$  pulse is initiated by the differentiated leading edge of waveform (*b*) (Fig. 5-10) of the output signal of the vertical blanking multivibrator V21 (Fig. 5-11). This positive pulse is applied to amplifier V108A (Fig. 5-9), the negative output pulse (*c*) of which is applied to binary counter Z107. The resulting positive output pulse from Z107 is applied to the  $9H$  gating-amplifier V111B from whose cathode circuit a positive gating pulse (*d*) is obtained and applied to the binary-counter gating amplifier V112. This permits the flow of 31,500-cps negative-triggering pulses (*f*) to the binary chain Z101 to Z103. The eighteenth trigger applied to the input of the counter chain causes Z107 to cycle. This action returns it to the state that existed before the triggering

pulse was received from the vertical blanking multivibrator, thus ending the  $9H$  gate. The ending of the  $9H$  gating pulse prevents further application of triggering pulses to the input of the binary chain until the next pulse from the vertical blanking multivibrator starts the entire process over again. Thus there is created a rectangular gating pulse ( $i$ ) which starts exactly at the beginning of the vertical blanking interval and which has a duration of exactly nine times the horizontal scanning interval. This gating pulse is combined with two others, as explained below, to form the composite signal that controls the stopping of the multivibrator that generates the synchronizing waveforms.

The second gating pulse that is required has a duration of three times the horizontal scanning interval or  $3H$ , then is off for a similar interval, and finally exists for another  $3H$  interval as shown by waveform ( $g$ ). The purpose of this gating pulse is to allow the formation of the equalizing pulses that exist just before and just after the vertical synchronizing pulse (Fig. 5-1). Accordingly, the start of the  $3H-3H$  gating pulse must coincide exactly with the start of the vertical blanking-pulse interval.

This gating pulse is formed with the aid of binary counter Z104, whose action is also initiated by the advent of a signal from the vertical blanking multivibrator V21 via amplifier V108A, just as in the case of binary counter Z107 already mentioned. Simultaneously, by the action previously described, 31,500-cps triggering pulses are admitted to the input of the Z101 to Z103 binary chain. Upon the application of the sixth input pulse, binary counter Z104 cycles and returns to the condition that existed before the application of the vertical blanking pulse. Thus a signal having a duration of  $3H$  is created. This is applied to a gating amplifier V113B. However, the action does not stop here, since, as already explained, a total of eighteen pulses reach the input of the binary-counter chain before they are cut off by the action of the gating amplifier V112. Therefore, at the end of the twelfth input pulse, the counter Z104 again produces a positive output pulse which lasts until the eighteenth and final input pulse occurs. Thereafter, the chain is inactive until the next vertical blanking pulse again starts the cycle. Thus the output from the cathode circuit of the  $3H-3H$  gating amplifier V113B consists of two positive gating pulses, each having a duration of  $3H$  and separated by a similar interval as shown by waveform ( $g$ ). This gating pulse is employed to control the formation of the trailing edges of the equalizing pulses in the final standard synchronizing waveform. From the plate circuit of the  $3H-3H$  gating amplifier V113B, similar pulses of opposite polarity are available. These are employed, with another pulse, to form the third and last gating waveform.

The third gating pulse has a duration three times that of a horizontal scanning interval and is used to permit the formation of the serrated verti-

cal synchronizing pulse (see Fig. 5-1) only during the vertical synchronizing-pulse interval. The  $3H$  gating pulse is created by the process of combining in the  $3H$  gate former tube V114, the positive  $9H$  pulse ( $d$ ) available from V111B with the negative  $3H-3H$  pulse ( $-g$ ) from V113B. The addition of these two waveforms results in a pulse having a duration of  $3H$  and beginning a similar time interval after the initiation of the vertical equalizing pulse. The output of the  $3H$  gate forming tube is a negative gating pulse suitable for allowing the trailing edges of serrations in the vertical synchronizing pulse to be formed. To obtain a gating pulse of proper polarity and amplitude, the negative pulse is applied to a  $3H$  gate inverter V115A which produces the required positive gating pulse ( $h$ ).

**Stopping-trigger Formation.** With the aid of the three gating pulses described above, the stopping triggers that are required for terminating the various synchronizing waveform pulses may be created. The delay between the stopping and the starting triggers determines the length of the pulse being formed, and the sequence in which these stopping triggers are presented determines the order in which the various pulses are created. The stopping triggers are generated, therefore, by pulses taken from suitable taps on the delay line, and the gating pulses are then employed to permit the passage of the stopping triggers in the correct sequence. Stopping triggers are thus formed in order to terminate the horizontal, the vertical, and the equalizing pulses.

The length of the horizontal synchronizing pulses is determined by stopping triggers obtained from a tap  $J$  on the delay line. The delay line output is amplified by gating tube V120 before being applied to the multivibrator V123 and V124 that generates the synchronizing waveform pulses. In addition, the  $9H$  gating pulse is also applied to gating tube V120 to prevent the passage of horizontal synchronizing stopping triggers during the equalizing and vertical synchronizing-pulse interval when other stopping triggers are active. Except for this short interval, the stopping triggers described are active and, therefore, in combination with the aforementioned starting triggers, generate horizontal synchronizing pulses continuously.

The stopping triggers required for generation of the serrated vertical synchronizing pulse are formed with the aid of the pulses obtained from tap  $C$  on the delay line and the  $3H$  gating pulses ( $h$ ) obtained from V115A as previously described. The  $3H$  gating pulses are employed to permit the formation of the stopping triggers for the vertical synchronizing pulses only during that short interval, once per field, when the vertical synchronizing pulse exists. At all other times, the stopping triggers associated with the formation of the vertical synchronizing pulse are prevented from reaching the multivibrator that forms the synchronizing waveforms. Gat-

ing amplifier tube V121 is employed to amplify the output from the delay line and, with the aid of the gating signal, to control the flow of the stopping-trigger pulses to the multivibrator V123 and V124.

The equalizing pulses, which exist for only a  $3H$  period immediately before and immediately after the vertical synchronizing pulse, require stopping triggers that are generated with the aid of the  $3H-3H$  gating pulse ( $g$ ) obtained from V113B as described above and the pulse output of tap  $H$  on the delay line. The position of this tap determines the length of the equalizing pulses, and the gating pulse regulates the period during which they are created. Gating amplifier tube V122 is employed for the formation of these pulses, and its output, consisting of two groups of stopping triggers occurring once per field, is used to control the equalizing pulses formed by multivibrator V123 and V124.

**Synchronizing Signal Formation.** The three separate sets of stopping triggers generated by gating amplifier tubes V120, V121, and V122 are combined into one composite signal by applying the output of these tubes to a common plate resistor  $R$  (Fig. 5-9). This results in a series of stopping triggers so spaced as to create the trailing edges of the entire synchronizing signal. The leading edges, it will be recalled, are initiated by the output of the starting-trigger amplifier V119A. Thus, the starting and the stopping triggers, acting in a coordinated manner, determine the operation of the multivibrator V123 and V124 which generates the waveform ( $l$ ). This waveform, after being operated upon as explained in the following paragraphs, finally becomes the synchronizing signal.

It will be recalled that the output signals from the delay line which supplies the pulses used to generate both the starting and the stopping trigger pulses are at a 31,500-cps rate. This is the correct frequency for the generation of the equalizing pulses and the serrations in the vertical synchronizing pulse, but it results in the formation of twice as many horizontal synchronizing pulses ( $l$ ) as are required. It is necessary, therefore, to remove every other horizontal synchronizing pulse from the output of the synchronizing waveform generating multivibrator. This is accomplished with the aid of suitable gating pulses and gating amplifier V125 which is inserted between the output of the pulse-forming multivibrator and the output clipper stage.

Amplifier V125 is controlled by gating pulses that are applied at a 15,750-cps rate to remove alternate horizontal synchronizing pulses. However, since no horizontal synchronizing pulses, as such, exist during the equalizing- and the vertical-pulse periods, the deleting action must be omitted during these periods that are contiguous and total  $9H$  in duration. A gating control signal suitable for accomplishing this action is obtained by combining the 15,750-cps output of a 2-to-1 counter V26 and amplifier

V25A (which is driven by the frequency-determining master oscillator through amplifier V25B) with the  $9H$  gating pulses ( $d$ ) from V111B. Both waveforms are applied to mixer V126, where the 15,750-cps pulses are removed by the  $9H$  gating pulse when they are not desired. A clipper and phase inverter V115B follows the mixer tube, and the resulting gating pulse ( $m$ ) for deleting the alternate horizontal synchronizer pulses is then applied to gating amplifier V125 as shown in Fig. 5-9.

The synchronizing waveform signal from V125 is applied to a clipping amplifier V119B, after which it is fed to the output amplifier stage V127. Synchronizing pulses of positive polarity ( $p$ ) are obtained from the cathode circuit of this tube; those of negative polarity, from the plate circuit.

**Blanking-pulse Formation.** The starting edges of both the vertical and the horizontal blanking pulses are derived from the master oscillator. This procedure ensures against the possibility of there being any "jitter" between the leading edges of the two types of pulses. In addition, it allows the starting edge of the vertical blanking and driving pulses to be precisely determined and controlled with respect to the horizontal synchronizing pulses. All the circuits and the tubes required for the formation of the blanking pulses are contained in the timer-chassis portion of the synchronizing waveform generator described.

The vertical blanking pulses are formed with the aid of the trigger amplifier V20 (Fig. 5-11) which provides the pulses necessary to start the vertical blanking multivibrator V21. The input to the vertical blanking starting amplifier is obtained from tap  $E$  on the delay line, as shown in Fig. 5-4. The pulses obtained from this source, however, come from the master oscillator which is operating at a 31,500-cps rate. Since vertical blanking pulses occur only at a 60-cps rate, it is necessary to gate the starting pulse amplifier V20 in a manner which will permit only every 525th pulse to pass. The necessary gating pulses are obtained by differentiating the output of the 525-to-1 binary chain Z1 to Z10 after it is amplified by the binary-chain output amplifier V15B. The duration of the vertical blanking pulse is determined by the action of the dual-triode cathode-coupled multivibrator V21, which circuit is provided with a suitable control (variable resistor in the grid circuit of one of the triodes) for adjustment of the output pulse length.

The horizontal blanking pulses are formed by multivibrator V23 (Fig. 5-11) which is triggered by a gated amplifier V24. This horizontal blanking starting amplifier is driven from tap  $F$  on the delay line (Fig. 5-4). However, since blanking pulses occur at a 15,750-cps rate and the output of the delay line is at twice this frequency, it is necessary to gate the starting pulse amplifier in a fashion which will result in only every other pulse

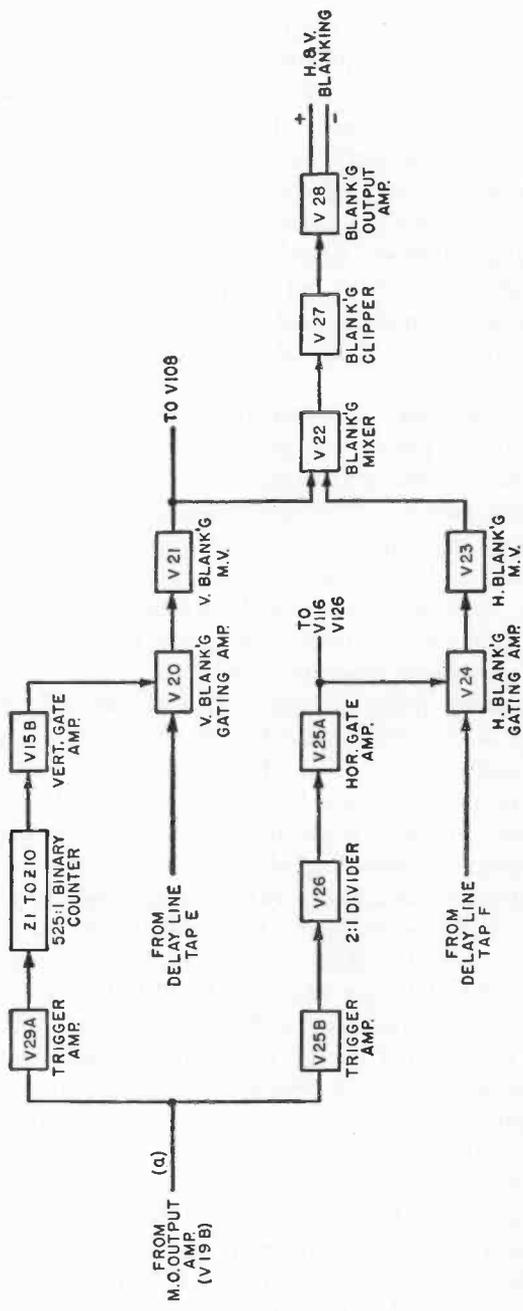


FIG. 5-11. Block diagram of the circuits employed for generating combined horizontal and vertical blanking pulses with the aid of outputs obtained from a master oscillator and an associated delay line.

being permitted to pass. This is accomplished by applying a gating signal that consists of a 50 per cent square wave, at a 15,750-cps rate, obtained from a horizontal-gate buffer amplifier V25A. This tube in turn is driven by the master oscillator through an amplifier V25B and a 2-to-1 divider V26. The duration of the horizontal blanking pulses is determined by the action of the cathode-coupled multivibrator V23 which forms the pulses. A variable control is provided in this circuit to adjust the length of the blanking pulses to standard proportions.

The output of the vertical blanking multivibrator V21 is applied to the control grid of one section of the dual triode V22. The output of the horizontal multivibrator V23 is applied to the grid of the second section of the same tube V22. The outputs of the two sections are then mixed in a common plate load resistor to produce a combined horizontal and vertical blanking pulse which is then applied to a blanking clipper V27. Finally, the output of the clipper is applied to a blanking output tube V28 from which is obtained both positive and negative blanking signal outputs.

**Driving-pulse Formation.** In the synchronizing waveform generator described, the circuits and the tubes required for the formation of the vertical and the horizontal driving pulses are contained on the shaper chassis of the assembly. The driving pulses are formed in much the same manner as are the blanking pulses described above; however, since both the timing and the duration of the driving pulses differ from those of the blanking pulses, separate circuits must be employed for the formation of the two kinds of pulses.

The vertical driving pulses are formed with the aid of an amplifier tube V108B (Fig. 5-12) which is employed to trigger a multivibrator V109. The input for the amplifier V108B, which starts the formation of the vertical driving pulse, is obtained by differentiating pulses (b) (Fig. 5-10) at vertical or field frequency that are obtained from the output of the vertical

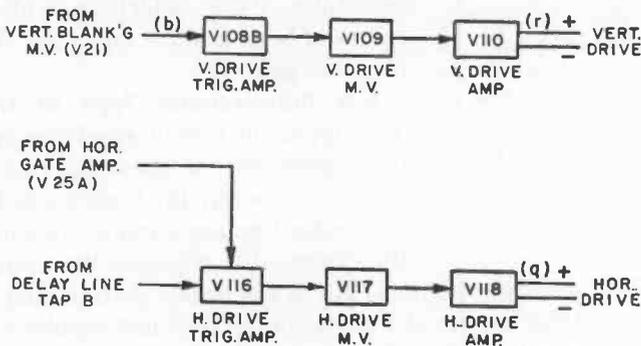


FIG. 5-12. Circuits employed for the separate formation of vertical and horizontal driving pulses.

blanking multivibrator V21 (Fig. 5-11). Amplifier V108B is biased so as to prevent clipping of the positive portion of the differentiated pulse while completely clipping the negative portion of the input pulses. The resulting output pulses of V108B are employed to trigger the action of the dual-triode multivibrator V109. A variable resistor is employed in conventional fashion to control the duration of the vertical driving pulses generated by the multivibrator. An output stage, V110, is employed to amplify the output of the multivibrator and provide vertical driving pulses of both positive ( $r$ ) (Fig. 5-10) and negative polarity.

Horizontal-frequency driving pulses are created by a gated amplifier V116 which drives a multivibrator V117 (Fig. 5-12). The 31,500-cps input for the gated amplifier is obtained from tap *B* (Fig. 5-4) on the delay line while the 15,750-cps gating pulses are obtained from the output of horizontal-gate buffer amplifier V25A. (Fig. 5-11). The resulting output of the horizontal-drive gated amplifier is at horizontal frequency and is employed to trigger the action of dual-triode multivibrator V117. This multivibrator generates the horizontal driving pulses whose width is determined in the usual fashion by means of an adjustable resistor. The output of the multivibrator is amplified by a horizontal driving-pulse output tube V118, which provides output pulses of both positive ( $q$ ) (Fig. 5-10) and negative polarity.

#### 5-5. Pulse-counter Type of Generator.

The appearance of a synchronizing waveform generator of the type that employs pulse-counter circuits is shown in Fig. 5-13. The pulse-forming circuits are contained in the chassis that occupies the upper part of

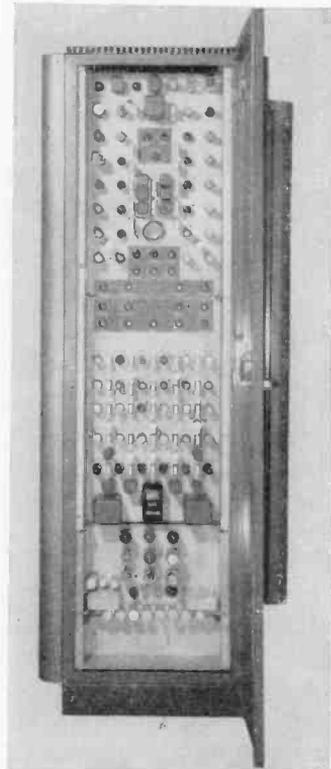


FIG. 5-13. This synchronizing waveform generator consists of a pulse-former chassis at the top of the equipment rack, a pulse-shaper unit immediately below it, and a regulated power supply at the bottom of the assembly. (Courtesy of Radio Corporation of America.)

the rack, the pulse-shaper circuits are in the center portion, and a power-supply unit is at the bottom of the assembly. The unit employs a total of about 60 vacuum tubes which, together with all controls and major components, are mounted on the front of the vertical chassis.

A block schematic diagram of the circuits employed in the synchronizing waveform generator illustrated is given in Fig. 5-14. In this diagram, rectangular blocks represent circuit functions rather than individual tubes so that a given block may represent one or several tubes. The upper part of the illustration shows the pulse-former section of the device and the lower contains the pulse-shaper section.

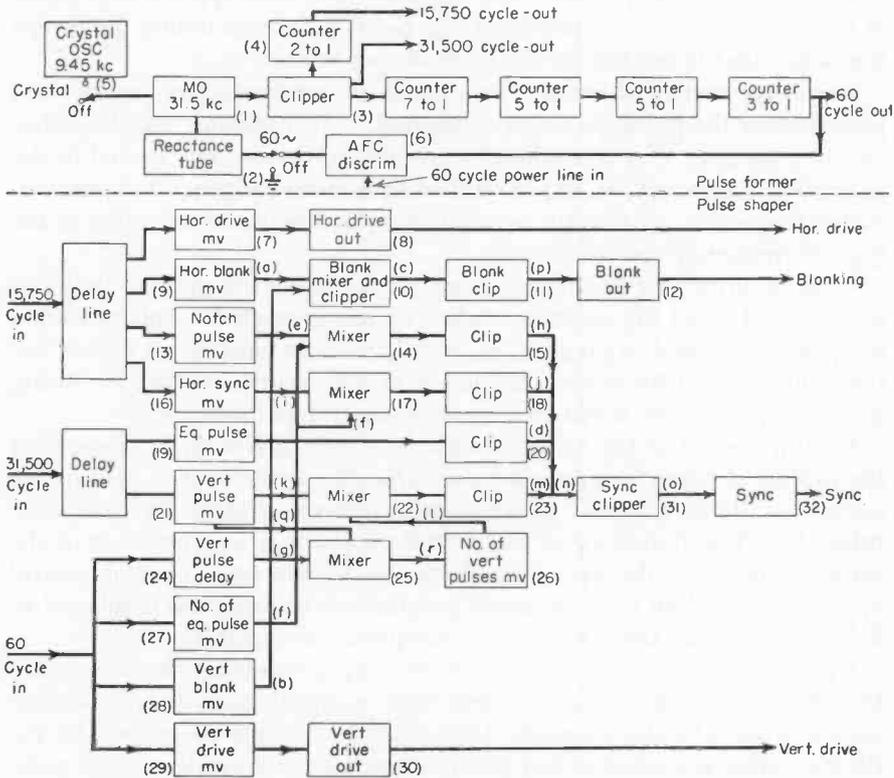


FIG. 5-14. Block diagram of pulse-counter type of synchronizing waveform generator.

**Frequency-generating Circuits.** The pulse generator creates and establishes the relative timing or phase relationships of pulses at three different basic frequencies: 60, 15,750, and 31,500 cps. The pulses are properly timed with respect to each other by the expedient of deriving them from a common master oscillator, the frequency of which may be controlled either by automatic comparison with the frequency of the power line or by a crystal-controlled oscillator.

The master oscillator (1) has a free-running frequency determined by an inductor, a capacitor, and the impedance presented by the plate circuit

of the reactance tube (2). The output of the master oscillator drives an amplifier and clipper (3) which furnishes the required 31,500-cps pulses to the pulse shaper. In addition, the 31,500-cps output of the clipper (3) is applied through a buffer tube to a 2-to-1 counter circuit (4). This divides the frequency in two and provides the 15,750-cps pulses required by the pulse shaper.

The 31,500-cps output from the clipper (3) is also applied to a series of four counter circuits as shown in Fig. 5-14, in order to obtain the 60-cps frequency that is needed for the pulse-shaper unit.

**Frequency-control Circuits.** Four methods of frequency control are provided for the pulse generator illustrated. The oscillator may be either (a) free-running, (b) controlled by an internal crystal, (c) locked to the power-line frequency, or (d) controlled by a remotely generated synchronizing frequency. A selector switch is provided to permit selection of the type of frequency control desired.

When adjusted for free-running operation, the control grids of both the oscillator (1) and the reactance tube (2) are grounded. This condition of operation is used in practice under only two circumstances: during initial adjustment of the natural frequency of the master oscillator or during emergency operation when all frequency-control methods fail.

Crystal control of the master oscillator is accomplished by connecting the output of a crystal-controlled oscillator (5) to the control grid of the master oscillator (1) and grounding the control grid of the reactance tube (2). The frequency of the crystal oscillator is equal to that of the third harmonic of the master oscillator, or 94,500 cps. Crystal control operation is seldom used for fixed installations but may be employed in field setups where the power-supply frequency is unstable.

Lock-in to the 60-cps power-line frequency is obtained<sup>2</sup> by comparing the 60-cps pulse from the counters with a signal from the power-line source in an a-f-c discriminator (6). The d-c voltage developed by the discriminator as a result of any phase differences between the 60-cps pulse and the 60-cps power source varies the bias on the control grid of the reactance tube (2) which acts to correct the frequency variation.

When it is desired to control the frequency of the synchronizing waveform generator from a remotely generated source, a control voltage similar to that derived from the internal discriminator circuit may be applied directly to the control grid of the reactance tube (2). This mode of operation may be employed where a lap dissolve from a remote program origination to a local one is required. The auxiliary equipment necessary to accommodate this method of operation is described in Sec. 5-6.

<sup>2</sup> Bedford, A. V., and J. P. Smith, A Precision Television Synchronizing Signal Generator, *RCA Rev.*, Vol. V, No. 1, p. 51 (July, 1940).

**Counter Circuits.** There are several forms of frequency dividing circuits in use including the blocking oscillator, the multivibrator, and the pulse-counter circuit. The first two are of the same general type whereas the last is entirely different. For example, the multivibrator circuit may be adjusted so that, when driven at a frequency that is some multiple of its natural frequency, it will oscillate at its natural frequency under the

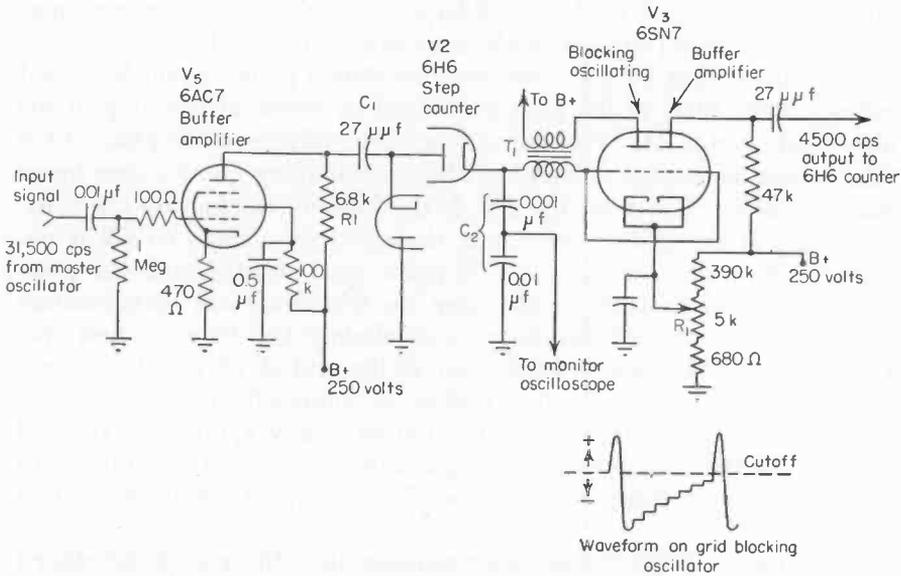


FIG. 5-15. Schematic diagram of a typical pulse-counter circuit and a detail of the waveform that is applied to the grid of the blocking oscillator.

control of the higher driving frequency. The pulse-counter circuit, on the other hand, may be arranged to produce a single output pulse, after the stimulus of a predetermined number of input pulses, but regardless of the frequency of occurrence of the activating pulses. Although pulse-counter circuits are somewhat more complex than multivibrator circuits, they offer certain advantages of stability, and their use is therefore preferred for applications such as in synchronizing waveform generators.

All six of the counter circuits employed in the pulse former illustrated operate in a similar manner; consequently, the operation of only one unit will be described. For example, Fig. 5-15 shows the circuit details of the 7-to-1 counter that is used to divide the 31,500-cps output of the master oscillator producing a 4,500-cps output as shown in the upper part of Fig. 5-14. The pulse-counter circuit employs a double diode V2, a double triode V3, and is driven by a buffer tube V5 (see Fig. 5-15).

The action of the circuit may be traced by first assuming that there is no initial charge on capacitors  $C1$  and  $C2$  and that the grid of  $V5$  is at its maximum negative value. Under these circumstances the plate current is cut off and there is no voltage drop across the plate load resistor  $R1$ . As a result, the entire  $+B$  voltage is applied across the series combination of capacitors  $C1$  and  $C2$  and the first diode section of  $V2$ . The  $+B$  voltage is divided between the two condensers inversely as their respective capacitances and  $C1$  is made small and  $C2$  large so that  $C2$  has the lower proportion of the voltage (approximately one-fortieth of the  $+B$  voltage).

When the grid of  $V5$  goes positive, a maximum plate current flows and voltage at the plate of the tube is reduced by virtue of the drop in the plate load resistor  $R1$ . This swing to a lower voltage at the plate of the tube causes the second diode to conduct, discharging  $C1$  to a new lower plate potential. However, the first diode does not conduct on the negative swing of the plate voltage and, therefore, the charge on  $C2$  is unaltered. But, when the grid of  $V5$  again goes negative and the plate voltage increases to its maximum value, the first diode will again conduct and  $C2$  will receive a fresh charge only slightly less than the first one. The process continues with each swing of the grid of  $V5$  with the charge on  $C2$  increasing in a stair-step fashion as indicated in Fig. 5-15. As shown, the rise in voltage across  $C2$  asymptotically approaches the  $+B$  voltage, and the voltage increments gradually decrease in amplitude. In practice, however, this process is generally interrupted before proceeding too far.

For example, in the circuit under consideration, the voltage developed across  $C2$  is applied to the grid of a blocking oscillator  $V3$  (first section) through transformer  $T1$ . A definite cathode bias, obtained from a voltage divider across the  $+B$  supply, is applied to the blocking oscillator tube during the charging time of condenser  $C2$ . The value of this bias determines the point at which the blocking oscillator fires. For the particular counter under discussion, the value of bias is such that the seventh step of charge applied to  $C2$  develops sufficient voltage on the grid of  $V3$  to trigger the blocking oscillator. During the following positive swing of the grid voltage, the grid of  $V3$  draws current and discharges  $C2$ , forcing the grid beyond cutoff, where it remains until the tube is triggered by the next series of seven steps.

The grid of the blocking oscillator is directly coupled to the grid of the amplifier formed by the second half of  $V3$ . The operating conditions of this tube are such that only the blocking oscillator pulse is amplified after which the essentially rectangular output pulse is applied to the next counter in the series.

The frequency dividing circuit described is seen to produce one output

pulse for a predetermined number of input pulses. Furthermore, although not of great importance for the present application, the input pulses may be applied at a random rate over a rather wide range of values. The real advantage of pulse-counting circuits over multivibrators lies in their ability to maintain accurate counting in the face of changes in tube characteristics and  $+B$  voltage. Any changes in the  $+B$  voltage will result in a corresponding change in the magnitude of each step of charge on C2. However, the bias voltage on the cathode of the blocking oscillator tube that is triggered by the charge on C2 is also a function of the  $+B$  voltage. Accordingly, the two effects tend to cancel each other, and the resulting operation is largely independent of  $+B$  voltage variations. The merit of a circuit of this type lies in the fact that, to a certain extent, tubes act only as electronic switches so that stability is determined largely by the characteristics of capacitors and resistors.

**Pulse Shaper.** The function of the pulse shaper is not only to shape the output waveforms of the pulse generator unit properly but also to phase them correctly with respect to each other and to combine them in the required manner and in the proper amplitude relationships.

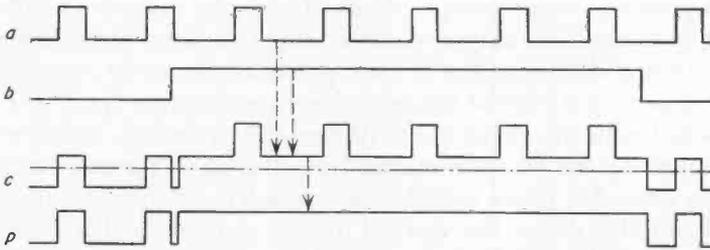


FIG. 5-16. By combining horizontal blanking pulses (*a*) with vertical blanking pulses (*b*), a third waveform (*c*) is created which, when clipped at the level indicated, results in the formation of a combined horizontal and vertical blanking waveform (*p*).

In order to achieve the necessary phase relationships, the 15,750- and the 31,500-cps signals from the pulse former are each applied to delay lines in the pulse shaper. The outputs of these delay lines are used to synchronize a series of multivibrators which are used to generate the output waveforms. For example, the combined vertical and horizontal blanking signal consists of 60- and 15,750-cps pulses as shown by diagram No. 2 in Fig. 5-1. The 15,750-cps pulses are generated by the horizontal blanking multivibrator (9) and have the appearance shown at (*a*) in Fig. 5-16. The horizontal blanking multivibrator is synchronized, in the proper phase relationship, by negative pulses from an associated delay line which, in turn, receives its input from the 15,750-cps output of the pulse former.

The 60-cps pulses, (*b*) in Fig. 5-16, required for the combined blanking signal are obtained from the vertical blanking multivibrator (28) which is synchronized by a portion of the 60-cps output from the pulse former. Positive pulses from both the horizontal and the vertical blanking multivibrators are applied to separate grids of the blanking mixer and clipper dual-triode tube (10). The two signals are mixed in the load resistor common to both sections of the tube and result in the summation waveform shown at (*c*) in Fig. 5-16. This combination waveform is then clipped at the level indicated by the broken line by the action of a second clipper tube (11) with the final result shown at (*p*). By this method, the 15,750-cps blanking pulses are eliminated during the occurrence of the 60-cps blanking pulse. The completed waveform is then applied to the blanking output amplifier (12) from which positive and negative output pulses are obtained from the cathode and the plate circuits, respectively.

Horizontal driving signals of the type shown by diagram No. 4 of Fig. 5-1 are obtained by utilizing the 15,750-cps output of a delay line to synchronize a horizontal driving multivibrator (7) (see Fig. 5-14). The positive output pulse from this multivibrator is applied to the grid of a horizontal driving output tube (8) which produces pulses of the desired type. A positive output pulse is obtained from the cathode circuit of this tube while a negative output pulse is obtained from the plate circuit. Thus horizontal driving pulses of both polarities are made available.

Vertical driving signals of the type shown by diagram No. 3 of Fig. 5-1 are obtained with the aid of multivibrator (29) (see Fig. 5-14) which is synchronized by the 60-cycle output from the pulse former. In this instance no delay for phase adjustment is needed. A positive pulse from the multivibrator drives the vertical driving output amplifier tube (30) and produces pulses of the type desired. Positive and negative vertical driving signals are obtained from the cathode circuit and the plate circuit, respectively, of the output amplifier tube.

**Synchronizing Waveform Generation.** The standard synchronizing waveform consisting of horizontal synchronizing pulses, vertical synchronizing pulses, and equalizing pulses, as shown by diagram No. 1 in Fig. 5-1, is obtained by combining eight different signals at various stages. Basically, the final signal consists of 15,750- and 31,500-cps pulses that recur at a 60-cps rate. The manner whereby this complex waveform is synthesized may be described with the aid of the block schematic diagram of Fig. 5-14 and the waveform charts of Fig. 5-17.

The synchronizing waveform as finally produced has the appearance shown at (*o*) in Fig. 5-17. This signal is the same as that shown in diagram No. 1 of Fig. 5-1 except that positive- rather than negative-going pulses are shown. (For greater clarity, the waveforms are not drawn ex-

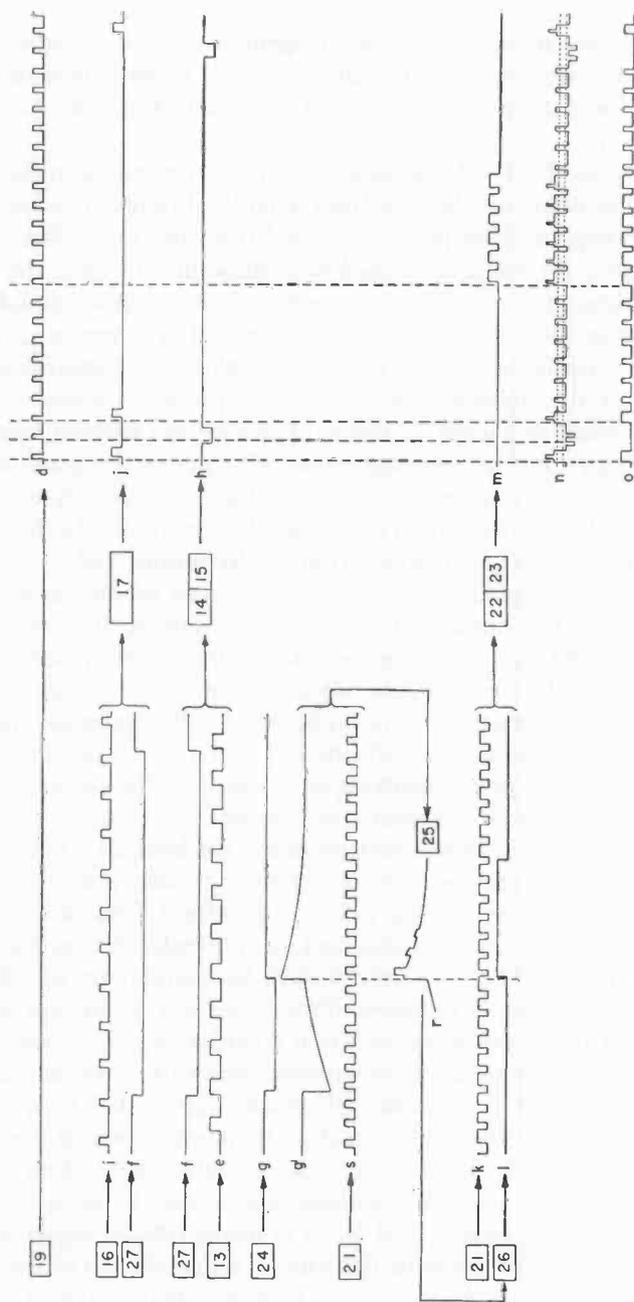


FIG. 5-17. The synthesis of a composite synchronizing waveform (o) is accomplished by combining waveforms (d), (f), (h), and (m) and clipping the resultant (n) at the levels indicated. The aforementioned waveforms are themselves created by the combination of various waveforms as shown at the left. The numbered rectangles refer to similarly labeled vacuum tubes in Fig. 5-14 (associated clippers are omitted for clarity).

actly to scale.) The final waveform ( $o$ ) is obtained by clipping wave ( $n$ ) along the two dotted lines. Wave ( $n$ ), in turn, is formed by adding together the four signals ( $d$ ), ( $j$ ), ( $h$ ), and ( $m$ ). Of these four signals, all except ( $d$ ) are formed by combinations of other waveforms as shown at the left in Fig. 5-17.

The pulses of waveform ( $d$ ) become the equalizing pulses in the final waveform and are obtained directly from a multivibrator (19) synchronized at a 31,500-cps rate by pulses obtained from the delay line. The pulses in waveform ( $j$ ) when combined with those of ( $d$ ) form the horizontal synchronizing pulses. The front edge of every other equalizing pulse ( $d$ ) becomes the front edge of the horizontal synchronizing pulse in waveform ( $n$ ), while the trailing edge of waveform ( $j$ ) determines the over-all length of the horizontal synchronizing pulse. However, since horizontal synchronizing pulses do not exist during the vertical synchronizing interval, they must be removed during this period as shown at the center of ( $j$ ). This waveform is created by the combination in mixer (17) of the 15,750-cps waveform ( $i$ ) obtained from multivibrator (16) and the 60-cps waveform ( $f$ ) obtained from multivibrator (27).

Since only alternate equalizing pulses are employed for the creation of the leading edge of the horizontal synchronizing pulses, the remaining ones must be removed except during the interval immediately before and after the vertical synchronizing pulse, when the equalizing pulses exist in their own right. Notching pulses are employed for this purpose and are created by combining the two waveforms ( $e$ ) and ( $f$ ). Here waveform ( $e$ ) is the basic notching pulse occurring at a rate of 15,750 cps and waveform ( $f$ ) is the 60-cps waveform mentioned above.

Just as for the horizontal synchronizing pulse, the leading edges of the six pulses that make up the vertical synchronizing pulse are created by the leading edges of an equalizing pulse. Waveform ( $m$ ) is therefore created to add to the equalizing pulses and form thereby the vertical synchronizing waveform. This is accomplished by combining waveforms ( $k$ ) and ( $l$ ). The former is obtained directly from a 31,500-cps multivibrator (21), but the latter is created by a complex process designed to ensure that the series of six pulses ( $m$ ) always start with a whole pulse.

This process starts with waveform ( $g$ ) which is generated by a 60-cps multivibrator (24) and then differentiated to produce waveform ( $g'$ ) which is applied to No. 2 control grid of mixer tube (25). This waveform is combined with ( $s$ ), which is actually waveform ( $k$ ) inverted (*i.e.*, of opposite polarity), via control grid No. 1 of mixer (25) to create waveform ( $r$ ). This consists of a few of the narrow pulses from ( $s$ ) keyed in by the trailing edge of waveform ( $g'$ ). The first narrow pulse of waveform ( $r$ ) is employed to trigger a multivibrator (26) which produces the

waveform ( $l$ ). However, this narrow pulse corresponds to the intervals between the wide pulses of waveform ( $k$ ). Consequently, the multi-vibrator that determines the number of pulses that will be passed to form ( $m$ ) will always be timed so that associated circuits become conducting during wide pulse *intervals*. Thus, the arrangement ensures that the circuit is conducting upon the arrival of a wide pulse and, consequently, that the group of pulses passed always starts with a whole pulse.

Finally, the complex signal ( $n$ ) resulting from the four signals that are fed to a common load resistor is applied to the synchronizing signal clipper (31) and the resulting signal ( $o$ ) fed to synchronizing signal output tube (32). A positive polarity signal is available from the cathode circuit of this tube and a negative signal from the plate circuit.

Thus, by the process of developing the leading edges of all synchronizing signals from one waveform ( $d$ ), which, in turn, is produced under control of the master oscillator, extreme uniformity in timing of the synchronizing pulses is achieved. The basic waveform ( $d$ ) by itself produces equalizing pulses on a continuous basis, the unwanted pulses being removed by notching pulses ( $h$ ) and by subsequent clipping action. The horizontal and the vertical synchronizing pulses are obtained by making the basic pulses wider by adding to their trailing edges the waveforms ( $j$ ) and ( $m$ ), respectively. These pulses are added with some overlap between the trailing edge of the basic equalizing pulse ( $d$ ) and the leading edge of the added pulses ( $j$ ) and ( $m$ ) in order to avoid any possibility of gaps appearing in the summation pulses. By use of a lap joint and subsequent clipping, considerable tolerance in the timing and shape of the various component waveforms is permissible without, in any way, affecting the high accuracy in timing of the leading edges of all pulses.

**5-6. Synchronizing Signal-locking Circuits.** Facilities for locking in a local synchronizing waveform generator with signals received from a remotely located unit are available in several forms and are exceedingly useful in a variety of circumstances.

**Applications.** Where synchronizing signal-locking facilities are not available, switching from remote to local program sources (or vice versa) can be done only ( $a$ ) on a quick-switch basis, with a good probability that the picture on a portion of the television sets receiving the program will momentarily fall out of synchronism and "roll," or ( $b$ ) by fading to black, switching to the new synchronizing signal source (but also with a black signal), and then fading in the new program material. Under the latter circumstances such receiver "rolling" that occurs will probably take place while the picture tube screen is blank and, therefore, will not be obvious. Switching on this basis, however, is not generally considered to be so subtle as lap dissolves and similar effects.

In a sense, the objection to a quick switch from one picture source to another is analogous to the undesirable reaction that usually results when an abrupt change is made from one source of audio program material to another. In both the audio and the video case, these objections may be overcome by first fading out one source of program material and then fading in the other. If, at the midway point, a portion of program material from both sources is permitted through the system, there is created what in the video (and motion-picture) field is called a lap dissolve (see also Sec. 3-2, *Video Mixer Circuits*). However, when dissolving from one picture to another, it is obviously essential that both pictures be correctly centered on the viewing screen. This, in turn, requires that the output of both picture sources be exactly in phase as regards both field (vertical) and line (horizontal) frequencies at the point where the mixing is being undertaken. Where separate synchronizing generators are employed by each source of program material, it is evident that means must be provided for locking the two synchronizing generators together, field for field and line for line. Synchronizing locking equipment has been developed for this purpose and is employed in those instances where the advantage to be gained justifies the additional equipment that is required.

Another application for synchronizing signal-locking equipment is in the operation of replacing noisy, badly distorted synchronizing and blanking signals with re-created noise-free signals of standard proportions. This procedure sometimes becomes advisable for signals received from a distant point which, as a result of their passage through intervening radio links, video repeaters, network circuits, or other transmission media, have had their synchronizing and blanking information degraded. These waveforms, because of their precisely defined shapes and the fact that the synchronizing signal represents a maximum amplitude in a negative transmission system (see Sec. 1-17), are particularly susceptible to distortion in any transmission system that is overloaded, in poor adjustment, or operating under adverse conditions. (However, since in both transmitting and receiving systems there are methods of correcting for these shortcomings, whereas it would be very difficult, if not impossible, to remove similar distortion from the video or picture waveshapes, the negative transmission standard is fully justified.) On the other hand, properly shaped and properly proportioned synchronizing and blanking pulses are essential for the operation of many television-system equipments. For example, it is common practice for stabilizing amplifiers to clamp on the back porch (see Secs. 1-9 and 6-7) or on the tip of the synchronizing pulse. In either case, the existence of noise, spikes, or other spurious signals on that portion of the signal employed as a reference will seriously affect the effectiveness of the clamping action. In fact, if the degradation is sufficiently severe, the

clammer may fail completely to operate. Furthermore, it is undesirable to broadcast waveforms that contain spurious signals in the synchronizing information because of the possible adverse effect of these irregularities upon receivers.

Restoration of the synchronizing waveforms may be accomplished neatly by the expedient of stripping off the distorted synchronizing signals and replacing them with newly generated standard waveforms (Fig. 5-18). This operation requires the use of a synchronizing waveform generator which is locked in with the composite signal that is to be rehabilitated. Properly designed lock-in circuits are capable of operation even in

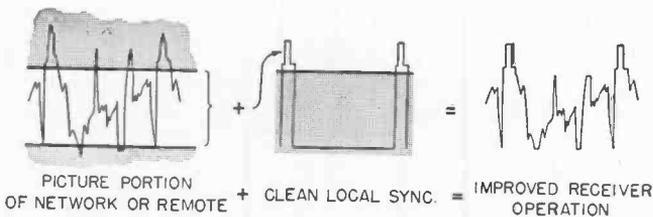


FIG. 5-18. Poorly defined synchronizing signals may be restored by stripping off the degraded synchronizing signals and replacing them with newly generated waveforms from a synchronizing generator that is locked to, and automatically maintained in phase with, the original composite signal.

the presence of considerable noise and waveform distortion; consequently, rehabilitation of the synchronizing signal as outlined is entirely practicable. The ability to replace degraded synchronizing information with clean, noise-free pulses is invaluable for coping with poorly constituted incoming video signals whose waveforms are beyond the control of those at the receiving point. This is also an important application for synchronizing signal-locking equipment.

**Operating Principles.** The basic methods employed in typical synchronizing signal-locking circuits consist of (a) comparing the frequency and phase of locally generated horizontal and vertical synchronizing pulses with those of corresponding pulses received from the remote source, (b) generating correcting signals that reflect the frequency and phase differences between the local and remote signals, and (c) applying the corrections to appropriate circuits in the local synchronizing waveform generator in a manner which brings its output into exact phase with the incoming pulses. The details of the manner whereby this is accomplished vary in different equipments, as do the effectiveness and noise immunity of the various methods employed.

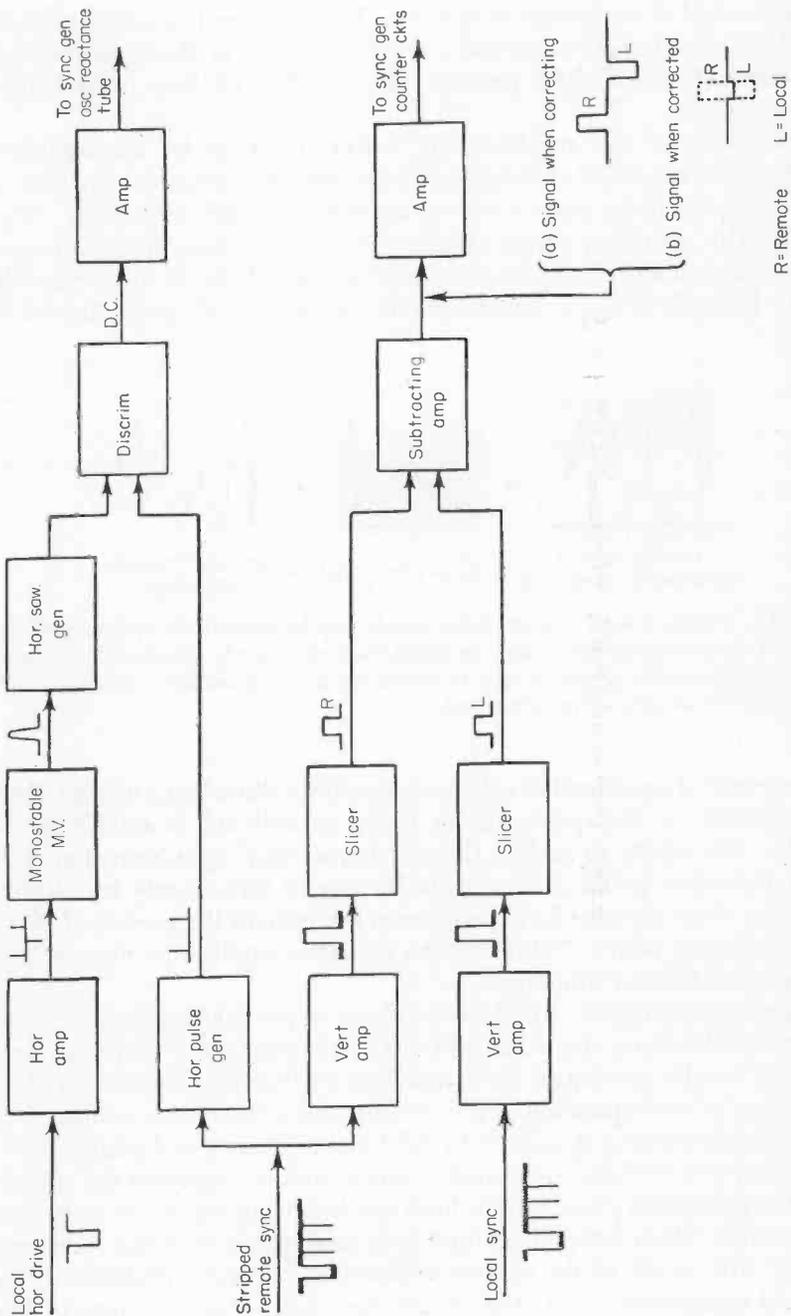


FIG. 5-19. A block diagram of a synchronizing generator locking device that is capable of automatically maintaining a local synchronizing generator in phase with an incoming composite video signal.

One example<sup>3</sup> of a synchronizing signal-locking circuit is illustrated in Fig. 5-19. For its operation, this circuit requires (a) horizontal driving signals from the local synchronizing waveform generator, (b) combined horizontal and vertical synchronizing signals from the same source, and (c) a sample of the composite synchronizing signal that accompanies the incoming composite video signal. The first two of these signals are normally available directly from the local synchronizing generator. However, the sample of the remotely generated synchronizing signal is usually obtained by stripping the synchronizing signal from the incoming composite signal by means of suitable auxiliary equipment, e.g., a stabilizing amplifier (see Sec. 6-7). This latter procedure permits operation of the locking circuit without the need for additional transmission facilities, between the remote and the local points, beyond those normally required for program transmission purposes.

**Horizontal-frequency Control.** Control of the horizontal frequency of the local synchronizing waveform generator is achieved by comparing the frequency of the locally generated horizontal driving signal with the incoming horizontal synchronizing pulses. In the synchronizing signal-locking device illustrated, the local horizontal driving signal is first amplified and then employed to trigger a monostable ("one-shot") multivibrator. The output pulses of the multivibrator, which are exactly in step with the horizontal or line repetition frequency output of the local synchronizing generator, are used to drive a saw-tooth generator at this horizontal frequency.

Simultaneously, the horizontal synchronizing pulses that have been stripped from the incoming signal are employed to drive a pulse-generating circuit that produces a very narrow pulse or spike in synchronism with the horizontal frequency of the incoming signal. The output of the horizontal-rate spike generator and that of the horizontal saw-tooth generator are combined in a discriminator circuit which develops a d-c output that is proportional to the difference in phase of the two input signals. After suitable amplification, this correction signal is applied to the master oscillator circuit of the local synchronizing generator in a manner that results in the frequency of the local generator being automatically brought into synchronism with that of the remote unit.

The horizontal-frequency control circuit just described operates very rapidly with the result that lock-in of horizontal scanning occurs within the matter of a few horizontal lines—for all practical purposes it appears to be instantaneous. Lock-in of the horizontal frequency alone is not sufficient, however, since this does not completely provide for synchronous

<sup>3</sup> Leeds, L. M., Automatic TV Sync Lock, *Electronics*, Vol. 24, No. 7, p. 99 (July, 1951).

scanning on a *field* basis of the two program sources. Although lock-in of the horizontal frequencies ensures the same field scanning *rates* for both program sources, it does not guarantee that both fields will start simultaneously. Coincidence of the two program sources on a field basis is necessary, of course, where lap dissolves, split screens, wipes, and other effects are desired. A second circuit is therefore employed to obtain and maintain proper phasing between the two field frequencies.

**Vertical-frequency Control.** The field-frequency control circuit also makes use of the remote synchronizing waveform that is stripped from the incoming composite signal. In this instance, however, the vertical synchronizing information is of interest. Accordingly, a pulse, corresponding to the incoming vertical frequency and slightly less in duration than three horizontal lines (*i.e.*, less than  $3H$ ), is formed with the aid of a vertical or field-frequency integrating amplifier and a slicer, as shown in Fig. 5-19. The slicer circuit is one which simultaneously clips the top and the bottom of the pulse thereby improving the pulse shape by removing any noise or other disturbances that the original pulse contained. Identical circuits are employed to perform the same operation on the locally generated synchronizing signal. The two resulting field-frequency pulses, one derived from the remote synchronous waveform generator and the other from the local generator, are then compared in a subtracting amplifier (which is essentially a mixer for comparing two different inputs, one of which is inverted before application to the mixer section of the device).

The amplitudes of the two pulses that are applied to the mixer are adjusted so that one is greater than the other. In the device illustrated, the amplitudes and the polarities of the pulses are such that at the output of the subtracting amplifier the pulses corresponding to the remotely located synchronizing generator are positive and of lesser amplitude than the pulses corresponding to the local synchronizing generator. In addition, this latter pulse is negative in polarity.

When the two pulses are not in step, a correcting signal, consisting of positive and negative pulses, is generated, as shown at (*a*) in Fig. 5-19. However, when the two pulses coincide in time of occurrence, the positive pulse is completely swallowed by the negative one and only a residual negative pulse remains [see (*b*) in Fig. 5-19]. The correcting signals, whatever their waveform, are applied to the counter chain of the synchronizing waveform generator through a buffer amplifier. Here, the application of a positive pulse stops the countdown of the chain for two horizontal lines in each field, the duration of the correcting pulses being somewhat less than  $3H$  as noted above. This action continues during successive fields until coincidence of the two synchronizing generators is established, at which time the correcting signal takes the form of a negative pulse only.

Since the counters are not responsive to negative pulses, the miscounting ceases as soon as complete coincidence occurs.

The phase angle between the vertical output waveforms of two synchronizing signal generators that are to be brought into step with each other may be anything up to almost one complete field. Consequently, the maximum correction that will ever be required amounts to 262.5 lines. Since the divider chain stops counting for two lines per field, it may require the passage of 131 fields (each having a duration of  $\frac{1}{60}$  second) or 2.2 seconds for the two synchronizing generators to become phased together. If this operation takes place during the transmission of a signal corresponding to black, there will be no visible effect upon picture monitors and receivers. On the other hand, if the phasing action takes place while a locally originated picture is being transmitted, two horizontal lines will be added to the picture during each field until the correction is completed. If, on the other hand, a picture originating at the remote point is being transmitted while the correction is taking place, then a horizontal black bar, corresponding to vertical blanking, will be seen traveling through the picture at the rate of two lines per field. In this latter instance, if the correction action were to start when the two synchronizing generators were completely out of phase, the bar would transverse the entire height of the picture just once. For a more fortuitous initial phasing condition, the bar would transverse somewhat less than the entire raster.

**Operating Features.** One of the features of the synchronizing locking equipment described is the incorporation of means for adjusting the duration of the front porch produced by the local synchronizing generator. By this means the length of the front porch is made substantially independent of the duration of the locally generated horizontal driving pulse. This is an important asset since existing standards (Fig. 5-1) permit more than a 2-to-1 tolerance in the duration of the driving pulse. When a separate front-porch control is not provided, the front-porch width becomes a function of the duration of the horizontal driving pulse. In the equipment described, control of the front porch is accomplished by adjustment of the pulse length of the monostable multivibrator (Fig. 5-19) which, in turn, controls the time duration of the fast portion of output waveform of the saw-tooth generator that is triggered by the multivibrator. This control provides the front-porch width adjustment.

The use of a synchronizing signal-locking device is an invaluable means for removing degraded synchronizing signals from an incoming program source and replacing them with accurately shaped pulses before further transmission. As a matter of fact, this technique is also of considerable value in large or complex studio installations where even locally originated signals sometimes acquire spurious spikes and other irregularities before

reaching the outgoing line. However, application of the system is not without some disadvantages.

For example, as detailed elsewhere (see Sec. 5-3, *Frequency-control Circuits* and 9-6, *Projector Synchronizing*), it is common practice to lock synchronizing waveform generators to the a-c power line in order that the operation of film projectors may be kept in step with the synchronizing generator by the simple expedient of employing synchronous motors in the projectors. When the local synchronizing waveform generator is locked to a remotely located frequency source rather than to the local a-c line, it is no longer possible to employ this method for keeping the film projectors in step with the synchronizing pulses. Under these circumstances, special provisions must be made if it is desired to integrate local film originations with program material that is arriving from a remote point.

One method of doing this is to take a portion of the 60-cps pulse output of the local synchronizing generator (which is assumed to be locked to a remote synchronizing unit), and either by straightforward waveform shaping and amplification methods, or by frequency-locking methods, generate sufficient 60-cps sine-wave power to operate the motors of the projectors. When this system is employed, flash-tube sources of light for the projectors (see Sec. 9-7, *Gas-filled Flash Tubes*) offer a decided advantage since these light sources are normally triggered by pulses derived from the synchronizing generator and hence they are always automatically in step with the synchronizing generator regardless of the frequency source to which it is locked. In addition, pulsed-light projectors do not require a mechanically driven shutter, and, as a result, the 60-cps sine-wave power that is required is limited to that necessary for the operation of the pull-down or intermittent mechanism on the projector. In applications of this type a precision-machined free-running intermittent mechanism, requiring a minimum size of motor, is a great asset.

Another possible disadvantage of synchronizing signal-locking operations is the momentary disturbance that may be produced when the local synchronizing generator is transferred from a local a-c power-line (or other) frequency control to synchronizing locking operation, or vice versa. As detailed above, phasing of the vertical frequency may take a second or two and, if this is undertaken during transmission of picture information, the disturbance will be seen on picture monitors and receivers. The obvious method of avoiding this is to effect the switch-overs between program originations or at any other time when the signal may be faded to black for the probable duration of the disturbance. A method for minimizing the disturbance would be to bring the local synchronizing generator manually into phase with the incoming signal and then to activate the synchronizing signal-locking equipment. Under these circumstances, the two signals

would be much closer to being in phase at the instant the locking equipment was brought into operation than would be the case if the control was energized at random.

Since the handicaps that may be imposed by the employment of synchronizing signal-locking techniques can be overcome by methods similar to those suggested and since the advantages to be gained by employment of the method may be numerous, the system (or its equivalent) will undoubtedly find considerable application in television broadcasting systems.

## CHAPTER 6

# Studio Television Equipment

AS A TELEVISION BROADCASTING STATION expands the scope of its program operations, the need ultimately arises for a permanently equipped studio or group of studios. Initially, it is often found to be entirely satisfactory to employ field pickup type of equipment in studios but, as the productions become more and more ambitious, the limited switching, fading, and other effects that can be achieved with field-type facilities are usually found to be a serious handicap. By judicious planning it is sometimes possible to employ a combination of permanent, studio-type equipment and field pickup equipment. In the long run, however, as the amount of studio rehearsal and production grows and as the complexity of the programs increases, it becomes advisable to install permanent facilities. By "permanent" facilities is meant the kind that are intended for fixed installation as contrasted with the temporary installation of transportable equipment.

**6-1. Studio System Considerations.** Most of the events that are televised in the field unfold without a great deal of control, if any, on the part of the program director. Rather, the director is faced with producing the best possible program from an event that is often not under his immediate jurisdiction. As a result, in his function as a program producer, he must concentrate on the camera work and on the camera switching and fading problems. In studio productions, however, the program director's activities usually cover a wider scope. He not only has the responsibilities already mentioned but may also be responsible for the timing of the production, for the cueing of the performers, for the lighting and the sound effects and, perhaps, also for the cueing in of program material originating outside of the studio.

Unlike a motion-picture production, once a television program gets under way, it must continue on to its completion, errors, missed cues, and other shortcomings notwithstanding. This requirement places a grave responsibility upon the equipment and those charged with its operation and maintenance. One of the prime requisites for the successful opera-

tion of a television station is absolute continuity of service throughout the broadcasting day. The necessity for this arises from the keen competition among the stations serving a given community and from the psychological reaction of the average person to an interruption of program service. Surveys have shown that many people who will sit through a mediocre program will immediately tune in another station when there is an interruption in the program material lasting only a few seconds. Naturally, those who react in this manner are quite likely to remain with the station to which they switched. Consequently after any interruption, the broadcaster is likely to have lost a part of his audience for the remainder of the broadcasting period. As a result, the one thread that runs through all broadcasting equipment, whether it is for television or aural broadcasting, is the precautionary measures that are taken and the devices that are provided to permit instant isolation and replacement of any equipment that becomes defective during the course of operations.

The electronic facilities required for a television studio, while similar to those used for field pickup purposes, differ from the latter in several important aspects. For example, not being faced with weight, size, and power-consumption considerations, more conservatively rated components may be used. This is desirable, particularly since some television studios are in more or less continuous use throughout the day for rehearsals and for air shows. In addition, since it is not so necessary to confine the equipment to a minimum of space, the various chassis may be designed for easy access to all tubes and other circuit components. This, of course, greatly facilitates the maintenance and servicing of the facilities. It also makes possible the installation of spare equipment, jack panels, and other aids that will ensure continuity of service in the event of equipment failure or other emergencies.

The extent of the equipment required for a television studio and master-control installation will depend, of course, upon the location of the station, the number of studios involved, the scale of operations of the station, and its program production policies. A station located in a large city and originating program material for a network requires a number of large studios and a relatively complex program distribution system for handling both the video and the audio signals. On the other hand, a station in a medium-sized community may receive the majority, if not all, of its elaborate programs from a network and therefore will need only relatively simple studio facilities. In still other instances, of course, a station may rely entirely upon network program material or television recordings, supplemented with field pickups and motion-picture film. In this case, of course, no live-talent studios are required.

All television studio installations, regardless of size, have many equip-

ment components in common. The difference in size of various installations is largely a question of the number of studios and the amount of equipment in each. The facilities in each studio and its associated control room may be much alike (except for the exact number of components of each type) regardless of whether the station is a large one or a small one. The physical layout of the equipment will differ, of course, depending upon the operating philosophy of the station personnel concerned. However, much the same fundamental units are employed by all stations, and the system design itself often follows a more or less basic pattern.

With the above considerations in mind, the broad functions of the equipment in a television studio are enumerated in the following section and then typical television studio audio and video systems are presented. Finally, those studio equipment components not described elsewhere in this book are covered in detail.

**6-2. Functions of Studio Systems.** As contrasted to field pickup equipment, a television studio video system is likely to be rather complex. The function of the equipment is to convert the optical images of the scene that is being televised into their corresponding electrical waveforms, blend program material of this type, but from a number of sources, into a coordinated whole, and provide means for adjusting the resulting video signals to the proper transmission level—all with the aid of picture and waveform monitors.

The sources of video program material that may be handled in a studio control room frequently extend to origination points outside of the particular studio in question, as indicated in Fig. 6-1. For example, it is often the practice to supplement the production taking place in the studio with motion-picture or still material emanating from projection machines and their associated film camera channels. In some instances, the projection system may be located in the studio control room itself. More frequently, however, such equipment is located elsewhere. In the smaller stations it is often a part of the master-control installation. In others, and almost invariably in large studio plants, the projection or telecine equipment is set up as a separate unit. This facilitates meeting any building codes that may be applicable to equipment installations where motion-picture film is being handled. In addition, by concentrating all telecine equipment at one location it can be made available, by means of suitable video and control circuits, to any studio for integration with that studio's own output. Under these circumstances, any equipment not in service at the moment can act as spare or emergency units for those that are in use. Furthermore, for a studio plant of any size, much less projection equipment will be needed with a central telecine room than if each studio is equipped with its own complement of projectors and film camera chains.

In addition to integrating program material from projector sources with that of the originating studio, it is often desirable to add material coming from other studios in the same group. This can be readily accomplished, assuming that adequate video switching and mixing equipment is available in the studio control room. Finally, it is sometimes necessary to handle video program material from off-premise locations as a part of a program originating primarily or in part from the studio. This latter operation can be undertaken on a switching basis with little trouble.

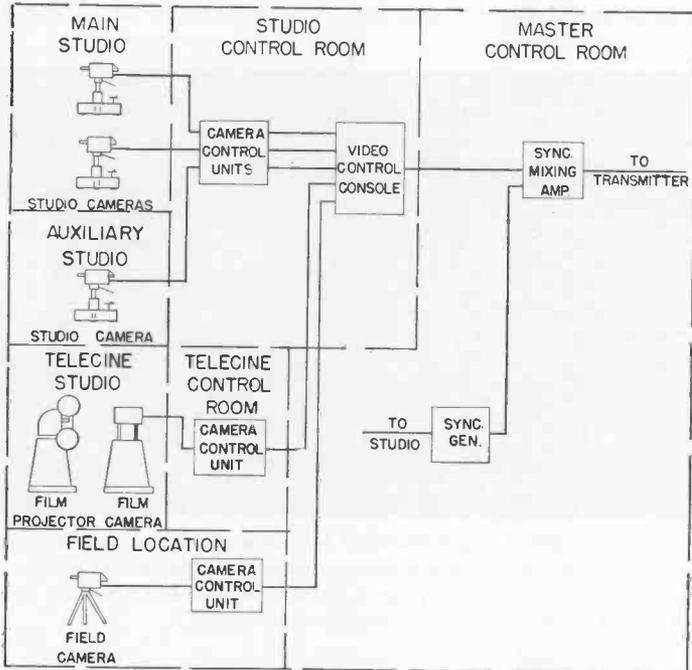


FIG. 6-1. An example of the manner whereby a television studio control room may handle program material from any one of four sources: a main studio, an auxiliary studio, a telecine room, a field location.

However, if it is necessary to create dissolves or montages, or otherwise integrate the off-premise program material with the studio origination, then special precautions must be taken to accurately phase the synchronizing signals used by the two program sources. This problem is covered in detail in Sec. 5-6.

Studio installations also differ from field pickup systems in the extent of the video switching facilities that are provided. In order to obtain the fades, lap dissolves, montages, wipes, and other special "effects" that are

sometimes desired, relatively elaborate video control equipment may be necessary.

The audio equipment required for a television studio may be very elaborate indeed—equal to, and often exceeding, that of the largest aural broadcasting studio. To some extent this is occasioned by the need for keeping the pickup microphones out of sight. This usually requires a large number of concealed fixed microphones or the use of elaborate microphone booms, as shown in Fig. 6-2. The studio audio console must be able to handle the audio pickup from the various movable microphones, from the fixed microphones, and from any associated announcer's booth.



FIG. 6-2. This photograph taken during a rehearsal illustrates the large number of microphones sometimes used on a television program. Visible in this portion of the set are two microphones on booms, two hanging microphones, and two floor-stand microphones. In all, 12 microphones were actually employed.

In addition, the audio console must coordinate the audio signals originating from sound-effects equipment, from any motion-picture films that are integrated with the studio production, from phonograph records that are used to provide incidental music or other background effects and, finally, the audio signals from any remote sources of program material (such as from other studios or field locations) that are woven into the production. Often, provisions must also be made for reproducing the background effects in the studio in order that the performers may be able to hear this portion of the program production. This usually requires modification of the control circuits in the audio console since most equipment primarily intended for aural broadcasting applications contains interlocking circuits designed to prevent this type of operation.

**6-3. Typical Studio Video System.** A studio video system parallels, in many respects, a studio audio system. For the most part, the individual video components are considerably more complex than their audio counterparts. However, systemwise, the video equipment units are arranged in much the same manner as the corresponding units of a broadcasting studio audio system. For example, the television camera corresponds to the microphone, the video preliminary amplifier to the microphone preliminary amplifier, the video mixing and switching equipment to the audio mixer, the video distribution amplifier to the audio program or bridging amplifier, the waveform monitor to the volume indicator, and the picture monitor to the loudspeaker. Film projectors correspond to turntables, background projectors to sound-effects devices, and so on.

In a studio video system, the output of each film or studio camera (which, unlike modern microphones, usually have their preliminary amplifiers built within the camera housing) is connected to a camera-control unit, as shown in Fig. 6-3. Associated with each camera-control unit there are a picture and a waveform monitor. The output of each camera-control unit is connected to an input position on a video control console. The function of this unit is to mix and switch the video signals in much the same manner as microphone and transcription inputs are mixed in an audio control console. Picture monitors are employed at this point also to assist in the mixing operation. From the video control console, the picture signal is usually amplified, synchronizing signals are added, and the composite waveform is then sent to the transmitter.

As compared to an audio system there are, however, several major differences in the video system. One stems from the complexity of the camera tube which requires that a number of electronic camera controls be given constant supervision if the highest picture quality is to be obtained. Although comparable to gaining an audio program, the camera-control operation is much more complicated. As a result, it is generally separated from the mixing and switching operation and performed at a camera-control unit. In all but the smallest setups, the camera-control function is performed by a person charged only with this responsibility.

Another major difference in video systems, as compared to their audio counterpart, is occasioned by the fact that video signals cannot be transmitted from place to place around a studio plant quite as freely as audio signals. The time delays that are suffered when video signals are transmitted any appreciable distance over cables must be taken into consideration when several signals are to be mixed together at some one point. Because of this factor, centrally located video relay switching systems are sometimes employed rather than individual manually operated switches located in each studio control room. Under certain circumstances, how-



ever, the latter type of switching system can be used with complete success, provided the necessary circuit design precautions are taken (*viz.*, equalizing the delay of all signals to a suitable common reference).

Television studio (and field) cameras have already been described in Chap. 2. The remaining units that are a part of a complete studio television system are described in the following sections.

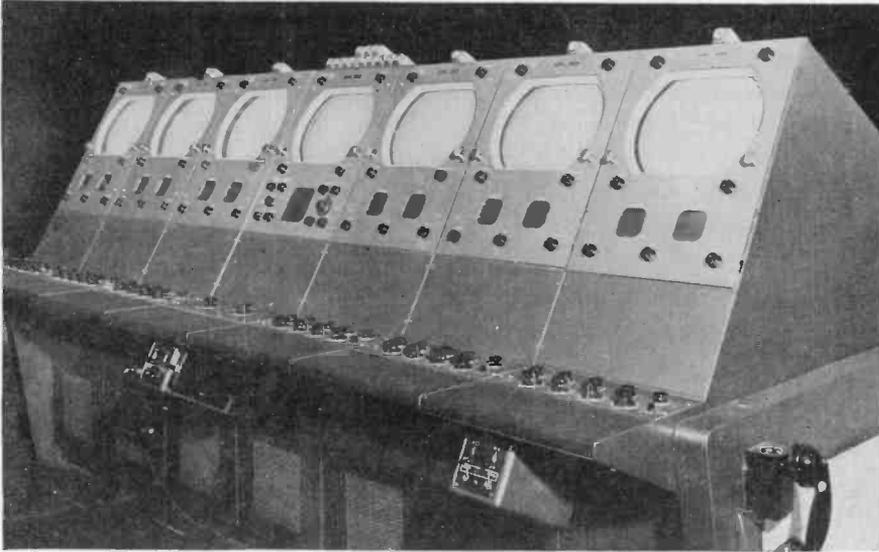


FIG. 6-4. An array of six studio-type camera-control units together with an associated outgoing-line monitor (at center). Each camera-control position includes a picture tube, two waveform monitor tubes (operating at horizontal and vertical rates), and a control panel for the associated camera.

**6-4. Studio Camera-control Units.** The functions of camera-control units have already been described in Chap. 2. For illustrative purposes and in order to cover the operation of the various circuits and controls, a typical field-type unit was detailed. Studio camera-control units perform much the same function as field units; consequently, the circuits employed are not detailed again. A bank of typical studio-type camera-control units is shown in Fig. 6-4. One camera-control unit is required for each studio or film camera, and it is the usual practice to group the units closely together in a studio control room.

In this particular installation the first two control units on the left end of the row are used for film camera operation. The third unit is for a studio camera, while the picture and waveform monitor in the center position is employed for monitoring the outgoing video circuit. The three remaining camera-control units on the right end of the row are associated

with an equal number of studio cameras. Thus the assembly, as a whole, accommodates two film cameras and four studio cameras besides providing an outgoing line monitor.

The camera-control units shown in Fig. 6-4 employ a 12-in. picture tube and two 5-in. waveform monitors. One of the latter is operated at a scanning frequency equal to one-half the picture horizontal or line scanning rate while the other operates at one-half the vertical or field scanning rate. Thereby, one oscilloscope displays two complete cycles of horizontal video information while the other shows that corresponding to two fields.

The camera controls themselves are located in a horizontal panel that is mounted flush with the desk top. The controls that are located on this panel, within easy reach of the camera-control man, are those for adjustment of video gain, blanking level, target voltage, beam current, beam focus, multiplier focus, image focus and horizontal and vertical shading signals.

The supporting circuits required for the camera-control unit illustrated are contained in an associated equipment rack. These include the circuits necessary for (a) amplifying the output signal from the camera preamplifier, (b) establishing black level, and (c) mixing in blanking pulses that are supplied by the synchronizing generator. In some instances (e.g., the equipment shown in Fig. 14-23) the auxiliary rack is dispensed with, and the equipment chassis required to perform the afore-mentioned functions are located in the base of the camera-control unit.

**6-5. Video Switching Console.** The video control console circuits shown in the schematic block diagram of Fig. 6-3 are arranged to accommodate 12 possible input signals. It is recognized that this may be a more elaborate arrangement than will be required by some television stations but, for the purpose of illustrating the principles involved, it is desirable to include provisions for all probable input sources. For any specific installation, only those input channels that are required need be included in the video control console.

**Input Circuits.** Each input circuit in the console provides a resistive termination for the signal source. The standard circuit impedance is 75 ohms (Table 1-1), but in practice it is often found desirable to employ a termination that may be varied approximately  $\pm 5$  per cent from this value in order to eliminate all traces of reflections chargeable to incorrect circuit termination.

The switching system illustrated in the afore-mentioned diagram employs a conventional grid arrangement wherein the horizontal busses carry the incoming signals and the vertical busses the outgoing signals. At the crossover points marked with either a cross or a circle-enclosed cross, the input and the output busses may be connected together at the will of the

control console operator. The actual connection may be effected by means of a manually operated switch, or remotely located video relays may be used for the purpose. All the circuits associated with any given vertical line of connections are interlocked so that only one circuit in the vertical line may be closed at a given time. Thus an outgoing circuit, represented by a vertical bus, will receive a video signal from only one source at a time.

The connections in the first horizontal row in the control console circuits shown in Fig. 6-3 are labeled "Black." These are actually the off-position connections, but in television broadcasting, "off" does not mean that no signals are transmitted—rather, blanking and vertical and horizontal synchronizing pulses *are* transmitted while only the picture signal is turned off. This maintains the scanning beam of picture monitors and television receivers in synchronism while blanking off the electron beam so as to avoid any visible trace.

**Camera Inputs.** The next four horizontal input busses are shown connected to the outputs of as many studio camera-control units. The signal received from these units consists of the picture signal plus blanking. In accordance with accepted practices, this is a black-negative signal having an amplitude in the vicinity of 1.0 volt, peak to peak.

The next two input positions, labeled Nos. 5 and 6, are spares that may be used (*a*) for additional studio cameras, (*b*) for picture plus blanking signals from other studios, or (*c*) for video signals from a film camera chain. The timing of any signals that are connected to these inputs must be commensurate with those being originated in the studio under discussion. Presumably the equipment supplying these supplementary signals will be operated from the same synchronizing generator that drives the main studio equipment or, if a separate synchronizing generator is employed, it will be locked in with the master generator. Furthermore, any delay suffered by either the main or the supplementary signals must be equalized before the two may be mixed and switched together.

**Remote Inputs.** The next three input positions, on the video console being described, are designed to accommodate an entirely different kind of signal than the first six positions mentioned above. Positions 7, 8, and 9 are designated "remote" because they are intended for handling signals received from off-premise pickup points. Signals of this type are usually transmitted over the interconnecting circuits as composite signals, *i.e.*, a picture signal complete with blanking and all synchronizing pulses. Signals of this type do not lend themselves to fades, dissolves, and other special "effects" since, if their amplitude is varied from normal, the synchronizing pulses are correspondingly varied in amplitude. Thus, if a composite signal is faded to black, the synchronizing information will

likewise be decreased and the television receivers and picture monitors on the circuit will very likely lose synchronism. Under these circumstances, the picture will roll or otherwise become unusable.

For this reason, when it is desired to effect any processing of the video signal, it is desirable to add the synchronizing signal after all switching, fading, or other control is effected. This applies even to quick switching of program sources since many receivers react unfavorably even to momentary interruption of synchronizing information. Unfortunately, when remote sources of program material are involved, the addition of synchronizing signals after switching cannot usually be practiced. Separate synchronizing generators are used at remote points and, unless synchronizing signal-locking equipment is provided (as explained in Sec. 5-6), they are not normally in synchronism with the unit at the main studios. Furthermore, the remote pickup program may be that from the incoming network, and in this case it is not feasible to lock the out-of-town synchronizing generator to the local unit. Further, although it is possible, it is not always practicable to lock in the local synchronizing generator with the remote unit because of the requirements of the film projectors (see Sec. 9-6, *Projector Synchronizing*) that play such an important part in program production. For these reasons, signals originating at remote points are invariably composite signals having all pulses present and properly timed with relation to one another.

The video console switching positions intended for handling remote programs are therefore arranged so that, whenever a remote program is switched to the outgoing line, local synchronizing pulses are automatically turned off. The circle-enclosed crosses in Fig. 6-3 indicate the switching system junctions at which this action takes place.

**Cue Input.** The tenth position on the switching console is set aside for cueing purposes. Prior to the studio in question beginning its broadcast, the picture signals from the preceding program can be sent to the control room of the waiting studio and observed by those responsible for timing the start of the new program. The cueing position is also useful if the studio under discussion is originating a portion of a program that is being coordinated by still another studio. Under these circumstances, the cueing position may be employed to watch the progress of the main portion of the program and thereby be forewarned as to when the local production is to begin.

**Test-pattern Input.** The eleventh position of the video console is permanently connected to a source of test-pattern signal. This source may be a film camera chain (used in conjunction with a slide or opaque projector), a flying-spot scanner, or a monoscope (see Chap. 8). The availability, at all times, of a suitably designed test pattern is a tremendous aid

in lining up circuits, picture and waveform monitors, provided (a) the linearity of the pattern, (b) the amplitude of the output signal and (c) the transfer characteristic of the signal generator are rigidly maintained at all times.

**Effects Circuits.** The twelfth and last input position of the switching console is connected to the output of an "effects" device. Two of the four outgoing circuits (vertical busses) of the switching system described are connected to the input of the effects device. Thus, any two of the six locally produced picture signals (positions 1 to 6) may be connected to the input of the effects unit. It is this unit that is employed to obtain the lap dissolves, the fades, the wipes, the montages, and the other special effects that are so vital to television program production.

**Outgoing Program Circuit.** One of the outgoing circuits (the third from the left) is connected to the main program channel. By operation of the proper control, this main channel may be connected to any of eleven incoming program sources. The only incoming program material that cannot be switched to the outgoing line is the cueing signal which, of course, should not be transmitted beyond the studio control room.

**Preview Circuits.** The fourth and fifth outgoing busses are connected to preview picture monitors that may be used to examine critically the video signal on any of the incoming channels. Thus, those responsible for the program production have a means of determining exactly what program material is available on a given channel before it is switched to the main outgoing circuit. In some installations the program production requirements are such that one preview monitor fulfills all needs. The preview channel may be dispensed with entirely in those cases where the picture monitors associated with the camera-control units are within the view of those responsible for program production and where it is not necessary to preview (a) incoming remote programs, or (b) the output of the effects units, or to have cueing facilities.

**Switching System Features.** Where instantaneous switching from one program source to another is desired, this can be effected by making the proper connections to the outgoing bus labeled "Line." While this type of operation is in progress, program material from any two of the first six input positions may be connected to the "effects" unit and, with the aid of a preview monitor, the desired special effect created. When adjusted to the satisfaction of those concerned, the output of the effects unit may be connected to the main channel by making the connection between the "Line" bus and the "Effects" bus.

If the effect being created is simply that of fading from one signal source to the other, either by first going to black or by a lap dissolve, then the effects unit may be released for the next setup immediately after the fade

or dissolve is completed. This is done by simply connecting the channel that was faded in via the effects unit directly to the main outgoing channel by effecting the proper connection on the outgoing line bus.

The outgoing bus marked "Line" could have been eliminated from the switching system shown and all signals passed through the effects unit. However, had this been done, there would be no opportunity to preset, during a broadcast, a particular effect that is desired. This is not serious so long as special effects are limited to fades and dissolves; where wipes and montages are employed, it is very helpful to have an opportunity to preview an effect before it is broadcast.

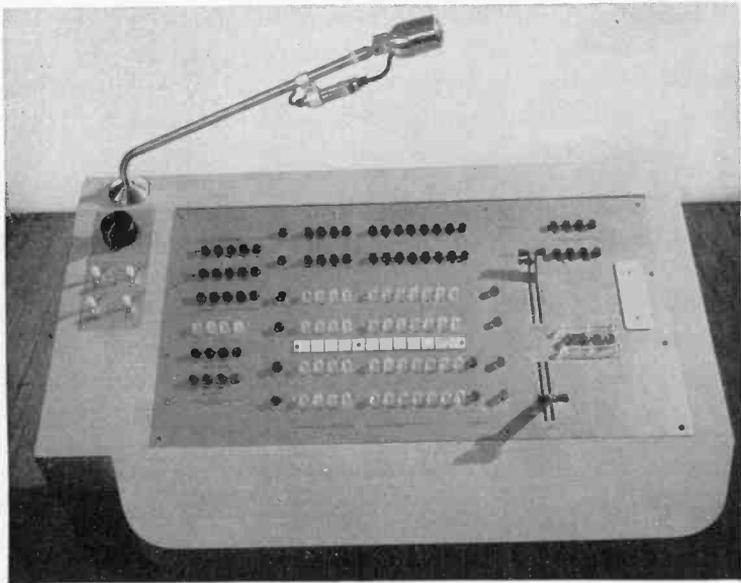


FIG. 6-5. In this video switching console the four rows of white buttons in the center of the panel perform the main camera switching functions described in the text. The two long rows of black buttons at top center are for preview channel selection. The small groups of four and five buttons at the left are used, respectively, for remote control of film projectors and for selection of program material for picture monitors located at strategic places in the studio and control room.

In Fig. 6-5 there is shown a video switching console which contains the features described above and, in addition, incorporates a second pair of effects circuits, complete with mixing amplifier and fader controls. This arrangement provides means for making a lap dissolve from a single picture source into a superimposition or a montage of two other picture signals, or vice versa. Alternately, a superimposition or a montage of as many as three program sources can be made simultaneously.

**6-6. Video Utility Amplifiers.** In television applications the nearest parallel to the conventional audio amplifier is the video utility or isolation amplifier. Actually this video amplifier is more nearly the equivalent of a specialized audio unit, the audio isolation amplifier, since the video counterpart usually has relatively little gain and is intended primarily to isolate one video circuit from another. In a complete studio television system (see Fig. 6-3) there are usually a large number of video isolation amplifiers because, unlike audio practice, when an auxiliary or supplementary feed is desired it is not possible simply to connect to a through video circuit with a bridging transformer. Therefore, a video isolation amplifier is usually employed at every point in a television circuit where, in the audio case, a bridging transformer or a dividing network would be used. A phenomenal number of video isolation amplifiers are required for a television studio plant installation of any size.

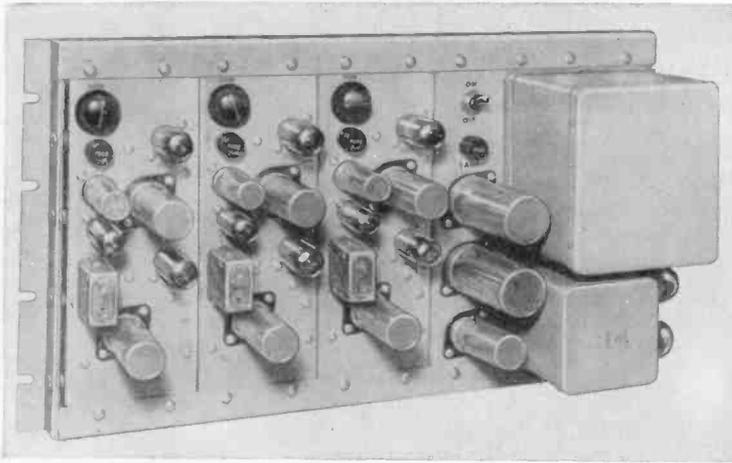
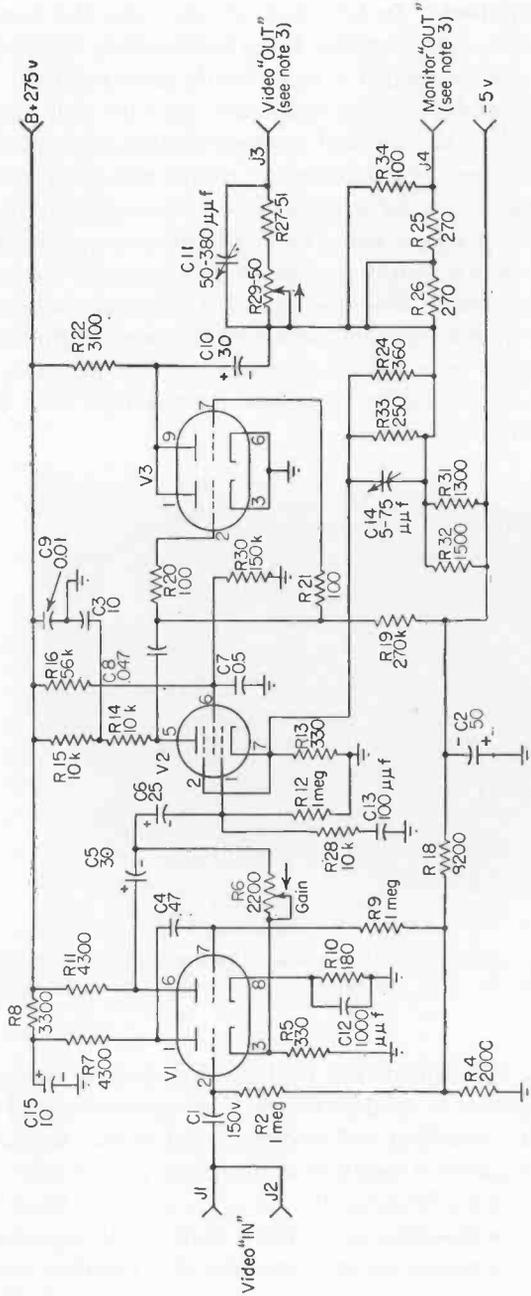


FIG. 6-6. Three video utility amplifiers and an associated power-supply unit mounted on a chassis that is suitable for rack mounting. (Courtesy of General Electric Company.)

In the block schematic diagram of the studio video system shown in Fig. 6-3, an isolation amplifier is used in the main program channel between the output from the switching unit and the input to the stabilizing amplifier. An isolation amplifier is required at this point since a relatively high impedance is required for bridging the program busses. Since the stabilizing amplifier used for this illustration has a finite input impedance, it cannot be bridged directly across the program circuits. Isolation amplifiers are also used to feed various monitoring circuits that are bridged across the output of the main channel.



**NOTES**

- 1.- Capacitor values are in microfarads unless otherwise indicated  
 $\mu\mu\text{f}$  = micromicrofarads

- 2.- Resistor values are in ohms.  
 k = multiply by 1000  
 meg = multiply by 1,000,000

- 3.- Amplifier normally connected as shown. This provides monitoring output equal to regular output & max gain of 25. For max gain of 4, & reduced monitoring levels, clip out R33, R34, R32 & C14. Monitor ratio is then 2/5. For monitor ratio of 1/5, clip out shorting bus across R26

Fig. 6-7. Schematic circuit diagram of a dual-output four-stage video utility amplifier that incorporates separate feedback loops around the first two and the last two stages.

A typical assembly of three utility video amplifiers and their associated power supply is shown in Fig. 6-6. Each of the amplifier units illustrated provides one video channel having a bandwidth of approximately 9 Mc, and in addition to a regular video output at 1.4 volts, peak to peak, a second output at the same level is also available for monitoring or other purposes. A compensating network is provided in the main output circuit to accurately adjust the internal output impedance of the amplifier to the standard 75-ohm value over essentially the entire transmission band. The monitoring output does not afford this refinement, although it is fed from a low-impedance source by means of a network that provides an output impedance that is essentially 75 ohms except at the high frequencies where capacitance effects come into play.

The gain of the video amplifier illustrated is normally adjustable over the range from 0.6 to 2.5 times which is adequate for the great majority of television applications. However, if a nominal amount of additional gain is required, this may be obtained by reducing the magnitude of the feedback applied by a feedback loop. Under these circumstances, the gain may be increased to four times but at the expense of bandwidth and of the output level available from the monitoring output circuit.

The circuit diagram of the video amplifier under discussion is shown in Fig. 6-7. The unit is seen to consist of four stages of amplification with a feedback loop applied from the plate of the second stage (second section of V1) to the cathode of the first (first section of V1) and a second feedback loop from the plate of the output stage (V3) to the cathode circuit of the third stage (V2). In effect, the unit consists of a pair of two-stage feedback amplifiers connected in cascade. The gain control is an adjustable resistor, R6 in the first feedback loop. Decreasing the amount of feedback increases the gain, and vice versa.

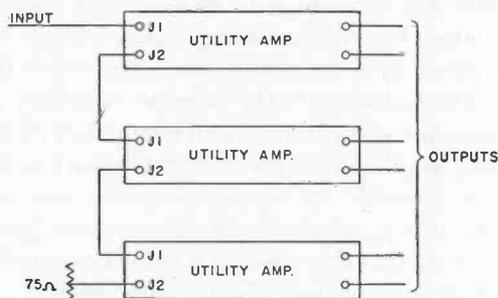


FIG. 6-8. A method of paralleling the input circuits of a number of video utility amplifiers. To avoid undesirable reflections, the input circuit termination is connected to the last unit in the chain.

As shown, the input impedance of the amplifier is high and is intended for bridging standard 75-ohm video circuits. Where desired, the amplifier can be provided with a 75-ohm input impedance by connecting a resistor of this value to connector J2 while employing J1 for the regular input connection. On the other hand, if a number of utility amplifiers are to be connected in parallel, the signal source may be connected to J1 of the first amplifier, and a connection from J2 of the first unit looped to the J1 connector on the second amplifier and so forth, as shown in Fig. 6-8. In this instance, it is important to place the terminating resistor on the J2 connector of the final amplifier in the chain if reflections are to be avoided. Furthermore, unless special precautions are taken, it is generally not possible to parallel more than above five amplifiers because of degradation of the response at the high-frequency end of the spectrum.

**6-7. Stabilizing Amplifier.** Just as in a broadcasting studio audio system, the mixing and switching circuits in a television system are followed by an amplifier. However, in the video application the amplifier used at this point in the system is called upon to do a great deal more than simply increase the amplitude of the signal coming from the video mixer circuit. In addition to this service, the unit is required to remove any low-frequency surges that may have been introduced by the switching and mixing operation, and to add synchronizing signals (both horizontal and vertical) to the picture and blanking signals that are obtained from local camera pickups. Furthermore, as is evident from Sec. 6-5, composite television signals may also be handled by the switching circuits although these do not require the addition of synchronizing signals upon entering the main video program channel. However, the synchronizing signals that are a part of the composite signals may have become compressed, noisy, or otherwise degraded somewhere along the way. In order to restore these synchronizing signals to the standard that must be maintained if successful television transmission is to be achieved, means must be provided for rehabilitating the synchronizing signal. These operations (and others) are undertaken by a stabilizing amplifier which from its location in the video circuit is analogous to the program amplifier in an audio system. However, because of the variety and complexity of its functions, the television stabilizing amplifier has no true counterpart in the audio field.

**Applications.** A versatile stabilizing amplifier can perform a large number of functions which, for clarity, are summarized below. A stabilizing amplifier may be used at any point in a video system where it is desirable to perform one or more of the following operations:

- a. Increase a picture signal level by a factor of ten times or thereabouts, depending upon the design of specific stabilizing amplifiers.

- b. Remove low-frequency distortion such as may be introduced by coupling circuits with inadequate time constants.
- c. Remove hum or other low-frequency disturbances, such as power-supply or switching surges, that are added to a composite signal (picture plus blanking) in the system ahead of the stabilizing amplifier.
- d. Control the amplitude of the synchronizing pulses independently of that of the picture signal in order to achieve desired picture-to-synchronizing-signal amplitude ratios.
- e. Control the amplitude of the picture signal independently of that of the synchronizing pulses.
- f. Remove noise and spurious spikes from synchronizing and blanking pulses.
- g. Limit white peaks to a predetermined level by means of a white clipper that removes large peaks and protects following equipment from overload.
- h. Reduce the level of black peaks with respect to the blanking level; *i.e.*, reduce the amount of setup.
- i. Mix synchronizing pulses with picture signals in order to form a standard composite video signal.
- j. Remove synchronizing signals completely from a composite video signal in order, for example, to replace degraded synchronizing signals with new ones of standard proportions (see Sec. 5-6).
- k. Strip synchronizing signals from incoming composite signals so as to make such synchronizing information available to other equipment for control purposes (*e.g.*, see Sec. 5-6).

**Circuit Arrangement.** A typical video stabilizing amplifier, intended for standard relay rack mounting, is shown in Fig. 6-9. The basic principles of its operation include (*a*) clamping to remove low-frequency disturbances, (*b*) separation of the synchronizing signal from the picture signal, (*c*) reshaping and level adjustment of the synchronizing signal, (*d*) black-and-white clipping of the picture signal (if desired) and adjustment of its level, (*e*) recombination of the processed synchronizing and picture signals, and (*f*) adjustment of the level of the reconstituted composite television signal.

The methods whereby these operations are undertaken may be explained with the aid of the block diagram shown in Fig. 6-10. The upper row of blocks shows the picture-signal amplifier stages, the second row the clamping diodes, and the third row the synchronizing signal clipping, shaping, and clamping pulse circuits. Tube V1 is a cathode follower having an input gain control in its cathode circuit which permits adjustment

of incoming signals to a specific level at the input to V2. Tubes V2, V3, and V4 are three stages of video amplification employing shunt peaking circuits (except in the last stage) in order to achieve the desired transmission bandwidth.

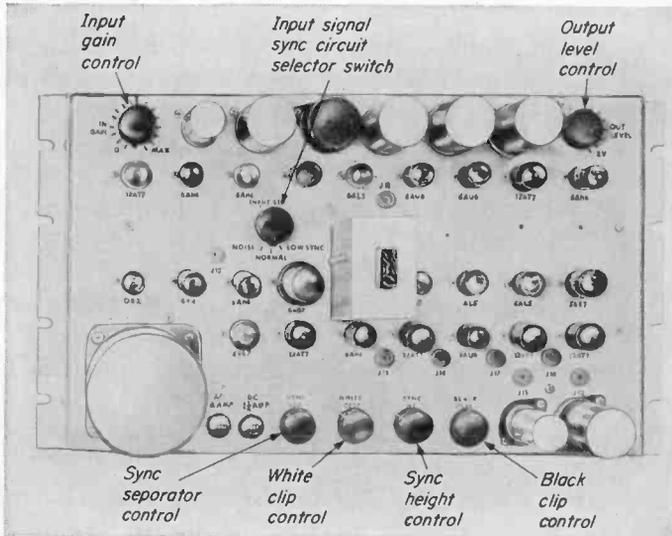


FIG. 6-9. A video stabilizing amplifier chassis suitable for rack mounting. (Courtesy of General Electric Company.)

A dual-diode clamper, V11, across the grid of V3, provides a means whereby white peaks may be limited as determined by the setting of a white clipping control. In addition, a negative blanking signal may be applied to V3 in order to increase the blanking level at the output of this video stage. This blanking signal must, of course, be in exact phase with that of the composite signal applied to the input of the stabilizing amplifier. Consequently, if the input signal is from a remote point and the blanking signal is to be supplied by a local synchronizing signal generator, then the latter must be phased with the remote synchronizing generator by means of a synchronizing signal-locking circuit such as is described in Sec. 5-6. If, on the other hand, the input signal is of local origin, then it is necessary to provide only the applied blanking signal with the correct phase delay to match the composite input signal, assuming that the applied blanking signals are obtained from the same source as those originally employed to construct the composite input signal.

A dual-diode clamper, V12, connected at the input of the next video stage V4 operates in conjunction with the following clipper stage V5 to

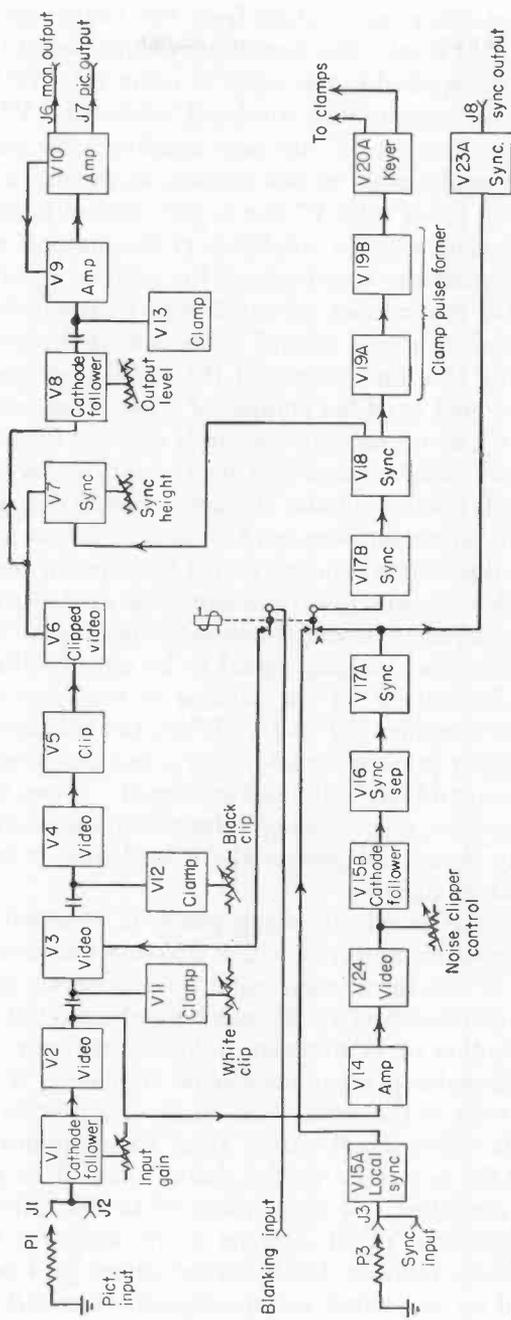


Fig. 6-10. Schematic block diagram of a stabilizing amplifier. The tubes along the top row are video amplifiers, those in the middle row are clampers, and those in the bottom row are concerned with processing the synchronizing signal.

remove the synchronizing information from the composite video signal at or near the blanking level. The remaining picture signal (without synchronizing pulses) is applied to the input of mixer tube V6 which shares a common plate load resistor with a second mixer tube V7. The input signals to this second mixer, V7, are new synchronizing pulses that are obtained from one or the other of two sources, as explained below. The synchronizing signal mixer tube V7 has a gain control in its grid circuit which permits adjustment of the amplitude of the inserted synchronizing signal without affecting the amplitude of the picture signal. The combined outputs of the mixer tubes are applied to a cathode-follower stage V8 which, by means of a gain control in its cathode circuit, provides a means for adjusting the final output of the stabilizing amplifier to the desired level. The final amplifier consists of a two-stage feedback amplifier, V9 and V10, whose circuits are similar to those of the last two stages of the utility video amplifier described previously (see Sec. 6-6). This arrangement provides both a regular and a monitoring output circuit both having an internal output impedance of 75 ohms over most of the transmission range. A dual-diode clamper V13 at the input of the first stage of the output amplifier restores the d-c component at the grid of V9 and removes any low-frequency disturbances introduced prior to this point.

The source of the synchronizing signal to be mixed with the stripped picture signal is determined by the position of the relay shown in the center of the block diagram Fig. 6-10. When the movable arms of the relay are in the upper position, synchronizing and blanking signals from an external source are added to the picture signal. When the relay arms are in the lower position, synchronizing information that has been stripped from the incoming signal and processed (as explained below) is recombined with the picture signal.

The external source of synchronizing pulses is obtained via amplifier V15A, the black-positive output of which is connected to one of the stationary contacts of the afore-mentioned synchronizing-signal-selection relay. The internal sources of synchronizing and blanking pulses, which are applied to the other set of stationary relay contacts, are obtained with the aid of a synchronizing separator circuit employing a group of five tubes. The first tube in the series, V14, receives a portion of the black-positive composite video signal output from V2, amplifies it, inverts it, and applies it to the next tube in the chain, V24. Here the composite signal is further amplified and again inverted so that a relatively high-amplitude black-positive signal appears at its output. This signal is applied to a cathode follower V15B across whose grid is connected a crystal diode and an associated resistor-capacitor network. The circuit constants are arranged so that, when noise on the synchronizing signal

peaks exceeds a predetermined value, the crystal conducts and effectively connects the network across the grid of the cathode follower. This produces a shunt clipping action that partially eliminates the noise on the synchronizing signal peaks. One of the elements in the network is adjustable and determines the amount of noise limiting.

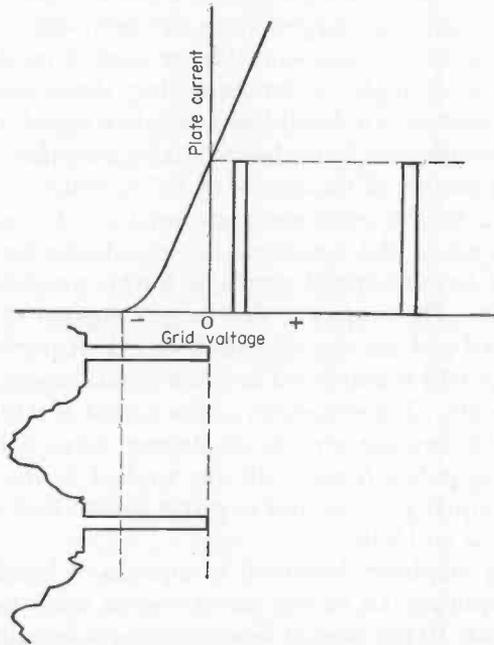


FIG. 6-11. By applying a composite video signal to the grid of a clipper tube in the relationship shown here, an output signal may be obtained that is a slice of the synchronizing signal portion of the composite input signal.

The black-positive output of cathode follower V15B is applied to synchronizing separator tube V16. The output of this tube, which is operated at zero bias and low screen voltage, is a black-negative synchronizing signal, all traces of the picture signal having been removed. This result is obtained by virtue of the peaks of the synchronizing signal being held to zero voltage on the grid of V16 by the diode action between grid and cathode. The amplitude of the composite picture signal applied at this point is such that part of the synchronizing signal and all of the picture signal portion drive the grid of V16 to cutoff, as illustrated in Fig. 6-11. The resulting signal is a slice of the synchronizing pulse portion of the composite input signal.

This negative synchronizing signal is applied to the grid of V17A which is driven beyond cutoff by the signal with the result that the peaks of the output are clipped. This removes noise and other disturbances that may have been riding on the peaks. A portion of the output of V17A is applied to V23A where the positive-going signal drives the tube to zero bias, thereby removing any noise or irregularities from the base line of the synchronizing signal. The resulting output is a black-negative synchronizing signal which, having been stripped from the incoming composite signal, shaped, and amplified, becomes available for control purposes in external equipment as, for example, a synchronizing signal-locking unit (see Sec. 5-6). Approximately a 4-volt black-negative signal in a 75-ohm load is available for this purpose from the stabilizing amplifier illustrated.

The remaining portion of the output of V17A, which is a black-positive signal, is applied to the synchronizing-signal-selector relay mentioned above. The output of the synchronizing-signal-selector relay, whether from the internal or the external source, is further amplified, shaped, and inverted by V17B. The output of this tube is applied to V18 where the base line is clipped and the signal again inverted. A portion of the black-positive output of V18 is employed to drive synchronizing mixer tube V7 described previously. The remainder of the output of V18 is used to drive the clamper pulse-forming circuit employing tubes V19A and V19B. Delayed clamping pulses from V19B are applied to the input of V20A which produces equal positive and negative pulses that are used to key clampers V11, V12, and V13.

The stabilizing amplifier described is capable of handling composite, black-negative input signals having picture-signal levels between 0.15 and 3 volts with at least 10 per cent of synchronizing information. The input impedance of the amplifier is high, and it may, therefore, be used either as a bridging amplifier or with a terminated input. The transmission bandwidth of the unit exceeds 6 Mc. The output of the amplifier is a black-negative signal, the picture signal portion of which is adjustable to any value between 0.4 and 1.4 volts. The synchronizing portion of the output signal is independently adjustable to any value between 0 and 50 per cent of the picture signal. However, the maximum output (picture plus synchronizing signals) cannot exceed 2.5 volts, peak to peak. The output from the monitor circuit is the same as that from the regular output circuit and, as previously mentioned, both circuits provide an internal output impedance of 75 ohms.

**Operation.** The ability of a properly designed and carefully adjusted stabilizing amplifier to correct deficiencies in composite television signals is rather remarkable. Its ability to perform the functions listed under *Applications* (above) stems from four basic operating features: (a) video

amplification, (b) clamping circuits, (c) synchronizing signal shaping and amplification circuits, and (d) synchronizing and picture-signal mixing circuits. A stabilizing amplifier cannot perform miracles, however, and the signals that are applied to its input for rehabilitation must contain sufficient pertinent information for the circuits to discern the vital reference points. For example, stabilizing amplifiers that clamp on the back porch (as do this unit and most of those employed in broadcasting station applications) must be afforded a signal with a recognizable back porch. Moderate amounts of noise and spurious spikes can be coped with, but a stabilizing amplifier cannot be expected to perform its clamping function properly if the back porch is degraded to the extent that it is no longer perceivable as such. However, where an adequate back porch exists, stabilizing amplifiers will minimize or completely eliminate spurious low-frequency components that have been added to the picture signal ahead of the stabilizing amplifier (see Figs. 6-12*a* and *b*). These spurious components may include hum induced by a-c power systems, abrupt level changes caused by power-supply surges, distortion introduced by poor low-frequency response in video amplifiers, and by amplifier microphonics.

There are, however, limitations in the type and the magnitude of the signal discrepancies that can be corrected. Since, by clamper action, a reference level is established at the beginning of each horizontal line, any spurious signals that cause negligible amplitude changes within the period of one line will be completely eliminated even though, over a period of many lines, the aggregate amplitude change may be considerable. The clamping circuits in the stabilizing amplifier will bring each horizontal scan back to the reference point, line by line, over a wide range of amplitudes. This explains the ability of the stabilizing amplifier to eliminate, for example, the effects of hum pickup, since with 60-cps hum it requires an elapse of  $\frac{1}{120}$  second for the hum signal to progress from one extreme to another. During this time, one-half of a field or 131 lines (on the basis of 60 fields per second and  $262\frac{1}{2}$  lines per field) have been scanned. Thus, assuming a sinusoidal distribution, the maximum amplitude change during a line is less than 1.8 per cent (where the slope of the sine wave is a maximum) and is negligible at the peaks of the sine wave.

On the other hand, if the total amplitude of the spurious signal is so great as to cause overloading somewhere in the system, then compression or amplitude modulation of the signal will take place. Under these circumstances the stabilizing amplifier will remove the spurious signal but not the modulation. However, to the extent that the compression takes place in the synchronizing signal, the discrepancy can be corrected by amplification or stretching of the synchronizing signals by the processes already described. Furthermore, in anticipation of compression of the

synchronizing signal, in a particular transmission system, the synchronizing-to-picture-signal ratio may be deliberately increased or preemphasized with the aid of the circuits available in a stabilizing amplifier.

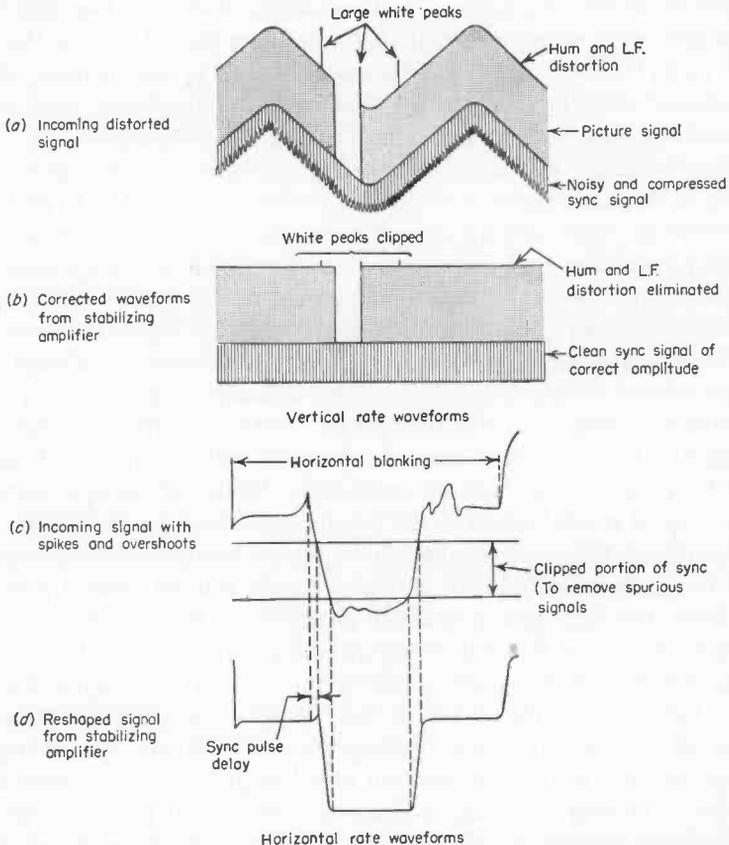


FIG. 6-12. Examples of the manner whereby a stabilizing amplifier can rehabilitate degraded television signals. At *a* there is depicted an incoming signal containing hum, low-frequency distortion, excessively large white peaks, compressed and noisy synchronizing signals. Under proper operating conditions, a stabilizing amplifier can restore these signals as shown at *b*. At *c* there is shown a detail of a horizontal synchronizing pulse that is badly deformed. An example of the extent to which this pulse may be improved is shown at *d*.

In both these applications there are limitations to the character of the signal that can be accommodated. The operation of the amplifier is predicated upon the presence of synchronizing information in the incoming signal. If the synchronizing-to-picture-signal ratio is unreasonably low

(less than about 10 per cent for the unit described), the stabilizing amplifier will be unable to separate one from the other and perform its intended functions. At the other extreme, too large ratios of synchronizing-to-picture-signal ratios may require considerable readjustment of the controls.

The worthy performance of the stabilizing amplifier is not, unfortunately, attained without some detrimental properties. However, in a well-designed unit these are not of major significance and the advantages to be gained by its use usually outweigh the disadvantages. One drawback of the unit is the delay that is introduced in the horizontal synchronizing pulse, *i.e.*, lengthening of the front porch. This stems from the clipping action which is employed to remove a useful portion of the synchronizing signal from among the spurious signals that may accompany it, as shown in Figs. 6-12*c* and *d*. Depending upon the slope of the original synchronizing signal and the characteristics of the stabilizing amplifier itself, this delay may amount to a few tenths of a microsecond, *i.e.*, a few per cent of the original width of the horizontal synchronizing pulse.

By the same action, the back porch may also be somewhat lengthened; the extent to which this occurs, however, is usually of little practical consequence. What is of importance, though, is the notch that is sometimes put into the back porch by the action of the clampers. Although not of any significance in so far as the stabilizing amplifier that generates the notch is concerned, it may degrade the back porch in an undesirable manner from the viewpoint of subsequent stabilizing amplifiers which employ the back porch for reference purposes.

**6-8. Picture and Waveform Monitors.** The television equivalents of the loudspeaker and the volume indicator used in an audio system are the picture and the waveform monitors. With the aid of a picture monitor, the composition and the quality of a picture signal may be judged. The waveform monitor, on the other hand, shows the amplitude of the white peaks and of the black peaks in the picture signal, together with the blanking level and, if present, the synchronizing level.

**Combination Monitors.** As shown in the block diagram of a typical studio video system (Fig. 6-3), a picture and a waveform monitor are always associated with a studio camera-control unit. Without these monitors it would be virtually impossible to adjust properly the controls that are a vital part of this unit. In the typical camera-control units illustrated in Fig. 6-4, picture and waveform monitors occupy the entire upper portion of the assembly.

Picture and waveform monitors are also employed in many other parts of the television system. For example, in a television studio plant they are used (*a*) with film camera-control units, (*b*) for monitoring the com-

posite signals on incoming program circuits from studios, remote points, and network circuits, and (c) on outgoing program circuits that feed transmitters and networks. At television transmitters, they are used to monitor the incoming program material, which often requires processing by means of a stabilizing amplifier before being sent to the transmitter. Monitors are also utilized to determine the nature of the signal being fed to the transmitter and to observe the demodulated output of the transmitter to ensure conformance with the rules and regulations that govern these transmissions.

A combination picture and waveform monitor may be seen in the center of the array shown in Fig. 6-4. This combination monitor, which is intended primarily for studio and transmitter control-room installations, includes built-in calibration facilities for peak-to-peak signal amplitude measurements, an adjustable calibration pulse for determining signal amplitudes on a percentage basis, and expanded sweeps for detailed examination of either vertical or horizontal synchronizing signal intervals.

The built-in calibration source consists of a square-wave generator operating at power-line frequency which may be adjusted to supply a signal having a peak-to-peak amplitude of 3 volts across a continuously adjustable potentiometer. The potentiometer is equipped with a calibrated dial so that known voltages of any value from 0 to 3 volts may be obtained and applied to the input terminals of the monitor. Thus the gain of the waveform monitor amplifier may be adjusted so that any predetermined voltage (within the range of the instrument) will produce a standard deflection (see also Sec. 16-2).

The calibration pulse that is incorporated in the monitor illustrated consists of a narrow pulse whose amplitude may be adjusted by known amounts, percentagewise, with the aid of the calibrated potentiometer. Thus the pulse may be adjusted so as to correspond to the crest value of some particular peak that is of interest, and its amplitude, in per cent of reference deflection, read from the calibrated dial.

Expansion of both the horizontal and the vertical sweep rates is also provided in the waveform monitor illustrated in order to permit detailed examination of the composite waveform. The frame rate (actually one-half the vertical rate) sweep may be expanded to approximately ten times its normal value, and the time of occurrence of the sweep adjusted so as to permit examination of the vertical blanking interval. Thus, details of the equalizing pulses, the vertical synchronizing pulse, and the vertical blanking signal may be observed. The line rate (actually one-half the horizontal rate) sweep may be increased to approximately three times its normal value, and the time of occurrence adjusted so as to permit inspection of horizontal blanking and synchronizing pulses.

**Picture Monitors.** In many television studio applications there is need for picture monitors without an associated waveform monitor, as provided in the combination units described above. For example, as shown in Fig. 6-3, picture monitors only are used with the preview circuits and for reproducing the outgoing picture signal. In addition, picture monitors are often used for cueing purposes in the announcer's studio, on the floor of the studio itself, in the telecine room, and at the audio console, the sound-effects console, and the lighting switchboard.

For picture monitor applications in studio control rooms, medium-size ( $14 \pm 2$  in.) picture tubes are usually adequate. This stems from the fact that, in this case, the units are generally mounted in a control or a production console, and those concerned are seated relatively close to the picture tubes. For other applications, however, larger picture tubes are essential. For example, a large picture is desirable on the floor of a studio, or in a telecine or master control room where the monitor may be at some distance from those who are concerned with the display.

A studio floor monitor is a utility piece of equipment that is invaluable in a television studio. In addition to providing a professional-type picture monitor for the benefit of those in the studio, it often combines, in a single mobile cabinet, a loudspeaker and a clock. As explained in a following section (Sec. 6-13, *Talkback Cueing System*), the loudspeaker is normally connected to the studio talkback circuit. The picture monitor, however, normally reproduces the program material on the outgoing video line from the studio; if more than one floor monitor is available, the second is sometimes used on an incoming line for preview purposes. On the other hand, if a given production involves several sets, it is often desirable to locate a

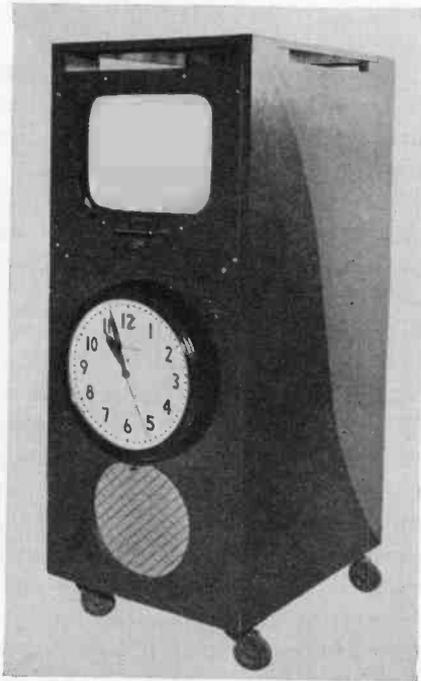


FIG. 6-13. This studio floor monitor combines a 21-in. picture tube, and its supporting circuits, with a loudspeaker and a clock to provide visual, aural, and time information to those involved in the production of a television performance.

floor monitor at each set in order that all concerned may follow the action originating on other sets as well as from film camera chains and remote origination points. A typical unit of the type described is shown in Fig. 6-13.

Small studio monitoring units, consisting only of a picture monitor (although sometimes a small loudspeaker is also included) are often employed to provide the sound-effects man, lighting-panel operator, announcer, and others in the studio with picture information for cueing purposes.

**6-9. Camera Pedestals and Cranes.** In studio work, just as in outdoor pickups, a firm support must be provided for the television camera. In field applications, camera tripods set up in carefully selected locations usually prove entirely satisfactory in spite of the fact there is no easy and quick means of moving the camera from one place to another during the pickup. Studio productions, however, demand ready mobility of the camera at all times and in all directions, both horizontally and vertically since, once a program is started, it must be continued to a conclusion, without any interruptions for new camera or other setups. This method of operation is peculiar to television and is not ordinarily found in motion-picture work. In the latter instance, the photography of a scene can usually be stopped at any point, camera locations redetermined, and the work continued. In television, not only must each program be produced in its entirety but, often, several programs following upon the heels of each other originate from the same studio. This requires that means must be available for easily and quickly moving television cameras from one set to another, which at times may be 100 ft or more away.

In television applications the camera support not only must be readily movable from one location in the studio to another but, in addition, must provide means for smoothly and silently raising and lowering the height of the camera while it is in actual service. Finally, a mechanism must also be available for enabling the operator to turn the camera in any direction horizontally and to tilt it up or down as desired. By one means or another, the camera must be maintained in perfect balance during these operations so that it will remain in any desired position without the need for clamping the movable parts. These latter functions are performed by a camera friction head which is described in Sec. 3-5.

Two basic types of camera supports are commonly used in television studios. One is generally called a camera pedestal or one-man dolly, and the other a camera crane or two-man dolly. As the names imply, only one man, the cameraman, is normally required for operation of the pedestal whereas two men, the cameraman and a crane or dolly operator, are needed for the other unit.

**Camera Pedestal.** A typical pedestal type of camera support is shown in Fig. 6-14. This unit is ruggedly built and is sufficiently heavy to provide a firm and stable support for the camera. In spite of its massiveness, the pedestal can be easily maneuvered into small areas. The wheel crank, extending up from the base of the unit, controls the height of the camera platform which may be adjusted from approximately 40 to 62 in. above the floor. The large wheel, mounted on the pedestal itself, steers the three rubber-tired wheels on which the unit rides. In steering, the three wheels turn in any direction simultaneously by virtue of a chain-drive mechanism that links them together. A small pedal is also provided to raise or lower a swiveled foot that, effectively, raises one wheel and makes the pedestal maneuverable about a fixed point. The triangular base of the unit measures approximately 40 in. on a side and the weight, without friction head or camera, is 450 lb. The mounting arrangement at the top of the pedestal is such as to accommodate a standard television camera friction head.

Camera pedestals are extensively used because of the ease with which they can be handled on the studio floor and their ability to meet a large majority of production needs. However, there is a practical limit to the minimum and maximum heights to which pedestals can be adjusted; further, a pedestal-mounted camera cannot be swung out and over any but the smallest of objects.

**Small Camera Crane.** In order to overcome the limitations of pedestals it is necessary to make use of a considerably larger and more cumbersome structure, namely, the camera crane. A popular type of studio camera crane or dolly is shown in Fig. 6-15. A unit of this kind permits a camera



FIG. 6-14. A camera pedestal with the camera-supporting column partially raised. Units of this type are equipped with large rubber-tired wheels and can be readily moved across smooth studio floors by the cameraman.

to be lowered to within 23 in. of the floor and raised to a height of 74 in. The crane boom on which the camera is mounted is raised and lowered by the inclined control wheel at the base of the boom. A second control wheel, having a vertical shaft, turns the boom turret on the chassis. The mechanical design is such that relatively little effort is required to operate

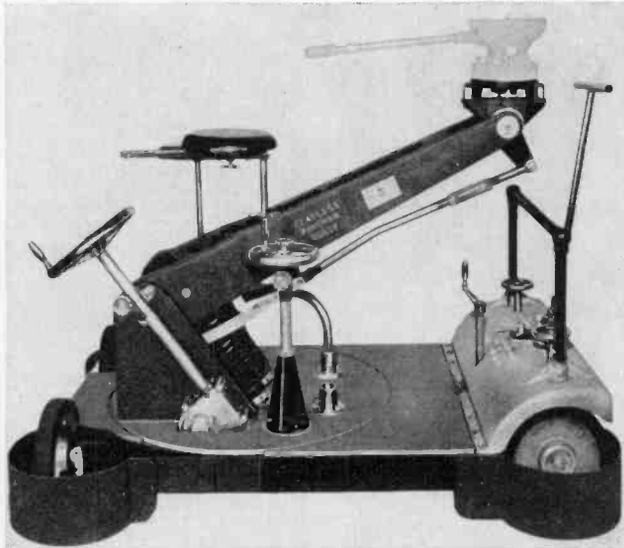


FIG. 6-15. A small camera crane with the camera tongue, which may be rotated in a complete circle, swung toward the rear of the unit. As the tongue is raised or lowered, the table that carries the camera friction head always remains in a horizontal plane. (Courtesy of Houston-Fearless Corp.)

the control wheels. The boom, upon which the camera friction head and the camera are mounted, may therefore be raised, lowered, and swung completely around. This movement, together with motion of the chassis itself, can be smooth and steady as is essential for camera motion that takes place while the camera is in use.

The camera crane illustrated may be pulled back and forth by means of the extension handle that also controls the direction in which the rear wheels of the device are turned. The front wheels may also be turned until they are at right angles to the length of chassis by operation of the single-arm control handle extending up from the base of the chassis just in front of the fixed horizontal railing at the rear of the unit. Operation of this control rotates the front wheels and simultaneously lowers a fifth wheel or caster located at the rear of the dolly. This permits the front of the unit to be swung around while the rear pivots on its caster. Alter-

nately, when the front wheels are turned and the fifth wheel lowered, the dolly may be moved sideways, a feature that is useful for maneuvering into small areas. The chassis of the unit illustrated is roughly 3 ft wide and 5 ft long and weighs about 750 lb. The dolly is usually manned by two operators, one who maneuvers the unit and another who trains and focuses the camera.



FIG. 6-16. A large camera crane which employs electric-drive motors for moving the unit across the studio floor. The platform carrying the camera and cameraman remains horizontal for all positions of the tongue. (Courtesy of Houston-Fearless Corp.)

**Large Camera Crane.** Where the range of height adjustment of the crane described above is insufficient, it becomes necessary to make use of a crane of the type shown in Fig. 6-16. This crane can be lowered until the base of the camera is within about 16 in. of the floor and raised until it is 9 ft high. The turret table is an integral part of the crane and is permanently mounted on the cameraman's platform. It is capable of 180-degree rotation and contains the cameraman's seat, foot pedals for rotating the turret table, and an adjustable friction-type turret lock within the cameraman's reach.

The center post of the crane is a telescopic tube that permits the boom to be swung around or panned a full 360 degrees in azimuth. It can also

be raised 55 degrees or lowered 45 degrees from horizontal, thereby providing a total up-and-down swing of 100 degrees. The turret table remains horizontal regardless of the tilt of the boom. Finally, a hydraulic cylinder, mounted within the telescoping tube, provides a means for raising the boom assembly 15 in. vertically.

The entire assembly may be dollyed back and forth manually or by means of a 2-hp d-c electric-drive motor. A solenoid-operated brake mechanism is also provided so that the motion of the dolly can be remotely controlled, if desired. A control unit containing a motor control, a reversing switch, and a brake control permits various degrees of acceleration and deceleration of the crane's motion along the floor of the studio. The maximum over-all length of the crane illustrated is approximately 13 ft, the base is about 6 ft long and 34 in. wide. The unit weighs about 1,200 lb with camera and personnel aboard. Although it can be moved through a doorway 3 ft wide and 6 ft high and turned in a circle having a 6-ft radius, a crane of this type requires a reasonably large television studio to be used effectively.

**6-10. Microphone Booms.** The constant movement that takes place during a television studio production not only makes it necessary to use easily maneuvered pedestals and cranes for the cameras but, in addition, corresponding equipment must be provided in order that the microphone may also follow the action. If anything, complete mobility of the microphone is more important and more difficult to attain than for the television camera. Should the camera be a little too far from the scene of action, the resulting picture will be slightly smaller than desired, but this deficiency may be painfully apparent only to the program director. On the other hand, if the microphone is too far away from the performer, the sound level may be so low as to be indistinguishable. Poor sound with a good picture is just as annoying as good sound with an out-of-focus picture.

The microphone pickup problem in the television studio is complicated by the need, in most cases, of keeping the microphone out of the field of view. About the only exception to this general practice is for news broadcasts where it is common practice to show the commentator's microphone. In almost all other productions, the microphone is either kept out of the picture area or is concealed in or behind stage properties. Keeping the microphone out of the picture is made difficult by the fact that both the camera and the talent often move about in a large area. Furthermore, when several cameras are trained on a given scene, as is almost always the case, a microphone that is far enough away from the performers to be out of the picture of one camera, may not be for another because of a different camera angle or a larger field of view or both. In order to cope with these

problems, it is common practice to make extensive use of microphone booms—the counterpart of the camera crane.

**Light-duty Boom.** An elementary type of television studio microphone boom stand is shown in Fig. 6-17. The boom portion of this microphone stand includes two telescoping 4-ft sections and may extend so that its terminus may swing in an arc having an 18-ft radius, or tilted upward until the end of the boom is 21 ft above the floor. However, this full range of extension is available only when using microphones weighing less than 1 lb because of the limitations imposed by the counterbalance, the rigidity of the boom, and the friction locks. With a microphone weighing 4 lb (an average weight), the radius of the arc is limited to 9 ft and a height of 17 ft. The minimum radius of the boom is 5 ft.

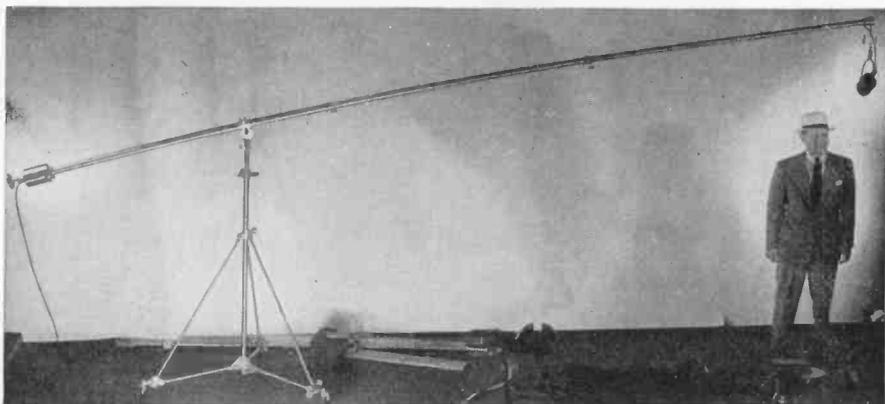


FIG. 6-17. A lightweight microphone boom that is capable of 360-degree rotation and of supporting a microphone 18 ft from the center of the base. (Courtesy of Display Lighting, Inc.)

In practice, a boom of the type illustrated is very useful for applications where it is necessary to suspend a microphone at a considerable height or distance from the point of support. It is not particularly useful for following action on the television stage. This results from the relatively lightweight construction of the unit and, more particularly, because of the lack of means for continuously varying the length of the boom. The former limitation results in a willowy type of motion if an effort is made continuously to adjust the boom during use, and the latter makes it necessary to move the entire stand continually back and forth in order to keep the microphone over the performers.

**Heavy-duty Boom.** The more elaborate type of microphone boom shown in Fig. 6-18 overcomes these two objections. It is actually a boom

and a perambulator and requires two operators in order to take full advantage of its potentialities. The perambulator has three pneumatic-tired wheels, one of which is a steering wheel that swivels in a 180-degree arc. In addition, the steering wheel may be clamped to hold the motion of the perambulator to a given radius. The tiller handle, when pushed back, operates a brake on the steering wheel in order to lock the perambulator in position. The wheel tread of the perambulator can be narrowed to 27 in. to permit passage through a 30-in. door. A hand wheel on the side

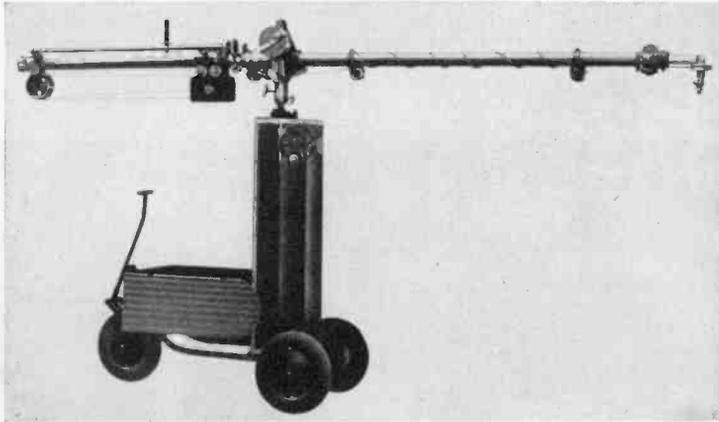


FIG. 6-18. A popular type of microphone boom for television studio applications. The boom may be extended, tilted, turned in a circle, the supporting column raised, and the perambulator wheeled across the floor of the studio as desired. (Courtesy of Mole-Richardson Co.)

of the column raises the pivot point of the boom from a height of approximately  $6\frac{1}{2}$  to  $9\frac{1}{2}$  ft. The operating platform raises with the boom so that the operator is always conveniently located with respect to the boom controls. A hand-operated crank governs extension and retraction of the boom, while a hand rail controls the azimuth and tilt adjustment. The boom may be tilted upward to about a 45-degree angle and may be depressed until the microphone touches the floor.

The boom when retracted operates over a radius of approximately  $7\frac{1}{2}$  ft and, when extended, reaches 17 ft (see Fig. 6-19). When the boom is retracted, the microphone cable is received on take-up sheaves. In addition, the position of a counterweight is automatically adjusted to keep the boom in proper balance at all times. This counterweight is also adjustable to accommodate microphones of different weights. At the terminus of the boom, the microphone is carried by a mechanism that permits rotation through an azimuth angle of 280 degrees. This adjustment is under

the control of the boom operator and is very useful when directional types of microphones are used on the boom, as is often the case in practice. The microphone boom illustrated is made of duralumin tubing of sufficient size to ensure rigidity and absence of whipping effects under any conditions of operation. The total weight of the device is just under 600 lb.



FIG. 6-19. This microphone boom is extended 17 ft, thereby placing a microphone over the scene of action without having to encroach upon the set.

**Microphone Types.** The pickup of sound on a television production is much more difficult than for aural broadcasting because, as a consequence of the practice of keeping the microphone out of the picture, all speech pickup is more or less "off-mike" by aural broadcasting standards. The greater distance that television performers are from the microphone than their aural broadcasting conferees results in a higher ratio of background noise to desired signal. This problem is complicated further by the fact that there is always a great deal more motion, scene changing, and even more people in the television studio than in the aural broadcasting case, all of them potential sources of disturbing noise. Finally, television studios are invariably larger than their equivalent in aural broadcasting and this, in itself, often makes for considerably more noise. In fact, the noise problem in television studio microphone pickup work is sometimes so severe that in some circles background noise has come to be called "foreground" noise.

The use of directional microphones will partially relieve this situation because of their discrimination against sounds originating in directions corresponding to their insensitive zones. On the other hand, noise origi-

nating in one part of the studio may find its way even into a directional microphone by virtue of being reflected from the boundaries of the studio and from the contents therein. By making the walls and ceiling of the television studio highly sound-absorptive, this type of noise pickup can be materially reduced. At the same time, it reduces the ratio of reverberant-to-direct-sound pickup from the performers and tends to counteract the "off-mike" effect mentioned above.

In selecting microphones for a television production, it is important that all units used on a given performance have much the same response characteristic. Unless this is the case, the quality of a performer's voice may discernibly change in going from one microphone to another. Since television productions often take place over considerable studio area, it is not unusual for a given performer to be picked up, at different times, by a large number of different microphone units. This is more likely to occur when concealed microphones are used rather than microphone booms. Concealed microphones, when applicable, are very desirable since they eliminate the need for large and expensive microphone booms and the problems attendant on their operation during a fast-moving production. Small, high-quality microphone units have been successfully hidden in ashtrays, hollowed-out books, desk and table tops, flower bouquets, lamp shades, telephones, and many other stage properties.

**6-11. Studio Audio Facilities.** The audio facilities required for a television studio are, in many respects, similar to those employed for aural broadcasting. The extent of the facilities required for the two services is also similar; *i.e.*, small productions require only moderate amounts of equipment whereas elaborate programs require a great deal. The points of departure between aural and television audio facilities include the need in the latter service for (a) provisions for handling a large number of microphones, (b) synthetic reverberation devices, (c) special types of equalizers and filters, and (d) equipment for the reproduction of recorded sound in the studio *during* the broadcast.

**Quantity of Microphones.** The action during a television production is quite likely to take place over a much greater area than would be the case for an equally pretentious aural broadcast. This is the consequence of television's need for different stage settings to complement visually the thread of the program. In aural broadcasting, of course, the listener's imagination provides the settings and, except for physical and acoustical considerations, an entire audio production could take place before one or two microphones in a relatively small area. If microphone booms and perambulators are used for sound pickup, relatively elaborate television productions can also be staged with a few microphones with two provisos. First, the pace of the action must be such that the microphone booms can

get from one set to another fast enough to keep the performers "on-mike" at all times. Second, the studio floor must be free from camera, microphone, and lighting cables to enable the perambulator operator to wheel the microphone boom readily from set to set. In practice these limitations (or others) often preclude the possibility of handling the entire sound pickup with a few microphones. Instead, because of the relatively large areas covered, quite a number of microphones are likely to be used for television studio productions, as shown in Fig. 6-2. Television studio audio facilities should, therefore, have adequate means for handling a relatively large number of microphone circuits.

**Synthetic Reverberation.** For the reasons enumerated in Sec. 6-10, above, and in Sec. 14-4, *Studio Acoustics*, it is often the practice to build television studios with a relatively low reverberation time. This helps to reduce the studio noise problem and the tendency to excessive liveliness of voice pickup. Although the bulk of the sound pickup in a television studio concerns voices, there are occasions when a musical organization is the center of attraction rather than simply an adjunct to provide mood, bridge, or background music. Under these circumstances the average television studio will be found to be too "dead" acoustically for good musical performance. Preferably, a suitable studio should be used for this type of program production but, where alternate studios, equipped for television production, are not available, resort can be taken to synthetic means of increasing the liveliness of the pickup. To be certain, from the viewpoint of the musician, this procedure is not likely to be popular for a number of reasons but, in an emergency, synthetic reverberation is usually better than a lifeless, abnormally dead sound production.

Furthermore, as in aural broadcasting, there are often situations that require the addition of considerable amounts of reverberation to a voice pickup as, for example, when simulating a scene in a convention hall, a cave, or a dungeon. Television studio audio facilities should, therefore, include means for adding artificial reverberation to any selected incoming source of program material in an amount in keeping with the requirements.

**Equalizers and Filters.** Even though television studios are customarily designed to have a low reverberation time, they are not completely devoid of reverberant effects. This, coupled with the fact that television microphones are customarily farther from the performer than desirable for best results, often makes reverberation a problem since the ratio of direct to reverberant sound may not be in keeping with the scene being presented. When both a close-up and a long-shot camera are focused upon a given scene, the microphone must be far enough away to keep out of the field of view of the long-shot camera. Yet, as the picture is switched from one camera to the other, it is not feasible to change the microphone position.

This situation can sometimes be coped with by switching different equalizers into the microphone channel when cutting from one camera to another. Dialogue, perspective, presence, and voice-effort equalizers may be used for this purpose.

Special audio-frequency filters are also useful devices to include in television studio audio facilities. For simulating telephone conversation, radio communication channels, intercommunication systems, and other sound effects, an adjustable filter will be found very useful. A cascade arrangement of a low-pass filter and a high-pass filter, both with adjustable cutoff frequencies, will provide means for obtaining low-, high- and band-pass effects. By the proper choice of cutoff frequencies, the transmission of the particular audio channel in which the filter is inserted can be restricted to any desired extent. High-pass filters may also be useful in cutting out undesirable low-frequency rumble to which some large studios seem to be prone. Since many of these disturbances are often at very low frequencies, a 30- or 50-cps high-pass filter will prevent them from reaching the transmitter and causing undesirable modulation. If a condition such as this exists, it is important, of course, to verify that the magnitude of the disturbance is not sufficient to cause overloading in an amplifier stage *before* its further transmission is restricted by a filter.

**Reproduction of Recorded Sound.** Unlike the practice in aural broadcasting there is frequent need in television work to reproduce, on the floor of the studio, sound that is recorded on disk, magnetic tape, or another medium. This results from the practice of supplementing studio productions with recorded music for background purposes, for dance routines, for vocal accompaniment, or similar purposes. In still other circumstances, prerecorded voices may be used during a program to convey an actor's thoughts, to give voice to his conscience, or to relate a simulated dream. These types of sounds often must be made audible to the performers for cueing purposes. The studio audio facilities available for *aural* broadcasting purposes often include means for reproducing sound recordings, but usually an interlocking circuit arrangement is used to prevent reproduction of sound in the studio during a broadcast. Television studio audio facilities, on the other hand, must include appropriate circuits for transmitting the recorded program material to the studio whenever desired (*i.e.*, during both rehearsals *and* air programs) as well as to the outgoing audio line.

Since studio microphones may also be in use while the recorded program material is being reproduced, there is danger of an acoustical feedback occurring and causing the circuit to sing. If a conventional studio audio mixing system is in use, a feedback loop may exist from the loudspeaker reproducing the recorded material to a studio microphone (an

acoustical path), through the microphone's preamplifier to the mixing matching network and thence through the circuits and amplifiers leading back to the studio loudspeaker. The possibility of a feedback occurring in this manner may be avoided by special circuit arrangements. One which accomplishes the desired results, without the need of additional amplifiers, is shown in Fig. 6-20. The feature of this circuit is a resistance

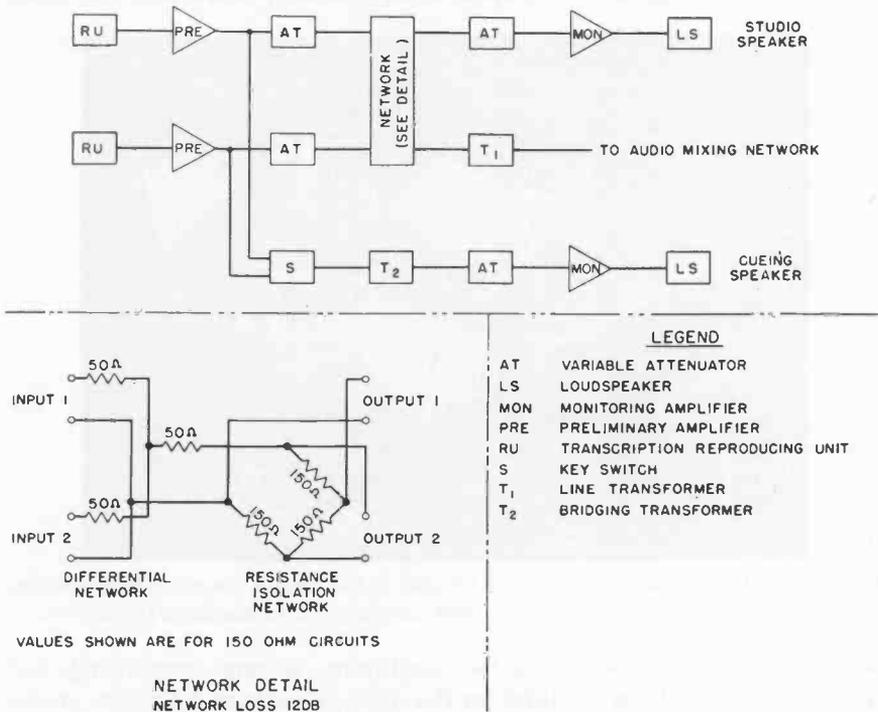


FIG. 6-20. A circuit arrangement for reproducing recorded music or sound effects in a studio while avoiding the possibility of acoustical feedback.

isolation network which affords a high degree of isolation (50 db or more, depending upon the precision of the network resistor values) between two circuits (Nos. 1 and 2) while causing only a 6-db loss between the input of the isolation network and either output. The particular network detailed in the illustration incorporates, in addition to an isolation network, means for combining two inputs into a common channel. This feature adds a 6-db loss so that the total loss of the specific network configuration shown is 12 db.

**Typical Audio Facilities.** Aside from the exceptions mentioned in the above paragraphs, television studio audio facilities are similar to those

employed for aural broadcasting.<sup>1</sup> It is to be noted, however, that government regulations covering the fidelity of television sound transmission parallel those for FM broadcasting more nearly than for AM broadcasting.

Conventional audio consolettes are suitable for many television studio applications, but where elaborate studio productions are undertaken, it is necessary to make use of much more complex studio audio facilities, *e.g.*, those shown in Fig. 6-21. In spite of its relatively small size, the audio



FIG. 6-21. A completely self-contained studio audio control console which contains adequate facilities to accommodate the most complex type of television production.

console illustrated contains all the amplifying, mixing, monitoring, and special-effects facilities required for the most pretentious television studio production. Also, despite its compactness, no sacrifice has been made in accessibility for maintenance and servicing of the various components. The console contains a total of 17 mixer positions which permits the simultaneous mixing of 11 studio microphones, one announcing booth microphone, two turntables, one sound-effects console, and two incoming-program-line channels. Program material for the latter two channels may be selected from any one of six sources by means of push-button selectors. Program material from film sound tracks or from remote program sources is handled by these incoming-line channels as shown in Fig. 6-22.

Two complete and independent program channels are provided. Both include a master gain control and their own volume indicator and moni-

<sup>1</sup> Monroe, R. B., and C. A. Palmquist, Modern Design Features of CBS Audio Facilities, *Proc. IRE*, Vol. 36, No. 6, p. 778 (June, 1948).

toring amplifier facilities. The second channel may be used as an emergency, test, or utility channel. Included are studio talkback facilities, synthetic reverberation facilities, turntable cueing channels, cue circuits for production personnel, cameramen, microphone boom operators, sound-effects filters, and means for utilizing voice effort, perspective, and dialogue equalizers.

**6-12. Sound-effects Console.** Television program production calls for a wide variety of sound effects, and various ingenious and unusual devices have been developed to produce these sounds. Many of the sound-creating devices are mechanical in nature and will not be considered here. The one important electronic unit is the sound-effects console<sup>2</sup> that contains the audio facilities necessary to produce and process the sounds that are in the form of audio-frequency waves.

One of the most prolific and convenient sources of sound effects is the phonograph record. A large library of authentic recordings of various sounds is in existence, and these recordings are regularly employed to create the desired sounds and sound backgrounds for television productions. As the sounds are reproduced from the record, however, they are usually only approximately satisfactory for the purpose in hand. As a result, they often must be modified, filtered, speeded up or slowed down, carefully cued, mixed together, or otherwise processed until just the desired result is obtained. The grouping of all the equipment necessary to do this into one console greatly facilitates the production of the required sound effects. The unit shown in Fig. 6-23 is compact and mobile and can be moved about the studio, or from one studio to another, if desired. It contains three variable-speed turntables and four record-reproducing arms. The mounting arrangement for the arms permits the simultaneous use of two arms on any of the three turntables. This makes it possible to play a record continuously. For example, a sound, such as rainfall, which is to be background for a long scene, may be continuously reproduced from a single record by starting a second pickup at the beginning of the record as the first nears the end. Other effects, such as echoes, may also be created by using two pickups on a single record.

The variable-speed turntables used in this console extend the scope of the sound-effects recordings to a remarkable degree. For example, a recording of an airliner flying at cruising speed may be made to sound like a fast fighter or racing plane by speeding up the turntable. This same record, when operating at slower-than-normal speed, may be used to simulate the sound of a large dirigible. Other records lend themselves to

<sup>2</sup> Monroe, R. B., and Price Fish, CBS-TV Sound Effects Console. Part I: *Audio Eng.*, Vol. 34, No. 3, p. V12 (March, 1950). Part II: *Audio Eng.*, Vol. 34, No. 5, p. V12 (May, 1950).

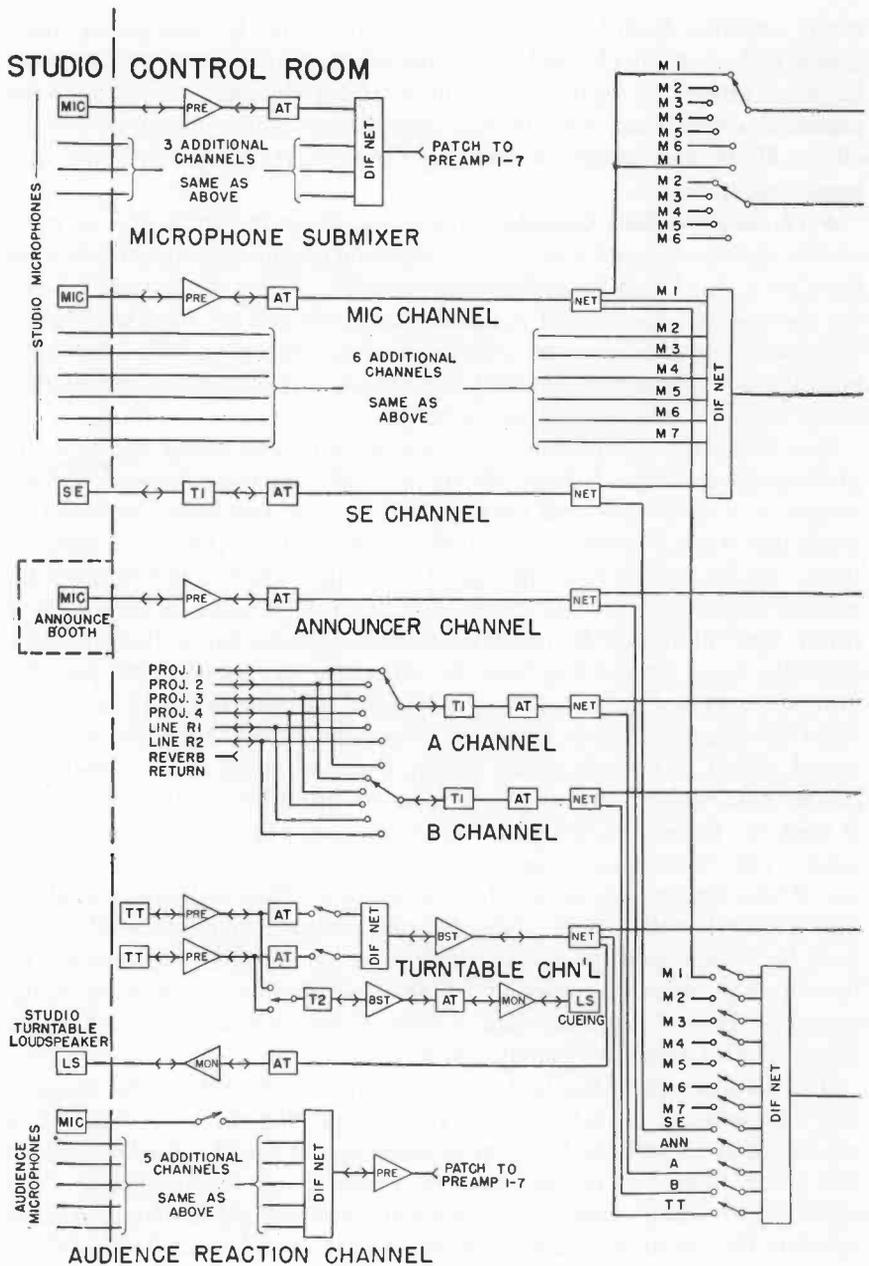
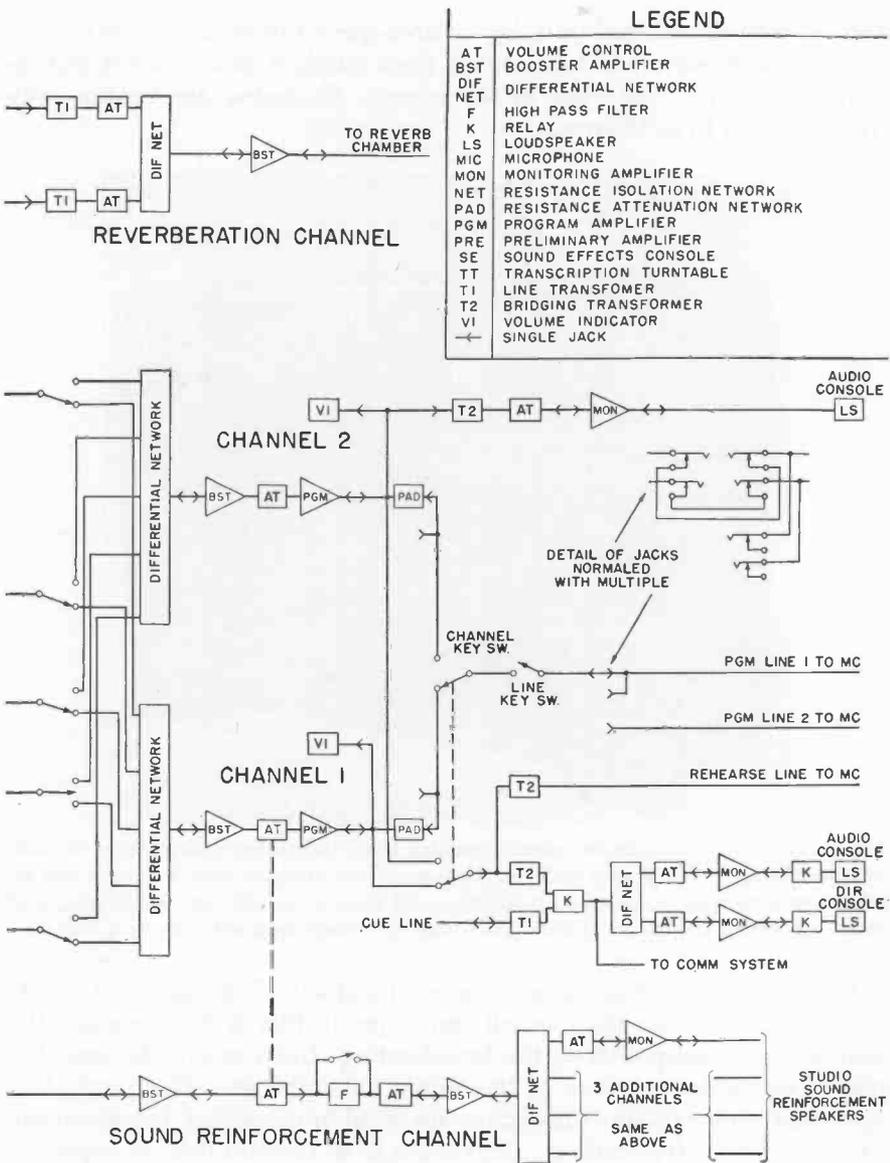


FIG. 6-22. A schematic block diagram of the basic circuits



incorporated in the studio audio control console shown in Fig. 6-21.

this same treatment, and thus the variable-speed turntable may be used to create a large variety of new sounds from standard sound-effects recordings. The units employed in the console illustrated are continuously variable from 10 to 130 rpm.



FIG. 6-23. This sound-effects console contains three turntables, continuously variable in speed from 10 to 130 rpm and four pickup arms so arranged that two arms can be used simultaneously on any one turntable. All mixing, amplifying, monitoring, and other supporting equipment is included within the completely self-contained unit.

In aural broadcasting studios, the usual method of mixing sound effects from recordings into the over-all studio production is to reproduce the sounds on a loudspeaker in the broadcasting studio where the sound is picked up by one or more of the studio microphones. This method of operation, although very satisfactory for aural broadcasting, is not entirely so for television applications. This stems from the fact that microphones on booms are used extensively in the television studio, and their relation to a fixed sound-effects loudspeaker is constantly changing and is completely unpredictable. Consequently, a different method of operation has been developed for television work.

The output of the sound-effects console is transmitted not only to a loudspeaker on the floor of the television studio but, in addition, to the

studio audio console (at normal program transmission level) where it is mixed with the other sources of audio signals accompanying the television program. This latter constitutes the main source of sound-effects signals for the television sound channel. The output of the floor loudspeaker is intended only for the benefit of the performers on the set, and the amount that is picked up by the studio microphones is insignificant.

In addition to sounds originating from recordings, it is the general practice to employ various mechanical devices for creating television sound effects. For example, to ensure proper timing and an authentic sound, use is frequently made of house, screen, and automobile doors, of squeaky windows and doors, of stairs and bare floors for footsteps, of bells, thunder screens, guns loaded with blanks, and the myriad other devices that are the tools of the sound-effects man. For the reasons just described, these sounds must be introduced into the television audio channel and also made audible on the set in use at the moment. The two utility input channels with which the sound-effects console described is equipped are normally employed for this purpose. These channels have sufficient gain to amplify the output of high-quality broadcasting-type microphones to the regular line and loudspeaker transmission levels. Thus, sources of sound other than from recordings may be handled by the sound-effects console and mixed with recorded sound if desired.

**6-13. Intercommunication Facilities.** The planning of really excellent intercommunication facilities is one of the most vexing design problems encountered in a television studio plant. The difficulty stems primarily from the wish of almost everyone in the organization, including the performers, floor directors, cameramen, camera dolly men, microphone boom men, sound-effects men, electricians, camera-control operators, the video switcher, the program director and his assistant, the audio man, telecine operators, master control personnel, and everyone else associated with a production, to talk to each other at some time or another. Furthermore, most of those concerned would like to carry on their conversations without the hindrance of microphones and headsets or of manipulating key switches to set up the desired communication channels. Naturally these desires can be met only to the extent that they are practical from a technical viewpoint; hence the perennial efforts on the part of the design engineer to improve the end result. In view of this, it is evident that too much thought and care cannot be given to the design of an intercommunications system for a television plant.<sup>3</sup>

**System Requirements.** Television intercommunications facilities are construed to include all the equipment and means that are employed to

<sup>3</sup> Monroe, R. B., CBS Television Studio Intercommunication Facilities, *Audio Eng.*, Vol. 34, No. 12, p. V3 (December, 1950).

convey intelligence to aid, direct, or cue members of the television staff or cast in the performance of their responsibilities. This includes the instructions given by the program director as well as by other key personnel in the control room associated with the studio. In addition, the audio portion of the program is equally important to many members of the staff because of the cues that they receive from it. A video picture monitor is also an important source of cues and therefore falls into the classification of intercommunication facilities. This device provides many members of the studio staff with important information. For example, the electrician can employ the unit to check the effectiveness of his lighting arrangements, the audio mixer and the microphone boom men to avoid microphones or microphone shadows in the picture, the sound-effects man to aid in synchronizing his work with the studio action, and telecine personnel to integrate their activities smoothly with those in the studio. Cueing aids, specifically for the benefit of the performers in front of the cameras include concealed radio receivers and written cues that are displayed in their line of vision (but not that of the camera). Thus it is seen that the intelligence transmitted via a television studio intercommunication system may take the form of spoken words, audio program material, written material, and picture program material.

The staff in the studio control room, which usually includes the program director, assistant director, camera-control men, video switcher, and audio mixer, generally carry on direct conversation without the aid of any intercommunication facilities. Further, the monitoring loudspeaker permits all to hear the audio portion of the program. Furthermore, if the basic principles of good control-room design have been followed, all control-room occupants are afforded clear views of the outgoing video line picture monitor as well as the monitors associated with the individual studio cameras. Thus it is seen that television intercommunication facilities serve primarily to convey information to and from those outside of the control room. Five basic systems of aural communication may be employed individually or collectively for this purpose, *viz.*, (a) an interphone system for telephonic communication, (b) a headphone cueing system, (c) a radio-frequency transmission system, (d) a telecine intercommunication system, and (e) a loudspeaker studio talkback and dressing-room call system.

It is from the program director's desk in the studio control room that most of the coordination of a television production takes place. Because of his many responsibilities, it is desirable that his communication with others be undertaken with the absolute minimum of key switch or other operations on his part. Ideally, all that should confront the director is a microphone. When he speaks, all concerned (but not others) should hear him.

In practice this ideal arrangement can be approached but not fully achieved. A few controls are usually provided at the director's position (see Fig. 6-24) for several special, although infrequent, operations as described below. In addition, it is usually desirable to provide a telephone jack into which a headset or a handset may be plugged by the director for two-way conversations with other points that are similarly equipped. It is also good practice to provide the assistant director with independent facilities identical with those provided the director.

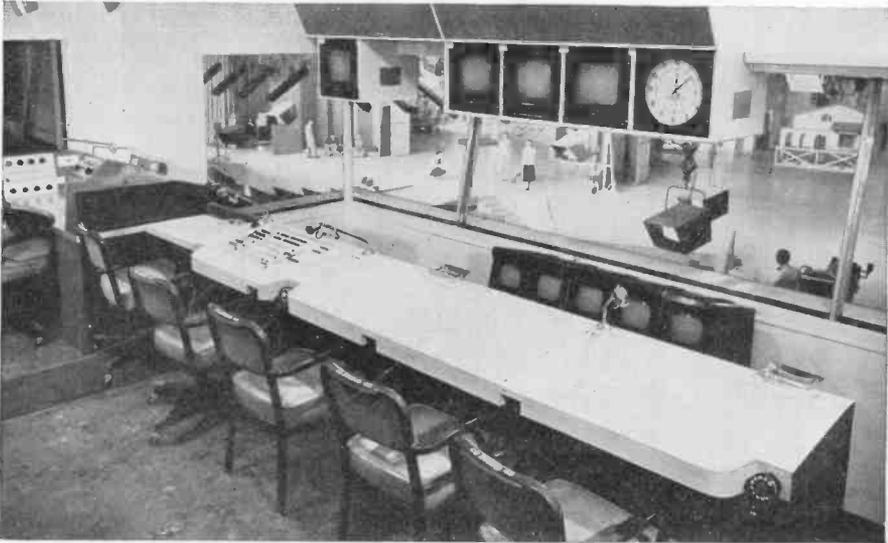
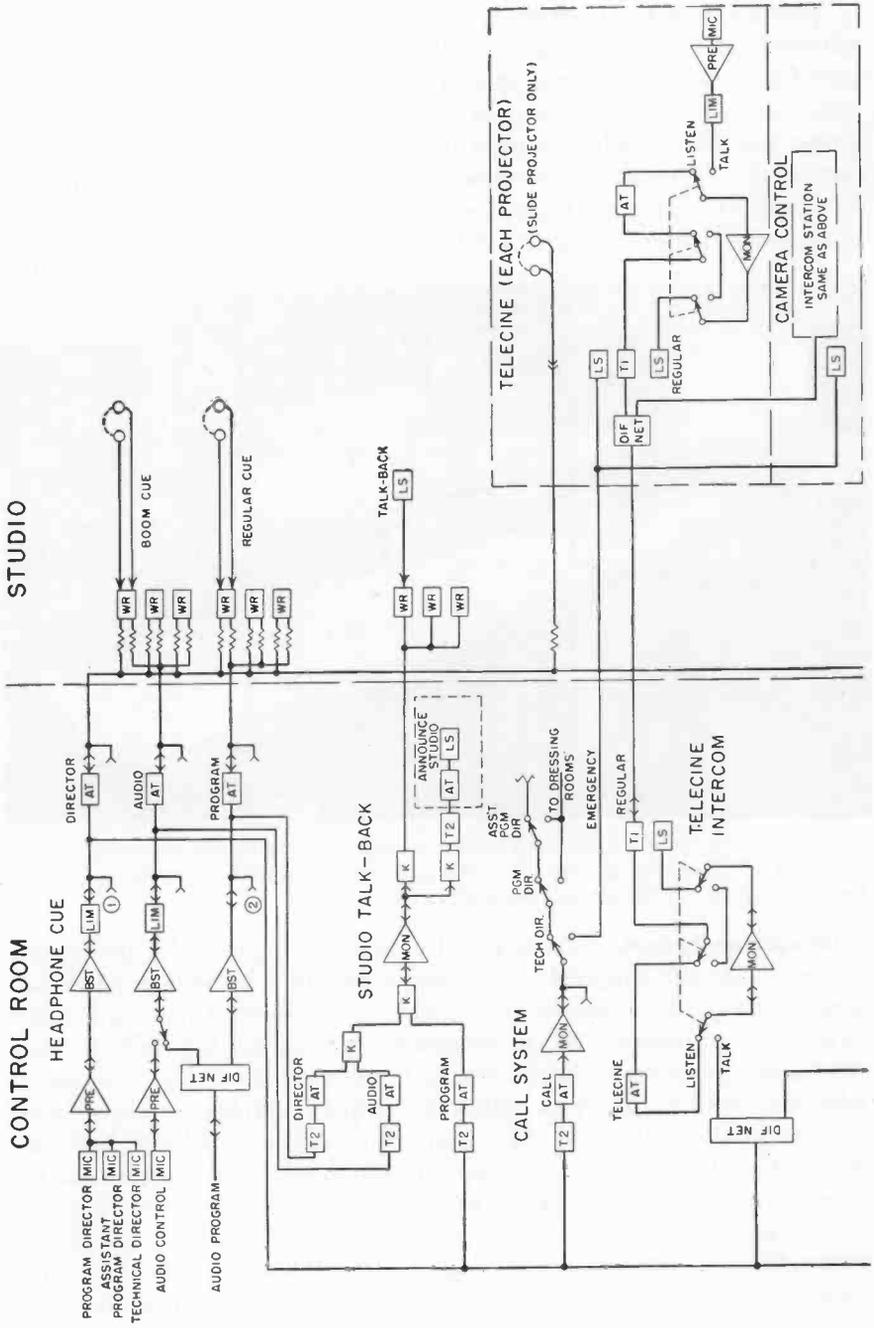


FIG. 6-24. This program director's console in right foreground has been kept as free and clear of equipment as possible. The only controls provided are those required for the operation of the intercommunication system.

**Interphone System.** The terminal equipment required for interphone systems is usually supplied as an integral part of television cameras and certain other video components, such as camera-control units and video switching equipment. When interphone stations are required at other points, the components can be readily installed as desired. In the case of television field facilities, a relatively simple interphone system often constitutes the entire and only intercommunication facilities (*e.g.*, see Sec. 3-4). Although adequate for intercommunication purposes for the simpler types of remote pickups, these basic intercommunication facilities are usually substantially augmented to meet the additional requirements encountered in television studio operations. This supplemental equipment is detailed after the following description of a typical studio interphone system.



STUDIO

CONTROL ROOM

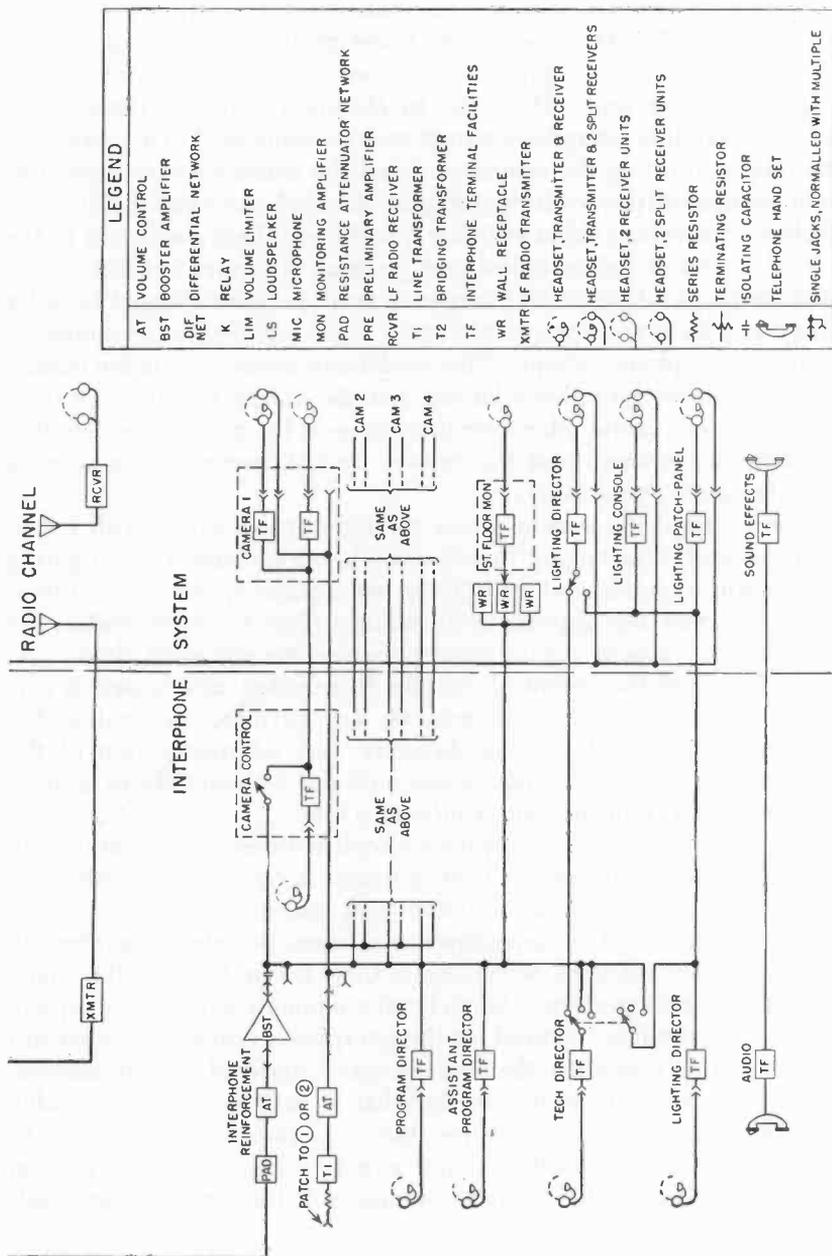


Fig. 6-25. A schematic block diagram of an intercommunication system suitable for use in a television studio.

A schematic block diagram of a television studio interphone system is shown in Fig. 6-25. As shown in the lower portion of the illustration, a private telephone circuit is provided between each camera and its associated camera-control unit. However, by closing a switch at the camera-control position, this interphone circuit may be connected to a conference bus thereby permitting the cameraman and the camera-control operators to be in communication with the program director, the assistant director, the technical director (video switcher), and any others connected to the bus. The voices of the technical and program directors are introduced into the conference bus via an interphone reinforcement channel in order that they may have an appropriate degree of priority over other conversations on the interphone system. This conference connection is the normal one for the camera interphone circuit, but the ability to cut away from this circuit is very useful whenever there is need for private conversation between the cameraman and the camera-control operator (*e.g.*, during camera alignment operations).

A second interphone system serves the lighting personnel with extensions in the studio for linking together the lighting director, the lighting control-console operator, and the lighting patch-panel operator. An extension of this system also appears in the control room to accommodate the lighting director should circumstances require his presence there. As shown in Fig. 6-25 the technical director is provided with a switch permitting the following circuit alignments: (*a*) private conversation between the technical and lighting directors, (*b*) interconnection of the lighting and the main conference busses, and (*c*) isolation of the lighting interphone circuit from the main conference bus.

Finally, there is a private interphone circuit between the audio man in the control room and the sound-effects operator in the studio in order that they may work out any mutual problems that may arise.

It is customary for the cameramen and camera-control operators to employ telephone headsets, which leave their hands free for the many operations they must perform. Some intercommunication systems supplement the single receiver required for the interphone system with a second one that is used to reproduce the audio program material. Many cameramen, however, prefer to hear directly what is happening in the studio. The single receiver headset serves the camera-control operators in the control room adequately, in any event, since the audio portion of the program is available to them by means of the control-room loud-speaker.

Either a headset or a conventional hang-up handset type of instrument may be used by the director, his assistant, the video switcher, and the audio mixer, depending upon the extent to which they have need to use

the interphone. A jack is usually provided at each of these positions to permit the use of either type.

**Headphone Cueing System.** The interphone system described above, while providing a number of auxiliary services, serves primarily as a means of continuous communication between the control room and the studio cameramen. These facilities must, therefore, be supplemented by others in order to effect the cueing that is essential for the operation of a television studio. One of the most important of the additional systems is the one that provides cueing information to persons other than the cameramen, *e.g.*, the microphone boom operators, the orchestra leader, the announcer, as well as the sound-effects man and the lighting personnel. These persons are often provided with a split headset, *i.e.*, one containing two headphones, both of which are connected to separate circuits to permit the reproduction of different information in each. These headsets, unlike the interphone headsets, are not equipped with microphones.

The audio that is applied to these split headsets is often known as *headphone cue*. Two types of headphone cue are sometimes provided: one known as *regular cue* and the other as *boom cue*. Regular cue normally reproduces the voice of the director or his assistant in one of the two headphones, and audio program material in the other. It is normally used by all concerned except the microphone boom operators. Boom cue, on the other hand, also reproduces the voice of the director in one headphone and program material in the other, but the audio mixer in the control room can break into the audio program side of the circuit at will and talk directly to the microphone boom operators. One manner in which these operations may be accomplished is shown in Fig. 6-25. The upper right portion of this illustration represents a studio area within which are located regular and boom cue outlets. Two circuits are brought to each receptacle (each line represents a pair of wires), and separate audio material is applied to each receiver of the headset. Tracing back from these outlets, it is seen that the upper circuit of all outlets is fed from the director's microphone via suitable amplifiers and an associated volume control. The lower circuits from these outlets are fed audio program material except that those from the boom cue outlets may be switched to receive the amplified output of a microphone located on the audio console.

As shown in the illustration it is desirable to provide volume limiters in the amplifier circuits associated with the directors' microphones. This feature compensates for the wide differences in speech level that may be encountered from the various users of the cueing system or, for that matter, from a given person who may speak in a calm manner at one time and shout excitedly at another. Thermistors can be employed to advantage in

volume limiters for this type of service (as can transistors for some of the amplifiers) in order to reduce the number of vacuum tubes, the supporting power supplies, and the maintenance of intercommunication facilities.

**Radio Cueing System.** The interphone and the headphone cueing systems described above provide communication and cueing facilities for most of the studio technical personnel and production staff. Both systems, however, require direct wire connections and therefore restrict the



FIG. 6-26. This floor director wears an antenna over his shoulder that supports a low-frequency induction-field receiver whose output actuates the headphones he wears. Thus he is free to move anywhere on the studio floor and still be able to receive instructions from the program director in the control room.

movement of the persons at both ends of the circuits. This is not a disadvantage in the majority of cases, since most of the studio staff are closely associated with equipment requiring other wire connections. Such equipment includes the cameras, microphone booms, sound-effects console, and

lighting control panels. Other persons, however, notably the studio floor manager, must often be free to move to any part of the studio without the encumbrance of a cable and yet be within the range of the voice of the program director at all times. A radio or an induction-field channel is provided for these persons.

The appearance of the receiving equipment employed in one type of "radio" link is shown in Fig. 6-26. This particular system is an amplitude-modulated induction-field system which operates with a few watts of power in the 100- to 200-kc range. A loop of wire around the perimeter of the studio serves to set up a strong enough field within the studio to provide satisfactory reception with the compact receiver illustrated. Different frequencies, within the band mentioned, are used for systems operating in adjacent studios.

Other types of radio cueing systems employ transmitters operating in the v-h-f portion of the spectrum.<sup>4</sup>

**Telecine Cueing System.** In television studio productions, program material originating from motion-picture film and from slides is often integrated with the material from the studio. For practical reasons, the projection facilities are usually centralized in one telecine room rather than in individual installations in each studio. In any event, the telecine facilities are almost always located elsewhere than in a studio or its associated control room. Under these circumstances, it is necessary to provide adequate intercommunication facilities between the studio control room and the telecine room.

Since a motion-picture projectionist must be free to move about for loading, unloading, and rewinding film, it is desirable to free him of the limitations of a telephone headset and to provide a loudspeaker for cueing instructions. The loudspeaker must be capable of operating at fairly high levels (considerably higher than conventional office-type intercommunication systems) in order to overcome the high noise level that usually exists when several projectors are in operation. One method of providing the necessary facilities is shown by the equipment arrangement in the telecine portion of Fig. 6-25. First, a microphone (usually suspended in a convenient place over each film camera chain), an associated amplifier, and a volume limiter are provided to permit communication *from* telecine *to* the studio control room, where the voice is reproduced by a small intercommunications loudspeaker. Next, a volume control, amplifier, and loudspeaker are provided in the telecine room (usually one over each film camera chain) to reproduce instructions from the director. This circuit is energized only when the director so desires (by operating a

<sup>4</sup> Hathaway, J. L., and R. E. Lafferty, Television Studio Cueing Equipment, *Electronics*, Vol. 24, No. 11, p. 110 (November, 1951).

suitable key switch); thus the telecine loudspeaker does not normally reproduce the almost continuous flow of instructions that the director transmits to the interphone, headphone, and radio cue circuits.

Although loudspeaker intercommunication facilities are usually found preferable for film positions, headphone cue is often considered preferable for slide projector positions. This stems from the need for closer coordination between the operator of the slide projector and those in the control room than in the case of film projector operation. In the latter instance, the projectors are often started and stopped by remote control from the studio control room. By contrast, the slide projector operator must usually set up, change, fade, and superimpose slides at the director's instruction. For this reason, the continuous flow of cueing information on the regular headphone circuit is generally more desirable than the intermittent type of instructions that are given over the film projector's intercommunication system. The manner whereby regular cue outlets may be provided in the system illustrated is also shown in Fig. 6-25.

The telecine intercommunication facilities shown in the diagram are those required for a single-film channel associated with a single studio. Similar equipment is usually provided for each film chain since, during the normal course of operations, various chains are likely to be associated with different studios. Furthermore, means must be provided to switch or patch the intercommunication equipment associated with a given projector to the studio with which it is to work. In addition to all this, duplicate equipment is often required for communication with the camera-control equipment associated with the telecine camera units unless these units are located immediately adjacent to the projection machines or in the control room associated with the studio with which the telecine output is to be integrated.

**Emergency Telecine Communication.** As mentioned above, each film camera location in the telecine room is generally provided with an intercommunication system which must be connected to the system of the desired studio control room. It is the usual practice for the projectionist to set up the circuits to provide communication with the studio with which he is to work. A problem sometimes arises when another studio wishes to communicate with telecine (*e.g.*, for a special test or during routine maintenance) and the circuits in telecine are not set up for communication with that studio. Similarly, the same difficulty arises if the telecine operator fails to arrange the circuits to the studio with which he is to work or if he inadvertently sets them up incorrectly.

One method of establishing communication under these circumstances is by regular telephone. However, the need for communication may be urgent, and the telecine telephone extension may be busy with other

calls. For this reason an emergency telecine intercommunication system has proved desirable in a number of instances.

As shown in Fig. 6-25, the emergency circuits may consist simply of a circuit direct from each studio control room to loudspeakers located where they are clearly audible throughout the telecine area. Under these circumstances, operation of a key switch in any control room permits the director to talk directly to the telecine room. Once attention of the telecine operator is attracted by this emergency circuit, he can set up the regular intercommunication circuits for two-way communication.

**Talkback Cueing System.** The cueing systems described thus far provide aural communication and cueing circuits for all technical and production personnel concerned with a television studio production. There still remains the need for communication to the performers in the studio during rehearsals. This is accomplished by means of a talkback circuit similar to that employed in aural broadcasting studios, which permits the program director and others in the control room to talk to those on the studio floor at any time during rehearsals. Interlocking relays, which disable this circuit when the studio is on the air, prevent the accidental use of this studio loudspeaker channel when the studio is originating a broadcast. Figure 6-25 shows the circuit arrangement of a typical television studio talkback system.

As compared to aural broadcasting studios, television studios are usually quite large and acoustically rather dead. The studio talkback loudspeaker must therefore be capable of producing rather high audio levels, particularly when it is desired to interrupt the playing of an orchestra. Rather than attempt to cover a large studio with a single high-power talkback loudspeaker, it is usually more practical to employ mobile loudspeaker units that can be moved to the area of the studio that is in use. The talkback speaker is often one component of the studio floor monitor described in Sec. 6-8 and illustrated in Fig. 6-13.

## Studio Lighting, Staging, and Camera Techniques

IF TELEVISION were a perfect visual reproduction medium, it would be possible to permit qualified persons to determine, solely upon an artistic basis, the lighting and scenery preparation or staging practices to be followed for television studio productions. Unfortunately, television is not a perfect reproduction medium as yet, and it therefore becomes necessary to temper artistry with technical realities. Television staging practices should be maintained, therefore, within the boundaries determined by governing technical characteristics, if the best possible image reproduction is to be achieved. When this is done, superior television images are obtained, but, when the relatively simple requisites are ignored, the full capabilities of the television system are not exploited and inferior images result. Fortunately, the observance of good lighting and staging practices need not stifle creative aptitude to achieve novel effects. Rather, a knowledge of the practices that achieve satisfactory results serves as a guide to those with creative abilities and aids in obtaining the most from the television medium.

In the following sections there is presented a discussion of the technical program production problems that are unique to television together with a summary of the technical considerations that govern television studio practices. The staging practices that experience has shown to be essential to good television picture production are then presented, and specific procedures recommended. Next, the elements of good lighting techniques are described, and a series of recommended lighting practices of a factual nature are listed. Finally, the camera operating techniques that should be adhered to in order to benefit fully from proved staging and lighting practices are given.

**7-1. Staging and Lighting Problems.** As compared to the legitimate stage or the motion-picture studio, television consumes a tremendous amount of program material. In the course of a day, a single television

station may broadcast, on an elapsed time basis, as much program material as a motion-picture studio would produce in a year's time. To be sure, the television program material may not equal the extravaganzas produced once or twice a year by a major motion-picture studio but the television programs are, for the most part, good entertainment. If they are not, they do not long survive. Similarly, as compared to the theater, television stations are called upon to stage, costume, light, and produce a prodigious number of programs.

In practice this tempo of operation presents certain problems because of time and space separation between the various activities that must be undertaken. For example, the scenery is often prepared and the costumes selected well before the performance date. In addition, lighting is sometimes arranged before the prefabricated scenery is set up although it can be finally adjusted only after the scenery with accompanying stage properties is actually in place. Camera facilities often are activated only during late stages of studio rehearsals. Thus, it is necessary that each group concerned with the production as a whole be guided by rules that allow them to work independently but with the assurance that their work will fit in with that of all other groups. It is much too late, for example, to make any but minor changes in the painting of a set when the lighting group begin their work. Similarly, when the dress rehearsal begins before cameras, it is usually too late to make changes in clothing colors and contrasts in time for the air show. Those responsible for the lighting must therefore be in a position to expect certain basic conditions in the stage setting, stage properties, and performers' clothing. The cameraman must be able to count upon a certain standard of staging, costuming, and lighting arrangements. With these interdependent relationships in mind, there are detailed in this chapter many of the fundamental technical conditions that should be observed in television studio production practices.<sup>1</sup>

**7-2. System Performance Considerations.** Available television transmission and receiving facilities have a number of technical characteristics constituting boundary conditions that should be observed in determining everyday lighting and staging practices. These include (a) total permissible contrast range, (b) shape of the contrast gradient or brightness transfer characteristic, (c) interaction between adjacent picture areas, and (d) detail resolving capability.

**Contrast Range.** The total useful contrast range constitutes one of the fundamental problems that must be given careful consideration if the final picture images are to be optimum. By way of comparison, the ranges

<sup>1</sup> O'Brien, R. S., CBS Television Staging and Lighting Practices, *J. SMPTE*, Vol. 55, No. 3, p. 243 (September, 1950).

of brightness \* values which can be accommodated by several familiar systems are given in Table 7-1. From these data it is seen that, if the determination of brightness range for a television set were left entirely to artistic judgment, a range of 100 to 1 might well result since the eye is quite capable of accommodating this range. Furthermore, if those making the judgments were skilled in motion-picture practices, a 40-to-1 range might result. Although a television system can accommodate this range under ideal conditions, practical considerations make it advisable to employ somewhat lower ranges in everyday operations. Because of the natural tendency, based upon visual artistic considerations, to employ excessive contrast ranges, it may be advisable to set a 20-to-1 contrast range as the goal with the expectation that somewhat higher ranges may result in practice.

TABLE 7-1. LUMINANCE RANGE OF VARIOUS SYSTEMS

	<i>Range</i>
Average human eye—for a particular luminance adaptation.....	100 to 1
35-mm motion-picture film—typical projection.....	40 to 1
Direct-view television—ideal conditions .....	40 to 1
Direct-view television—typical conditions .....	20 to 1
Color-film processes .....	15 to 1

**Brightness Transfer Characteristic.** The nature of the brightness transfer characteristics of the complete television system usually has the effect of increasing the apparent contrast between areas of a scene. For example, the over-all transfer characteristic of a television system, including the camera tube, the picture tube, and all the elements in between, often follows a power law such that a 2-to-1 brightness difference in the original scene manifests itself as a 6-to-1 difference at the receiver. Or putting it another way, the 40-to-1 brightness range that an average monochrome receiver is capable of reproducing may be produced by less than a 15-to-1 brightness range in the studio.

In any determination of the total permissible brightness range, consideration must also be given to the brightness transfer characteristic of the television camera tube. For example, the relation between the video output voltage of the image orthicon tube and the scene brightness is somewhat similar (see Fig. 2-14) to a sensitometric (H & D) curve for photographic film. However, unlike film, the shape of the transfer characteristic curve may be influenced by the level of the illumination incident upon the face of the camera tube. In the image orthicon tube this is true and, in addition, the transfer characteristic is a function of the ratio of the highlights to the average scene brightness and of the adjust-

\* Purists may read "luminance" for "brightness" here and on the following pages.

ment of the target voltage. With this camera tube, it is possible to have compression of one range of brightness values and expansion of another, all in the same picture. This situation calls for careful control of the over-all scene brightness distribution, for correct exposure and for proper camera-control adjustments.

**Interaction between Picture Areas.** To a certain extent some of the foregoing idiosyncrasies of the image orthicon camera tube are caused by the electron redistribution process inherent in commercially available tubes. In addition, this phenomenon often gives rise to several spurious effects in the tube or associated equipment. These, in turn, may be even more objectionable than those relating to transfer characteristics, because of their distinctive and unmistakable appearance. The obnoxious effects of interaction between adjacent picture areas may include:

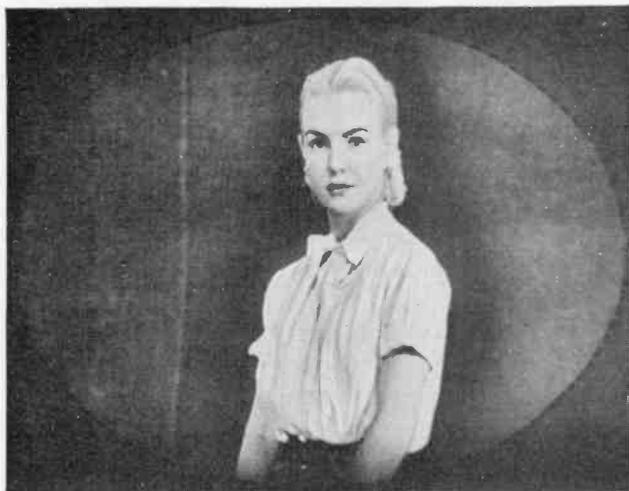
*Halo.* A black area surrounding a bright highlight, resulting from a rain of low-velocity electrons emitted from the highlight area on the image orthicon target, particularly severe around highly polished jewelry, white clothing, and similar objects in front of a dark background (see Fig. 7-1a).

*Image Orthicon Ghost.* A spurious, displaced image of a highlight area, most noticeable with marked contrast between highlight and background, resulting from high-velocity secondary electrons emitted from the highlight area on the image orthicon target (see Fig. 7-2a). Unlike the more common television ghost that is caused by a reflection, image orthicon ghosts are displaced from the ghost-producing area in a counterclockwise direction. The ghost may therefore appear to the right, to the left, above or below the ghost-producing object, depending upon the location of the latter upon the face of the image orthicon target. Furthermore, the displacement of the ghost from the original object is proportional to its distance from the center of the target.

*Clouding.* An electronic fogging or mottling of large dark areas similar in effect to lens flare and particularly severe where excessive contrast exists between large dark and large light areas and aggravated by the tendency of multiplier electrode spots to show through in dark areas (see Fig. 7-3a).

*Streaking.* A dark or light horizontal streak across the picture in line with excessively bright highlights or long, heavy scenery lines, usually resulting from improper low-frequency characteristics in the transmission system (see Fig. 7-4a).

These effects can all be reduced or adequately hidden (as shown by the illustrations) by the same careful control of staging, lighting, and camera



(a)

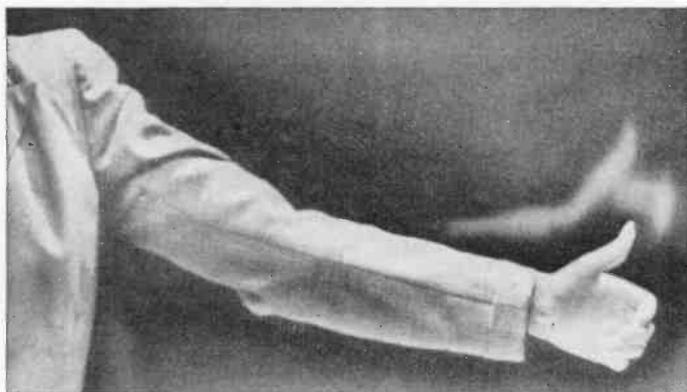


(b)

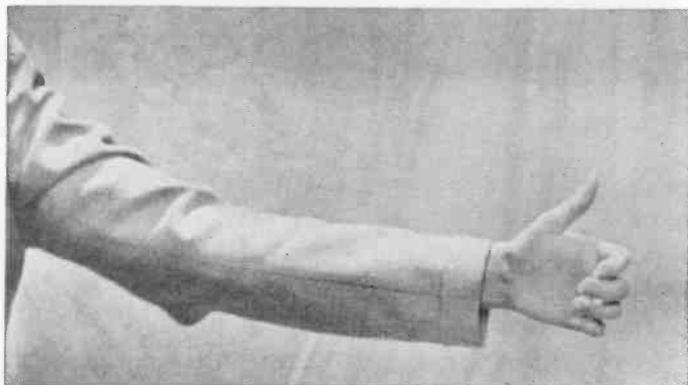
FIG. 7-1. A bright highlight on a dark background may result in an image orthicon halo as shown in (a) that can be avoided (or at least markedly reduced) by the employment of lighter backgrounds, as shown in (b).

operation that is required for working within the useful total contrast range and in obtaining good brightness transfer characteristics.

**Detail Resolving Capability.** The detail resolving capabilities of the television system depend upon a large number of factors, and a categorical statement cannot be made as to its ultimate potentialities. Indications are that the system is capable of resolution equivalent to 35-mm motion-



(a)

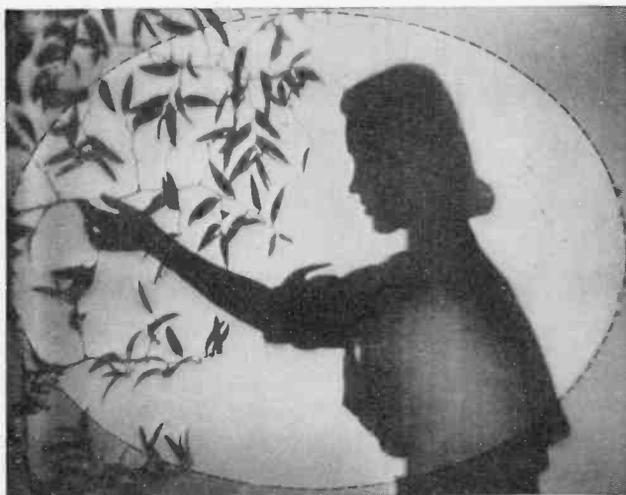


(b)

FIG. 7-2. Image orthicon ghosts such as shown in (a) can usually be eliminated by correct staging and lighting as shown in (b).

picture reproduction. However, depending upon a number of elements, commercially available transmitting and receiving equipment often delivers performance that may be considered to fall between the capabilities of 16- and 35-mm motion-picture film. On the other hand, when maintenance and operation techniques languish, television picture reproduction can be as poor as subnormal 16-mm film.

Fortunately, good resolution is aided by the same staging and lighting techniques required by the considerations already mentioned. For example, some of the defects of clouding may be minimized by image orthicon beam defocusing. On the other hand, proper control of scenery preparation and lighting avoids the creation of clouding effects in the first place. Consequently there is no need for degrading the potential performance of the camera in order to hide (or minimize) a defect of this



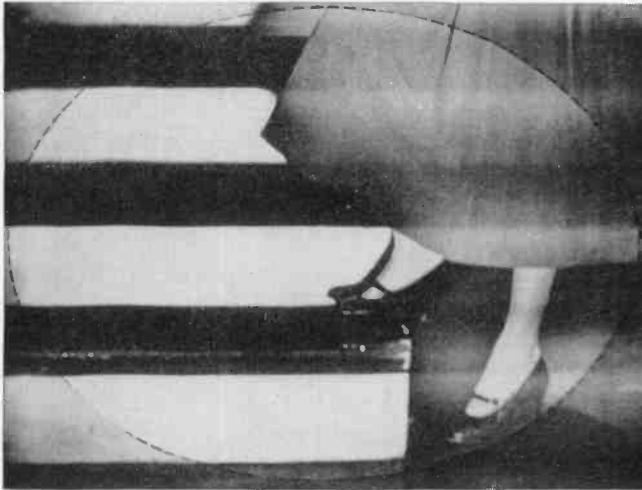
(a)



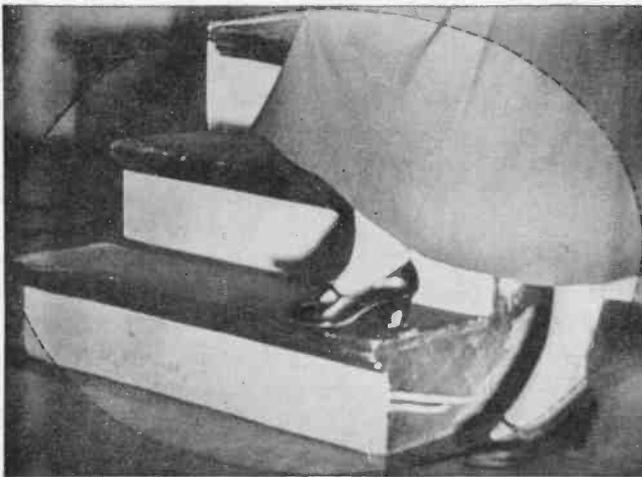
(b)

FIG. 7-3. The electronic clouding of large dark areas and the dynode spots evident in (a) can be eliminated by reducing the contrast range between large adjacent areas as shown in (b).

type. Again, an image orthicon ghost may often be minimized by image defocusing in the camera-control unit. However, if the staging and lighting are properly undertaken in the first place, the creation of image orthicon ghosts can be greatly minimized. In this manner the camera can be adjusted for peak performance rather than the compromise that is



(a)



(b)

FIG. 7-4. One method of minimizing the tendency for streaking of the type shown in (a) is to avoid prominent horizontal lines in the composition by the proper choice of camera angles as in (b).

likely to be necessary if the boundaries that should be observed are exceeded.

**7-3. Staging Practices.** In an image orthicon camera, the various spurious effects and the modifications of the brightness transfer characteristics mentioned in the preceding section are considerably aggravated by overexposure, *i.e.*, by too much light on the photocathode of the tube.

When this condition occurs, it is theoretically possible to correct the situation by reducing the iris opening on the camera lens. In practice, however, because of the pace of the average television production, there is seldom sufficient time for this operation except in those installations where control of the camera lens iris can be undertaken by remote control from the camera-control unit.<sup>2</sup> The cameraman himself is seldom in a position to perform this adjustment even when the lens iris control is within easy reach because of his preoccupation with training and focusing the camera. Accordingly, one of the principal objectives of good studio practice is the establishment of uniform brightness ranges throughout a given production and the maintenance of conditions that are within the capabilities of the television transmission system. This procedure greatly relieves the need for additional, critical adjustments of the cameras and their associated control circuits during the height of a program production.

From a purely technical viewpoint, a scene with flat lighting is the easiest to handle. However, from an artistic standpoint as much contrast as possible is often desired, particularly in monochrome transmission, to provide scope for artistic expression, illusion of depth, and establishment of mood. However, it is important that the technical, staging, lighting, and program direction groups all recognize the need for becoming accustomed to the somewhat reduced brightness ranges that are adequate for television as compared to motion-picture or legitimate stage productions.

By respecting the conditions that prevail, it is possible to obtain good quality and expressive pictures and to obtain them consistently. The general approach is to tell less of the story with brightness difference in the studio and more with form and character of the staging and lighting. When properly understood, the television system's characteristics may be used to advantage since much smaller contrasts in scenery, costuming, and lighting suffice than in motion-picture and stage practice.

Television also offers an outstanding advantage over photographic methods, namely, the means for immediately observing the effect obtained. Judgments based upon the display on the picture monitor automatically take into account the effect of the television system upon the original scene's appearance. This being the case, there is little excuse for an informed production group to produce inferior pictures on the air.

In the following paragraphs the various factors pertaining to scenery preparation that have a bearing upon the final television image are discussed in detail, and recommended operating practices are formulated.

**Scenery Reflectance Range.** For the purpose of the present discussion the reflectance of a scenery element is taken as the nonspecular reflectance

<sup>2</sup> Pourciau, L. L., *Television Camera Equipment of Advanced Design*, *J. SMPTE*, Vol. 60, No. 2, p. 166 (February, 1953).

averaged over the range of wavelengths to which the camera tube is sensitive. This type of measurement can be readily undertaken with the aid of a camera chain by comparison of the surface in question with a calibrated gray-scale step-wedge (see Sec. 7-7). This method automatically takes into account the spectral distribution, the surface texture, and the characteristics of the camera tube.

In considering scenery reflectance values, it is important to bear in mind that it is the product of the scenery reflectance and the incident light that actually registers on the camera tube. In other words, control of the scenery tone value range is only part of the entire problem. Consequently, recommended practices must be formulated on the basis of a reasonable division of the problem between staging and lighting procedures.

As a rule, the most important objects in a television scene are people. It is wise, therefore, to adjust other parts of the scene to obtain pleasing rendition of flesh tones. The alternate approach would be to make up the performers to complement the scenery. In practice it is simpler to paint the scenery correctly (it has to be painted anyway) and thus to minimize the make-up problem.

White flesh reflects 30 to 40 per cent of the light incident upon it. In high key scenes, basic scenery elements should be allowed to reflect only slightly more, say 50 per cent. In low key scenes, the basic scenery re-

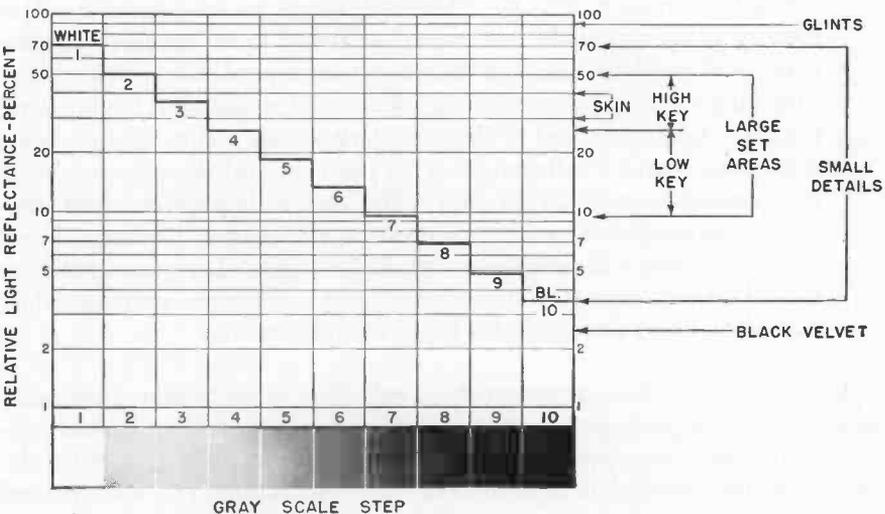


FIG. 7-5. Suggested reflectance value ranges for various subjects are listed at the right. The ranges indicated are those measured through a camera system, thus taking into account spectral distribution and surface texture.

flectance should be at least one third to one fourth as much as for flesh, say 10 per cent reflectance as a minimum. These limits allow only a 5-to-1 range for basic scenery reflectance values and, as shown by Fig. 7-5, include gray-scale steps Nos. 2 through 7. In practice, variations in illumination levels throughout the set may extend this range to perhaps 10 to 1. It is necessary to limit the range for larger areas (as seen in the television picture) to ensure good skin tones, to allow for camera dependence on average scene brightness, and to anticipate some variation in lighting intensity in different parts of the set.

For small details and features on the set, extreme white step No. 1 and extreme black step No. 10 may be used. The contrast range between these values is 20 to 1 but, again, because of uneven illumination levels throughout the set, this range may actually be considerably extended in practice. It is to be noted that the extreme values suggested are very nearly the practical limits of reflectance obtainable with flat paints.

Restriction of tone values to 10 steps (6 steps for large areas) has worked out very well in monochrome television practice and is in keeping with the tonal reproduction capabilities of the television system as a whole. Relating scenery tone values to those of a standard step-wedge gray scale has the advantage that the numbered steps may be made the basis of a precalibration system for rating various scenery paints and materials (see *Use of Color* below).

*Staging Practice No. 1.* The total range in brightness used in scenery painting should not exceed a 20-to-1 ratio between extreme white and extreme black or between colors producing such effects. This range should be covered in not over 10 steps, each having a reflectance  $\sqrt{2}$  times that of the next darker step. The extreme white step should have a reflectance of 70 per cent and the extreme black step a reflectance of 3.5 per cent. The gray scale on a standard step-wedge gray-scale chart may be used as a reference, the steps being numbered from 1 for white through 10 for black. Large areas of a set should be held between steps Nos. 2 and 7 inclusive, extreme white and black being used only for small accent features.

**Use of Color.** The representation of colors by tones of gray (necessary in monochrome photography and television) is a very complicated subjective process. For example, the appearance to the eye of a color depends on the spectral composition of the illumination and the spectral reflectance of the colored surface. Colored surfaces reflect light of many wavelengths and have a certain subjective color effect which corresponds to the dominant wavelength. The same apparent predominant wave-

length (or color) may be obtained with any of a number of different incident light and reflectance combinations.

A monochrome television system, on the other hand, interprets colors only as tones of gray. Here the spectral composition of the light, the spectral reflectance of the object, and the spectral response of the television system must all be multiplied together and integrated in order to determine the gray tone obtained. With all these factors involved, it is not surprising that, in television (and photography), colors sometimes come out a lighter or a darker shade of gray than might be expected. With modern television camera tubes, the orthodoxy of color-to-gray rendition is, however, quite satisfactory as long as reasonable limits are observed. Variations between camera tubes are negligible, and relatively small differences result from the use of fluorescent and incandescent illumination.

On the other hand there is a natural tendency to confuse color contrast with brightness contrast. Although two juxtaposed complementary colors may appear visually to be widely different in brightness, this effect may be wholly a matter of color contrast and not an actual reflectance difference. When translated into terms of gray, as in a monochrome television system, the two colors may appear exactly alike. Several cases are known of complete sets that were carefully worked out in beautifully contrasting colors only to appear on the picture monitor as essentially all one shade of gray. This illustrates the tendency of the eye to confuse color contrast with brightness contrast and, unaided, to be a misleading judge of staging propriety. Because of the difficulties in predicting results analytically and of the ease in checking conditions experimentally, it is recommended that television scenery colors and materials be precalibrated. A limited number of standard paints and surfaces may be selected and a sample card made for each one. These cards may then be held next to a standard gray-scale chart and observed through the television system under both incandescent and fluorescent light. The gray-scale numbers which most nearly correspond to the appearance of the sample as viewed on the television monitor may be noted on each card for each type of light. The sample cards should include, as well as saturated colors, all grays and color shades to be used. Subsequently, it will usually be sufficiently accurate to match scenery paint to these samples by eye or by a light meter used to measure reflected light.

The results obtained with a particular group of 25 color samples is shown in Table 7-2. This table lists the colors in ascending order (light to dark) of their gray-scale equivalent. This table of gray-scale equivalents is presented as an example of the results obtained with pigments of a particular brand and is not presented as working values to be used for other pigments. Rather, it illustrates the type of data that may be ob-

tained for the standardized colors used by a scenic design department. It also serves to illustrate how marked different color contrasts result in much the same brightness contrasts.

TABLE 7-2. GRAY-SCALE EQUIVALENTS OF SOME PIGMENTS

<i>Sample color</i>	<i>Scale step</i>	<i>Sample color</i>	<i>Scale step</i>
Lemon yellow . . . . .	2	Hanover green . . . . .	5
Chrome yellow (light) . .	2½	Harrison red . . . . .	6½
Chrome yellow . . . . .	3	Purple violet . . . . .	7
Chrome orange . . . . .	3½	Maroon . . . . .	8½
Yellow ochre . . . . .	3½	Malchite green . . . . .	8½
Golden ochre . . . . .	4	Burnt umber . . . . .	8½
Cerulean blue . . . . .	4	Burnt sienna . . . . .	8½
Cobalt blue . . . . .	4	Brown lake . . . . .	8½
Raw sienna . . . . .	4	Prussian blue . . . . .	9½
Vermilion (light) . . . . .	4½	Raw umber . . . . .	9½
Red . . . . .	5	Chrome green (deep) . .	9½
Magenta . . . . .	5	Black . . . . .	9½
Ultra blue . . . . .	5		

It is to be noted that a monochrome television system will perform equally well on gray painted sets as on colored sets. Color is more difficult to use than monotone values but can be used safely if the above procedure is adopted. The use of color is a valid means for making performers feel at home—even for helping to create a certain mood for the cast. However, its use can only result in tones of gray through a monochrome system and so should be kept simple and straightforward.

*Staging Practice No. 2.* Color may be used to obtain the various tone values in scenery and at the same time provide a more natural environment for performers. Generally, saturated colors are rendered by the television system into gray in accordance with the accompanying tabulation.

<i>Saturated hue</i>	<i>Monochrome appearance</i>	<i>Gray-scale step</i>
Violet	Black	8-10
Blue	Dark gray	5-8
Green	Light gray	2-5
Yellow	White	1-2
Orange	Light gray	3-4
Red	Light to dark gray	4-8

To achieve uniform reproduction, samples of all scenery colors, paints, and materials should be observed over the television system and numbered in accordance with the nearest gray-scale step.

**Extreme White and Black Areas.** The inclusion in every television scene of small areas of extreme whites and blacks is very helpful in the maintenance of correct video transmission levels throughout the transmission system. The signals corresponding to these areas may be used for monitoring the transmission on the waveform monitors throughout the system.

From Fig. 7-5 it will be noted that even low key scenes should be centered at a relatively light gray-scale step (No. 5). This is desirable because of the tendency of the television system to run the dark tones together toward black. However, more important than average tone in establishing key effect is the proper relative placement of dark and light areas and the use of form and pattern. In any event, regardless of average tone, the inclusion of small areas (or objects) having extreme black or white tone values (reflectance and light level are both involved here) serves to give snap and interest to a picture.

*Staging Practice No. 3.* At least a small area of both extreme white and extreme black should be included in every scene to aid video level adjustments.

**Adjacent Area Tone Relationships.** Spurious electronic effects in the image orthicon camera tube are most noticeable where large contrasts are present. For example, the inability of the image orthicon tube to maintain high contrasts over large areas is shown by Fig. 7-3a where clouding within the silhouette is clearly visible. A contrast ratio of 35 to 1 was used for this example. The effect will be recognized as being similar to lens flare; however, in the illustration it is entirely electronic in nature.

The effect of electron clouding can be relieved to a degree by reducing the contrast range between large adjacent areas. This is shown by Fig. 7-3b, which is similar to the first illustration except that the contrast ratio has been reduced to only 5 to 1. The clouding effect has now been materially reduced, and a pleasant silhouette effect is seen to have been achieved.

The reverse situation, namely, bright objects in front of dark backgrounds, creates equally severe problems. Therefore, the transition between areas differing greatly in tone should be made by interposing several intermediate steps. If this is not done, the large cloud of excess secondary electrons resulting from the large white area will fall back upon adjacent dark areas and create the black halo effect shown in Fig. 7-1a.

An intermediate tone area produces its own charge which tends to repel the excess electrons and minimizes the difficulty (Fig. 7-1b).

*Staging Practice No. 4.* The reflectance of relatively large (as seen by the camera) adjacent areas should not differ in tone value by more than 2 to 1 (two steps on the standard gray scale).

**Large Monotone Areas.** It is difficult to render properly large monotone areas over a television system because of the spurious electronic effects that such areas often create in the camera pickup tube. A large curtain, for example, is rendered best if it falls in shadowed folds, better yet if the material has a simple pattern. Bare walls of rooms may be painted to give a wallpaper effect; outside walls may be painted to represent brick, fieldstone, and other textured surfaces. If a large, unbroken area must be used, it should be relatively light in tone in order to minimize electronic effects which may cause a splotchy and cloudy rendition. At the same time, it should not be materially lighter than flesh tone or it may cause adverse effects on the rendition of the performers.

*Staging Practice No. 5.* Extremely large monotone areas, particularly those which are dark, should be avoided. If unavoidable, very large areas should be broken up by a pattern and should be light in tone (e.g., gray-scale steps 2 to 4).



FIG. 7-6. This scene was especially prepared to illustrate the undesirability of employing excessively busy backgrounds for television stage settings. (Courtesy of Eastman Kodak Co.)

**Background and Floor Detail.** Excessively busy backgrounds are not only a waste of painting time but are also confusing in television production. However, a compromise will sometimes be necessary where the same area will be viewed both as a close-up and as a long shot.

Linoleum, rugs, tile, and other floor coverings should also have simple patterns (see Fig. 14-6.). In addition they should be light in tone, not only to reduce random mottling from spurious electronic effects but also to assist in lighting by reflecting more light up into the shadows created by normal overhead lighting.

*Staging Practice No. 6.* Details which appear in long shots, including walls, floors, and stage properties, should be kept broad and simple. In addition, floors should be finished in light tones.

**Horizontal Structures.** It is sometimes difficult to prevent streaking from horizontal lines and structures (Fig. 7-4a) on a television stage set. Low walls, parapets, fences, and similar features, for example, should be broken up by painting them to represent stone or brick or by covering them with vines, ropes, nets, or other textured material. In addition, it is advisable to have any long lines run vertically or diagonally (20 degrees from horizontal or more, as seen in the camera), as shown in Fig. 7-4b. It should be recognized that it is the horizontal details as seen through the television camera that require attention. For example, a short, fine line on a wall representing a molding may be almost unnoticeable in a long shot but may become a heavy and objectionable horizontal line in a close-up.

*Staging Practice No. 7.* Continuous horizontal lines or structures of either dark or light tones should be avoided or broken up by a pattern or texture.

**Paint Type and Application.** In order to avoid specular or mirrorlike light reflections, which may cause halos, image orthicon ghosts, and other undesirable effects, glossy paints should be avoided. Instead, flat oil or water-base paints and dead-flat lacquers should be used. For example, kitchen cabinets, stoves, refrigerators, and other appliances that normally have a high-gloss surface may be refinished with an off-white, buff, ivory, or yellow flat paint. In monochrome transmission the color used is not critical, the object being to reduce the high specular reflectance of the porcelain or enamel surface by providing a matte surface. The light reflected from the surface should not exceed 60 to 70 per cent of the light incident upon it.

Where an object with a highly polished finish is brought into the studio for a single appearance, it may be refinished in water-base paint to facil-

itate removal of the paint. Or, if this is not practical, it may be given a sprayed coating of a low-gloss wax in order to reduce the specular reflectance.

Where the effect of catch lights is desired in painted stage scenery, it may be obtained by appropriate shading with low-gloss paint. This is an example of where the extreme white tone may be used to advantage. In order to avoid a splotchy or uneven surface rendition, all paint should be applied evenly, stippling and incomplete spray coatings being avoided.

*Staging Practice No. 8.* A low-gloss paint should be used for all scenery painting and should be applied in an even manner.

**Stage Properties.** Extremely dark stage properties should be avoided. Pianos are particularly troublesome because of their customary dark finish, high gloss, and large unbroken areas. Pianos and other large pieces of furniture regularly used on television sets should be refinished in a matte-surfaced medium gray or brown (about No. 6 on the gray scale). Where



FIG. 7-7. A mirror placed so as to reflect the keyboard of a piano is of considerable assistance in reducing the normally high contrast between the keyboard and surrounding dark areas. (Courtesy of KTTV, Los Angeles.)

this is not possible, the effective brightness of an object of this kind can sometimes be increased by adding diffuse lighting. A piano keyboard is a particularly critical point. A properly placed mirror (Fig. 7-7) or a light finish on the bottom of the keyboard cover will help by reducing the usual high contrast between the keyboard and adjacent areas.

The strong reflections from papers used for scripts, letters, placards, newspapers, photographic prints, and similar properties may also cause black halos, image orthicon ghosts, streaking, and other spurious effects.

An off-white or buff material with a matte surface should be used for this type of stage properties.

*Staging Practice No. 9.* Extremely dark, highly polished furniture and similar stage properties should be avoided. Scripts, letters, posters, and photographs should be printed on off-white or buff-colored, matte-surfaced paper.

**Exposed Lights and Flames.** Flames, even from small candles, act like extreme highlights and produce black halos, image orthicon ghosts, and other spurious effects. About the only technique that will keep this problem at least partially under control is to place the flames in front of light-toned and well-lighted backgrounds.

*Staging Practice No. 10.* Direct camera pickup of exposed lights and flames (candles, matches, etc.) should be avoided. If unavoidable, such lights or flames should be placed in front of medium- to light-tone backgrounds.

**Clothing.** A starched white collar, shirt, blouse, or cuff may have as much as 90 per cent reflectance and will produce the same ill effects mentioned in the preceding two discussions. Usually, however, since the effect is often very near to if not on the face of the performer, it is exceedingly distasteful. To avoid the black halo and ghosts (Figs. 7-1a and 7-2a, respectively), white clothing should be avoided entirely and an off-white, buff, light blue, yellow, or tan-colored material employed.

The undesirable effects are aggravated when white clothing is adjacent to or in front of a dark background. White handkerchiefs in the breast pocket of a dark coat, white shirts adjacent to dark coat lapels, white dresses in front of a dark background, and other similar combinations all tend to produce black halos and image orthicon ghosts.

Dark solid-toned suits and dresses should also be avoided. Tweeds, coarse herringbones, plaids, and simple broad patterns are generally satisfactory. Tans, light blues, and grays with simple patterns and textures are preferable. However, color combinations such as blue-red or green-orange may not show the patterns as well as colors upon a buff, yellow, or gray background. Patterns in tones of a single color are usually particularly effective. The average tone of clothing should be only slightly above or below that of the skin in order to avoid marked contrasts between a performer's face and his clothing.

Sequined materials, satin, patent-leather shoes, belts, handbags, and other accessories should be avoided because of the likelihood of specular reflection. Performers habitually wearing eyeglasses should have the lenses treated with anti-reflecting coatings.

*Staging Practice No. 11.* White, highly reflective clothing, tablecloths, bedspreads, uniforms, and accessories should be avoided in favor of light blues, tans, grays, yellows, and pinks.

***Jewelry and Musical Instruments.*** The strong, almost 100 per cent, specular reflection or glint obtained from jewelry, musical instruments, and other highly polished metallic objects causes strong black halos and very bad image orthicon ghosts. In addition they may cause streaking and confuse monitoring signal levels. Low-gloss jewelry, including watches, should be used. Various wax-spraying and talcum-dusting techniques are effective in reducing the reflections from glossy objects. If highly polished objects are unavoidable, some relief may be obtained by placing them in a completely diffuse field of light and against a light background.

*Staging Practice No. 12.* Highly reflective jewelry, musical instruments, and other objects should be avoided. If they must be used, they should be wax-sprayed or otherwise treated to reduce reflectance. If reflective objects are placed in a diffuse light with a medium to light background, some relief from undesirable spurious effects may be obtained.

**7-4. Lighting Practices.** If full benefit is to be derived from the scenery preparation staging practices recommended in the preceding section, it is essential that complementary lighting practices be followed. As a matter of fact, the staging practices themselves are predicated upon the expectation that certain fundamental lighting practices will be followed.

The several fundamental characteristics of a television transmission system which call for lighting techniques of a specialized nature were mentioned in Sec. 7-2. From a lighting viewpoint the brightness transfer characteristic of the camera tube and the permissible contrast ratio are of particular concern. The former is amenable to control by providing over-all scene brightness that is as uniform as practical, the latter by holding the reflectance of objects within specified bounds or by controlling the amount of light falling upon such objects. In practice, a combination of both methods is frequently employed.

One effect of major importance, not mentioned heretofore, is the loss of depth perception caused by two-dimensional monochrome reproduction of three-dimensional objects. An important consequence of this is the tendency of foreground objects to merge with the background under certain conditions. This situation may be alleviated by the use of backlight which introduces a form of brightness separation between foreground and background. These and similar problems are covered in detail in the following paragraphs.

**Base Light.** Base light is the light that provides the required over-all scene illumination to produce a television image having good resolution, uniform tonal gradation, and a high signal-to-noise ratio. Base light (see Fig. 7-8) in television corresponds to what is often called fill light in motion-picture practice. Because of the permissible contrast range and spurious electronic response characteristics of a television system, it is the most important of all lighting components. Accordingly, it deserves first attention, ahead of key or other effect lighting. The term "base light"



FIG. 7-8. Sources of base light for television applications should produce uniform light intensity over the entire scene as viewed from all possible camera angles as shown by this example.

connotes the basic importance, in television lighting, of covering all picture areas with a very uniform level of illumination. It is especially important that the base light be uniform over the entire working area of the stage *as viewed from all possible camera angles*. In addition, it should be directed into the set at as near a horizontal plane as possible in order to provide proper illumination of the hollows under the eyebrows and under the chin of the performers. By this same token, strong light from directly overhead (Fig. 7-9) should be kept to a minimum since, if used, it will only accentuate shadows under the chin and eyebrows. In addition, because of the high contrast that it often produces, top light tends to create image orthicon ghosts and halos.

Where the reflectance of scenery and set properties is controlled, uniform and diffuse base lighting will ensure similar operating conditions for all cameras on all the sequences of a given production. The importance of providing a uniform base light to ensure noise-free even-scale

pictures cannot be overemphasized. If the foundation lighting is inadequate for technical requirements, artistic effects will be lost. However, both technical and artistic requirements can be mutually satisfied by first giving consideration to the technical requirements and then building the



FIG. 7-9. Strong top light should be avoided since it not only accentuates shadows under the chin and eyebrows but, in addition, tends to produce image orthicon ghosts and halos.

artistic effects upon them. The tone scale expansion inherent in television picture tubes permits artistic effects to be obtained with considerably lower original contrast levels than customarily used in photographic and stage practice.

*Lighting Practice No. 1.* The standard lighting procedure should be (a) to establish first a uniform over-all base light which will ensure proper camera operating conditions for technically good-quality pictures and (b) then to add carefully balanced effects light to obtain the desired artistic results.

**Base-light Sources and Intensities.** The function of base light is to provide an even light level on all surfaces throughout a scene. These conditions can be readily fulfilled with either fluorescent (Fig. 14-6) or incandescent (Fig. 14-17) sources of light, *provided* good diffusion and even distribution are obtained. Mixtures of both types of lighting sources may be used since the difference in color rendering is insignificant when suitable types of light filters are employed with the television camera tubes (see Sec. 7-5). Also with equivalent diffusion, the various sources will give similar rendition of skin and material textures.

Since it is important that the base light fully illuminate all vertical surfaces in the scene, a number of the fixtures should be placed at the lowest practical height in front of the action. Furthermore, uniformity of base-light intensity throughout the stage and throughout the performance is essential because of the time required for making the camera adjustment necessary to obtain optimum picture quality for any particular illumination and scene condition. Any lighting departures required for special effects should be worked out with the technical crew so that adequate time may be provided for necessary camera readjustments.

Since brightness tolerances are rather closely defined, visual judgment of the lighting is rarely trustworthy. Furthermore, it is economically impractical to light a set entirely by observations of the effect through a television camera chain. A satisfactory alternative is to achieve the necessary lighting levels and distribution with the aid of a photocell light meter.

Base lighting measurements with a photocell light meter should be made with the meter aimed horizontally toward all camera positions from the various performer positions. Supplementary measurements should be made with the meter aimed vertically; base lighting components from this direction should be less than ( $\frac{1}{2}$  to 1 times) the horizontal component of the base light.

*Lighting Practice No. 2.* Base light should be obtained from large-area diffuse sources (fluorescent or incandescent) arranged to produce a uniform illumination level throughout the set and from the viewpoint of all camera angles. The lighting levels required will depend upon the camera tube. For example, with a type 5820 or 1854 image orthicon camera tube equipped with a Wratten No. 3 filter, the following levels have proved to be very satisfactory:

<i>Light Source</i>	<i>Horizontal * Light Intensity</i> (lumens per square foot)
Fluorescent white light (4500° K).....	100 ± 10
Incandescent light (2870° K).....	120 ± 10

\* The vertical light intensity should be less than ( $\frac{1}{2}$  to 1 times) the horizontal intensity.

**Effects Light.** Television pictures obtained with proper base lighting alone may be technically good but are likely to be artistically incomplete. However, to achieve artistic quality a relatively small amount of effects lighting is required, as compared to legitimate-stage, motion-picture, or still-photography practice. The television system does not tolerate violent lighting contrasts but, on the other hand, can produce pleasing results with relatively small lighting-intensity differences. Because of the nature

of the brightness transfer characteristic of the television system (see Sec. 7-2), it is necessary, in the final analysis, to observe the results of applying effects light by making observations on a television picture monitor. However, it is practical (and desirable) initially to adjust effects lighting intensities by measurement with a photocell meter pointed toward the fixture from the performer's or object position with all other lights turned off.

In lighting a complex set, care must be taken to avoid interference between the lighting and the camera operation in adjoining scenes and to avoid microphone boom or other shadows. The directional sources used for effects light cast much sharper shadows than the diffuse, widely scattered base-light sources.

*Lighting Practice No. 3.* To provide depth, to separate objects, and to add artistic interest to a picture, several types of effects lights should be added to the base light. Effects light may include key light, back light, modeling light, eye light, and special-effects light. In general these are best supplied from directional sources (usually incandescent) which can be conveniently adjusted in intensity, character, and coverage. Initial adjustments may be made with the aid of a photocell meter but final judgments should be made on a picture monitor.

**Back Light.** Unless proper lighting is employed, the reproduction of three-dimensional objects in two dimensions will often result in the loss of depth perception. The purpose of back light is to overcome this difficulty by providing a thin edge of brightness around foreground objects in order to delineate objects from the background. For back light to be most effective, it should originate from the far side of the subject (away from the camera) and be directed toward the camera. Practical considerations, however, require that it be placed at least as high as the top of the background set. Consequently, backlights are usually placed at the lowest feasible elevation above the upstage set flats and are directed downstage and at as oblique an angle as possible while still covering the farthest upstage acting area at head height (Fig. 7-10). When back light is combined with base light, the result shown in Fig. 7-11 is obtained as compared to the use of base light alone, as shown in Fig. 7-8.

The amount of back light required is a function of the person or object being illuminated. For example, blond hair requires less light than brown hair. As a guide, a light intensity reading obtained by pointing a light meter toward the back-light source, from all important subject positions and with all other lights out, should fall between 1 and 1½ times the base-light level.



FIG. 7-10. Back light, shown here without other supporting light, is usually at its best when applied from the lowest practical elevation.



FIG. 7-11. The result of combining back light with base light is shown here. This photograph should be compared to Fig. 7-8 wherein base light only was employed.

*Lighting Practice No. 4.* Back light should be directed from the lowest possible rear angle with intensity between 1 and  $1\frac{1}{2}$  times the base-light level. The light meter should be pointed toward the source of back light for this measurement, and all other sources of light should be turned off. Vertical top light is not back light and is to be avoided.

**Modeling Light.** Modeling light is also used to produce the illusion of three dimensions in a two-dimension picture by creating highlights and shadows (Fig. 7-12). It is useful in bringing out the textures of materials and in providing feature shadows of an object. Generally only a small amount of light is required to obtain the desired effect, and the added illumination will not be sufficient to influence camera exposure materially.



FIG. 7-12. Modeling light, shown here without supporting light, is employed to create depth perspective in a two-dimensional picture.

*Lighting Practice No. 5.* Modeling light should be directed from a side-front position and may be adjusted in intensity just to produce shadows. In general the amount of light required will not exceed  $\frac{1}{2}$  to 1 times the base-light intensity.

**Key Light.** In motion-picture practice, key light is often the most important and first established light. However, in television it is classified as an effects light because of the primary requirement that an even base light be established first. Key light is usually a front light, often high and from one side, to give the effect of a single predominant light source for the scene. In television applications, it is used in a fashion similar to modeling light but its effects are more prominent.

*Lighting Practice No. 6.* Key light used to give the effect of a predominant source of light may be from 1 to 2 times the base-light level, with any base light from the same direction as the key light reduced accordingly.

**Eye Light.** Eye light adds sparkle to eyes of performers. It does not add measurably to the over-all light level and reflects primarily from the

glistening surfaces of the eyeballs. This light should be supplied from approximately eye level and is desirable in close-ups. The photograph shown in Fig. 7-13 shows the results obtained with the application of base light, back light, modeling light, and eye light. It should be compared with Fig. 7-8 which shows the use of base light only.



FIG. 7-13. Eye light adds sparkle to the eyes as shown in this photograph which combines base light, back light, modeling light, and eye light and which should be compared to Fig. 7-8 which employed only base light.

*Lighting Practice No. 7.* Eye light may be added to brighten up a performer's eyes and to supplement the base light on close-ups. A small spotlight, mounted on the front of the camera (see Figs. 6-14 and 14-12) and having an intensity of not more than  $\frac{1}{2}$  to 1 times the base light, is useful for this application.

**Special-effects Light.** In the category of special-effects lighting are placed theatrical-type spot lighting, lights-out dramatic sequences, moon-light effects, street-light effects, and similar lighting which, from the viewpoint of basic television lighting principles, are abnormal. Theatrical lighting, primarily for the benefit of the relatively small studio audience, should not be used if the television picture quality is thereby impaired. The studio audience may number in the hundreds but the television audience in the millions.

Spot lighting, if practiced to the degree common in the theater, violates the fundamental television tenet of avoiding violent contrasts. If spot lighting must be practiced in order to show a performer or an object in complete isolation from the background, the background should be kept completely dark or use made of a black velvet backdrop. Black electronic

halos will usually not be visible against backgrounds of this type, although image orthicon ghosts may be quite noticeable. If the net effect obtained is tolerable, the special-effects light may be used but preferably for only very short sequences.

Whenever the general picture area is permitted to go dark, the remaining highlighted areas on the target of an image orthicon tube release clouds of secondary electrons which cause fogging or mottling of the dark area, severe halos around the highlights, bad streaking, and objectionable image orthicon ghosts. On the other hand, maintenance of a medium, even light throughout the picture area minimizes these spurious effects and actually provides a better darkened stage effect.

*Lighting Practice No. 8.* Special lighting effects, such as spot-lights, moonlight and lights-out sequences, may be obtained by reducing the base light to approximately  $\frac{1}{4}$  its normal value, and any special-effects lights then adjusted to bring the total illumination level up to 1 or  $1\frac{1}{2}$  times the normal base-light intensity (light meter aimed at camera positions).

**Window Light.** Light may be added to the normal base light on backgrounds to obtain effects such as sunlight, street lights, or automobile headlights shining through window frames, tree leaves, or other openings. The permissible total incident light obtained in this fashion will depend somewhat upon the tone of reflectance value of the particular portion of the set involved. More light may be added to the lower toned backgrounds and materially less to the lighter backgrounds. In general, a well-defined effect can be obtained, as judged on a picture monitor, with only moderate amounts of added light.

*Lighting Practice No. 9.* Effects light directed to backgrounds to create window and similar shadows should not exceed  $1\frac{1}{2}$  times the normal base light incident upon the background in question.

**Self-luminous Objects.** Where exposed lamps, lanterns, light bulbs, or windows lighted from the rear are part of a setting, such sources should be dimmed or filtered down to eliminate or at least minimize halo and image orthicon ghost effects. Where exposed bulbs are employed, as in lamps, lighted signs, or store windows, the effective exposure may be reduced by using orange or red-tinted bulbs. Placement of exposed lights against light backgrounds and in well-lighted areas will also help.

*Lighting Practice No. 10.* Self-luminous objects or areas such as exposed lamp bulbs, lanterns, and near lighted windows should not produce a light meter reading in excess of  $\frac{3}{4}$  to 1 times the normal

base-light reading, when the meter is held a few inches from the light source and directed toward it.

**Color of Light.** In monochrome transmission, light sources of different colors will, in general, produce different color-to-gray renditions since the output of a camera tube is a function of the color of the light applied.

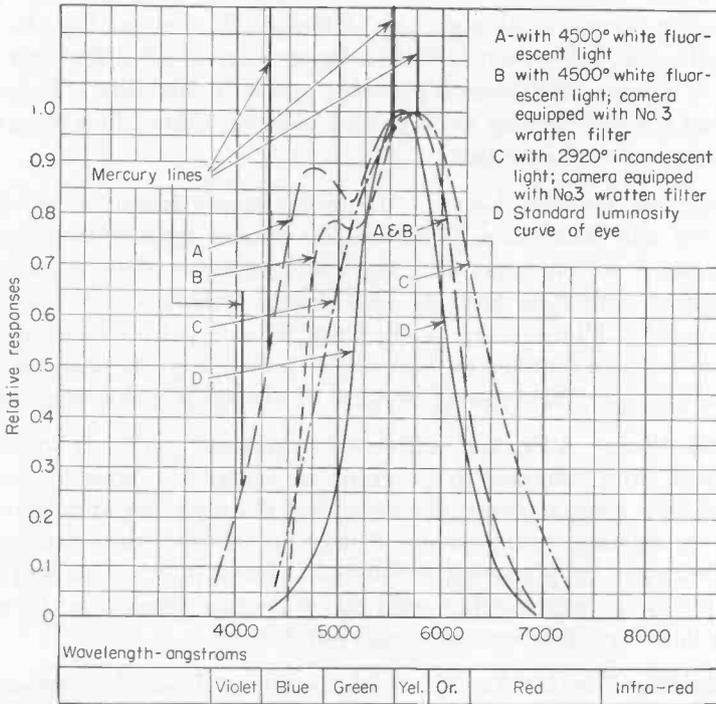


FIG. 7-14. Relative response of 5820 and 1854 image orthicon camera tubes to fluorescent and incandescent light.

The relative responses of the types 5820 and 1854 image orthicon tubes to both fluorescent and incandescent light are shown in Fig. 7-14. In practice it is found that, if the response of a camera tube peaks in the vicinity of yellow and green and falls away in both the blue and the red direction, the monotoned television picture will appear normal to the eye. The exact shape of the curve is of secondary importance. With this in mind, it is seen that the particular camera tubes illustrated, when equipped with a suitable filter, match the standard luminosity curve of the eye (curve D) very well when employing either 4,500-degree white fluorescent light (curve B) or 2,920-degree incandescent light (curve C).

In general, an illuminant which appears predominantly white to the eye will produce good results with panchromatic television camera tubes.

Illumination color, although a factor, is no longer the critical matter in monochrome transmission that it was with earlier camera pickup tubes. For instance, satisfactory color response may be obtained from a number of types of incandescent and fluorescent lights. In the latter category are the soft-white, warm-tone, daylight, 3,500-degree white, and the 4,500-degree white lamps. Although any of these light sources may be used successfully, the 4,500-degree white tube appears to offer the best compromise in camera effectiveness per watt and in availability. Tests have shown that there is nothing to be gained by using other tubes or in using combinations of various types.

*Lighting Practice No. 11.* In monochrome transmission, incandescent and fluorescent (4,500-degree white) light sources may be intermixed without impairing the color response where cameras are equipped with type 5820 or 1854 image orthicons and with blue-attenuating filters such as Wratten No. 3. Incandescent light sources can be dimmed to one-quarter normal light intensity without impairing spectral response because of change in color temperature.

**Lighting Plans.** A marked difference in picture quality is sometimes experienced from program to program on repetitive shows employing much the same stage settings. To the extent that such variation is caused by different lighting arrangements, it may be greatly reduced, if not entirely eliminated, by preparing a detailed lighting plan. This will assist persons not intimately familiar with the particular production to reproduce the lighting conditions previously established.

*Lighting Practice No. 12.* Lighting plans should be prepared in detail for all repetitive productions to ensure reproducibility of established lighting conditions.

**7-5. Camera Operating Practices.** In order to realize fully the benefits to be derived from the employment of correct staging and lighting practices, it is imperative that proper operation of the television camera also be practiced. Where image orthicon tubes are used, it is important that the many initial adjustments already described (Secs. 2-6 and 2-7) be carefully undertaken. In addition to these preliminary adjustments, the practices detailed in the following paragraphs should be observed.

**Light Filters.** Over and above the general radiation throughout the visible spectrum, fluorescent sources of light contain strong narrow-band components which are characteristic of the gas with which these lamps are filled. The violet and blue mercury lines are particularly strong (see

Fig. 7-14, curve A) and, if not filtered out, can cause undesirable color-to-gray rendition in monochrome television cameras. A Wratten No. 3 filter, and to a lesser degree a Wratten No. 6, have been found very effective in coping with this situation when types 5820 and 1854 image orthicons are involved. These filters cut off sharply in the deep-blue region thereby eliminating the color-response distortion that would otherwise be caused by the strong mercury-vapor radiation that is present in all fluorescent light. The Wratten filters mentioned are a good compromise between effective blue rejection and loss in over-all transmission, the filter increasing the required exposure by one lens stop.

A single glass-mounted filter, held immediately in front of the face of the image orthicon, is all that is required for each camera. This method of mounting makes it unnecessary to employ individual filters on each lens.

*Camera Practice No. 1.* A Wratten No. 3 (or No. 6) filter should be mounted in front of the image orthicon tube on all cameras used with fluorescent lighting. The filter may be left in place when incandescent lighting is employed.

**Lens Apertures.** Although some of the types 5820 and 1854 image orthicon tubes will produce satisfactory pictures from scenes illuminated with only 20 to 30 lumens per square foot, there may be a 3-to-1 variation in sensitivity among tubes. It is for this reason that light levels of 100 to 120 lumens per square foot were recommended above (see Sec. 7-4, *Base-light Sources and Intensities*). These levels are adequate to cover the range of camera-tube sensitivities encountered in practice and to provide a margin for filter absorption.

In television it is the general practice to regulate the exposure by adjusting the lens iris. This is contrary to motion-picture practice of setting the lens iris to achieve the desired depth of focus. As camera tubes become more uniform in sensitivity, it is reasonable to expect that the photographic practice will be applied to television. Meanwhile, with a number of cameras in use simultaneously, and with the possibility of a number of different camera-tube sensitivities, it is expedient to equalize exposures by adjustment of the iris openings. Therefore any statement of typical lens settings can serve only as a general guide as to the order of magnitude of lens speeds that are necessary. In practice, using the average run of camera tubes, it is found that lens openings ranging from perhaps  $f/8$  to  $f/16$  are required for the scenes that are staged and lighted in accordance with the foregoing suggestions. Unlike photographic practice, it is not necessary in television to set lens openings in accordance with light-meter readings since the television camera itself is, in effect, an excellent exposure meter.

If the depth of focus obtained by the method of adjustment outlined above is inadequate for a given production, it will be necessary to increase the light intensity in order to reduce further the size of the iris opening. Each time the light intensity is doubled, the iris may be reduced by one stop number. Actually it is not very practical to increase materially the depth of focus by this procedure since the required light intensities soon reach unreasonable levels.

If good television pictures are to be obtained, it is important to avoid either under- or overexposure. Underexposure leads to noisy, flat pictures with the blacks compressed, while overexposure aggravates the several spurious effects peculiar to image orthicon tubes including bad halos, image orthicon ghosts, washed-out blacks, streaking, and loss of facial and highlight detail.

*Camera Practice No. 2.* For the recommended staging and lighting conditions, type 5820 and 1854 image orthicons, equipped with Wratten No. 3 or No. 6 filters, will require lens stop openings in the vicinity of  $f/8$  to  $f/16$ . The exact lens opening should be reduced to the point where the signal resulting from significant highlight areas just starts to decrease in amplitude, as observed on a waveform monitor.

**Camera-tube Performance.** New camera tubes in good operating condition are usually capable of reproducing at least 10 gray-scale steps (Fig. 7-5) representing a contrast ratio of 20 to 1 and of resolving at least 600 lines in the horizontal direction. The performance of a camera tube in respect to resolution may be determined with the aid of a standard RTMA test chart, framed so as to cover exactly the raster of the camera tube (see Figs. 16-15 and 16-16).

The gray-scale rendition capabilities may also be ascertained with the aid of this chart, provided the gradation of the gray scales is sufficiently accurate. Where the accuracy of these printed scales on the RTMA chart is not sufficiently great for a particular application, resort must be made to gray scales prepared and calibrated especially for the purpose (see Sec. 7-7). The factors that have a bearing upon the performance of a given image orthicon camera tube include scanning-beam alignment, focus-coil current, beam current, target-screen potential, presence or absence of stray magnetic fields, photocathode illumination, optical focus, and monitor adjustment. All these items are discussed in detail in Chap. 2.

*Camera Practice No. 3.* Careful adjustment of camera-tube operating conditions is essential. As a *minimum* standard, it is recommended that at least nine steps of a standard gray scale (Fig. 7-5)

be reproduced and at least 500-line resolution be obtained on both vertical wedges and 350-line resolution on all corner wedges of a RTMA test chart. In addition, noise should be just barely discernible on a picture monitor.

**Gray-scale Rendition.** Color response differences among camera tubes are almost a negligible factor in gray-scale matching among cameras and account for very little of the camera matching difficulties sometimes encountered. On the other hand, the shape of the brightness transfer (gray-scale rendition) characteristic is markedly influenced by the target-screen potential of the image orthicon tube and by the average scene brightness (see Fig. 2-14). In addition, the amount of lens flare and the iris opening have an important influence upon the transfer characteristic. These four factors are the key to obtaining similar gray-scale rendition on all cameras associated with a given production.

In matching cameras as to their transfer characteristics, it is important that all camera-control picture monitors have similar characteristics or that all cameras be matched on one monitor. If the staging and lighting of a set are normal, it will generally be satisfactory to adjust for matched gray-scale rendition with the aid of an RTMA test chart. If, however, unusually light or dark sets are involved, matching adjustments should be undertaken with the aid of a standard gray scale (see Sec. 7-7) temporarily placed in the work area of the set and observed under actual lighting conditions. This enables camera adjustments to be made for uniform and optimum gray-scale rendition while taking into account the background tone of the actual set.

*Camera Practice No. 4.* All cameras associated with a given production should be adjusted to give similar gray-scale rendition against actual set backgrounds or their equivalents.

**Spurious Signals.** Spurious signals in the form of image orthicon ghosts, halos, clouding and streaking (see Sec. 7-2, *Interaction between Picture Areas*) will manifest themselves first to those responsible for camera operations. By taking corrective measures in line with the suggested staging and lighting practices presented, these difficulties can usually be corrected. Where a ghost-producing object must remain in a scene, the ghost may be hidden by keeping the object in center screen. When the ghost-producing highlight is at the center of the target, the excessive electrons fall back directly upon the highlight and the spurious signal is not visible. It is realized that there are few situations where a ghost-producing object can be placed exactly in the center of the screen and permitted to remain there throughout a production. The real remedy,

of course, is elimination of the cause of the spurious signal in the first place.

*Camera Practice No. 5.* Severe spurious signals, in the form of image orthicon ghosts, clouding, halos, and streaking, usually indicate incorrect lighting or staging. If they cannot be eliminated at their source, they may sometimes be minimized by placing the object in the center of the picture area or by slightly misadjusting electronic image focus.

**Lens Flare.** The illumination that reaches the photosensitive surface of a television camera tube (or of film in a camera) consists of both image-forming light and nonimage-forming or flare light. Flare light arises from several sources within the camera lens, including the scattering of light by (a) flaws in the glass, (b) dust and fingerprints on the lens surface, and (c) imperfections on the surface of the lens. Even in a lens of perfectly clear glass with absolutely clean smooth surfaces, scattering is caused by reflections from surfaces in the lens including (a) the surfaces of the individual lens elements, (b) the inside of the lens mount, and (c) the iris diaphragm.

Flare light decreases the contrast range of the light image by degrading the blacks which tend to become gray. In other words, there is a compression of the brightness differences, particularly in the shadows. Consequently, everything possible should be done to avoid flare light. Coating the surfaces of glass elements that comprise a lens greatly reduces the lens flare that arises from these surfaces. In addition, by the use of a lens hood, stray light may be prevented from striking the front surface of the lens and the metallic edges of the lens mount, thereby avoiding lens flare from this source. Hoods should be designed to shield the lenses just as much as possible without causing vignetting or cropping of the corners of the picture. In a lens turret, such as is commonly employed on television cameras, care must also be exercised to avoid intrusion by the lens hood of one lens upon the field of vision of another (see Fig. 6-14).

*Camera Practice No. 6.* Lens hoods should always be used to reduce the incidence of stray light upon the face of camera lenses. In addition, coated lenses should always be used.

**Picture Monitors.** In setting up picture monitors, the practice of adjusting the brightness control until retrace lines just disappear is unsatisfactory since, under these circumstances, there will be appreciable brightness when black signals are present. This results from the fact that the blanking level and the reference black level are not normally the same if standard transmission practices are being observed (see Sec. 1-12 and

Fig. 1-7). The correct method for adjusting the brightness of picture monitors is to use a blanking signal that is equal in amplitude to the reference black level and then to adjust the brightness until the raster is just extinguished.

Differences of phosphor color and brightness transfer characteristics of picture tubes sometimes make it difficult to match pictures on adjacent monitors. If it is impossible to assemble a group of similar picture tubes for a given installation, the outgoing-line monitor may be used as a common comparator. This practice is not so desirable as being able to compare simultaneously the various picture signals on their respective monitors since, not only does it become impossible to balance pictures before they are switched to the outgoing line but, in addition, the accuracy of the balance between pictures depends upon memory rather than a side-by-side comparison.

*Camera Practice No. 7.* All control-room picture monitors should be equipped with picture tubes having similar phosphor color and similar brightness transfer characteristics. The raster should be adjusted just to go black with a blanking signal equal in amplitude to reference black level. When in doubt, all camera balance judgments should be made on a single (line-output) picture monitor.

**Waveform Monitors.** It is unfortunate that no television equivalent of the standard audio volume indicator meter is in general use. The need for exercising considerable care in determining video signal levels with available waveform monitors may be appreciated when it is realized that standard transmission practice calls for maintaining black peaks at a level that is about 10 per cent of the total picture signal amplitude, a value that is not a great deal larger than the limiting accuracy in reading a waveform monitor. Therefore, waveform monitors should be equipped with well-focused bright cathode-ray tubes, the trace properly centered with respect to the deflection scale and the units carefully calibrated against a source of known voltage.

In checking the accuracy of a waveform monitor, it is important that the calibration be verified at all significant amplitude levels. Since a number of vacuum tubes are employed in the supporting circuits, there is no guarantee that the deflection amplitude will remain a linear function as tubes and other components age. Under these circumstances, adjusting a waveform monitor for correct deflection to only one reference level (*e.g.*, white level) may lead to erroneous results at other levels. All waveform monitors should, of course, be equipped with standard scales (see Sec. 16-2, *Oscilloscope Scales*).

*Camera Practice No. 8.* Particular care should be taken in reading waveform monitors in order to obtain accurate results. Calibration of the monitors against a source of standard voltage should be undertaken on a routine basis.

**Transmission Levels.** It is standard practice to transmit a composite signal from a program origination point to an outgoing video circuit at the following levels, relative to blanking level (see Fig. 1-7):

Reference white .....	+1.0 volt
Reference black .....	+0.1 volt
Synchronizing level .....	-0.4 volt

Reference signal levels represent the maximum permissible amplitude for important parts of picture information. White signal amplitudes greater than those indicated and black signal amplitudes less than indicated may result in loss of detail and compression of the extreme whites and blacks, respectively. On the other hand, signals that do not utilize the full available range from black to white may result in flat, washed-out pictures. It is desirable, therefore, to employ the full range between black and white reference levels for practically all pictures. To this end, as already suggested, it is advantageous to include small areas of extreme white and extreme black in every scene, for reference purposes.

Instances will be encountered, however, where there are no areas corresponding to true white or black. Under these circumstances, it is necessary to correlate the waveform monitor display with that on the picture monitor to ensure, for example, that flesh tones are held well below reference white level. Unless this technique is employed, there is the possibility that tones not truly white will be brought up to white level and the gray-scale rendition thereby distorted.

On occasion very strong glints or highlights, in which detail is not important, may be permitted to exceed the reference white level in amplitude. However, considerable care and good judgment must be used in determining the extent to which this practice may be permitted.

*Camera Practice No. 9.* Picture signal levels should be carefully monitored to maintain true black and true white signal peaks at their respective reference levels. The picture monitor display should be correlated with that of the waveform monitor to ascertain what peaks may be considered spurious and to judge picture quality where no true black or white signals exist.

**Close-up Shots.** The practice of opening a scene with a long shot to establish the locale should be reduced to a minimum in television pickups. Where extremely long shots are necessary, they should be held for a

minimum of time and, in their place, use made of sharp, clear close-ups to set the scene or the mood. These practices aid in the reproduction of good pictures even on television receivers that are not in the best of repair and, of course, in no way impair the quality of the reproduction on good receivers.

*Camera Practice No. 10.* Use close-up shots as much as possible and avoid extreme long shots except for short periods of time.

**High-angle Shots.** Where a high-angle shot is required, short-focal-length lenses should be avoided because of the extreme foreshortening that usually results. Where people are the subjects, the results are most uncomplimentary since a short-focal-length lens for a high-angle shot will result in the appearance of short extremely stout persons with foreshortened legs and distorted heads and bodies.

High-angle shots may sometimes be avoided entirely, while still obtaining a similar picture composition, by using a stage floor that ramps up from front to back. With this arrangement the action in the background will be visible even though the camera is only slightly elevated. This arrangement has been used very successfully for large chorus or dance numbers where, without a ramp, a high-angle shot would have had to be used to see the action in the background.

*Camera Practice No. 11.* High-angle shots with short-focal-length lenses should be avoided because of perspective distortion.

**Framing of Action.** As detailed elsewhere (see Secs. 7-6 and 10-2) there are a number of places in a television system where the edges of the picture may be cropped or trimmed. Under these circumstances, ample headroom should always be provided to avoid any possibility of a performer's head being partially cut off when reproduced on a television receiver. Where a full-length shot is called for and it is not quite possible to get the performer's entire length within the picture height, ample headroom should still be maintained even at the expense of cropping the performer's feet. Likewise all printed material should be carefully centered and completely enclosed, by an ample margin, within the area where essential information should be maintained.

*Camera Practice No. 12.* Ample headroom should always be maintained in order to avoid the possibility of cropping a performer's head. Furthermore, titles and other printed matter should be framed well within the area to which essential information should be confined.

**7-6. Area of Essential Information.** The cumulative frame cropping that is encountered in a television system, together with the variety of

shapes employed for television-receiver picture-tube masks, severely reduces the area of a picture raster that is suitable for the transmission of essential information. In a receiver, reduction in the size of the area covered by the original picture results from (a) overscanning of the picture tube, (b) incorrect centering of the picture, and (c) picture-tube masks that deliberately cut out corners of the picture in order to obtain the semblance of a larger display. Where television recording is also involved in the transmission of the program material, additional cropping may occur (d) in the recording camera, (e) in the film projector, and (f) in the scanning of the film camera tube's screen. The magnitude of the cropping that may be expected in practice has been detailed elsewhere (see Sec. 10-2).

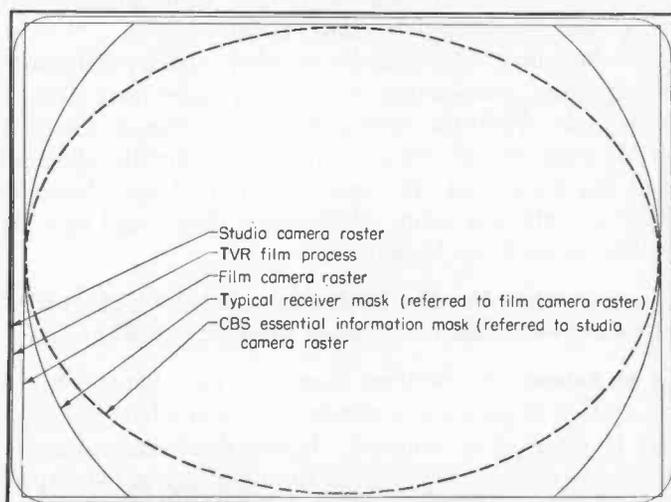


FIG. 7-15. The picture area covered by a studio camera may suffer successive reductions in the television recording process, in the transmission of such recordings, and in the receiver as illustrated. Consequently, it is best to keep all essential information in an ellipse having the proportions shown.

In any event, in framing the action being televised, due consideration must be given to the loss of picture content that may be encountered by the time the material is displayed upon the picture tube of a receiver. In order to avoid the placement of essential information in areas where it may be lost to the television viewer, boundaries may be defined on the picture monitor within which all important material should be maintained. These areas for essential information may be indicated on the face of picture monitors with the aid of transparent masks. A typical mask of this type, designed with the factors enumerated above in mind, is shown in

Fig. 7-15. In practice, these masks may be reproduced on photographic film and reduced or enlarged to the correct size for the particular type of monitor tube involved. The required sizes usually range from the 5-in. picture tube often used in electronic view finders to the 17-in. or larger master monitors used in studio control rooms. The finished masks consist of clear film upon which the three boundaries appear as black lines. The outermost boundary is simply the trim line and duplicates the shape of the mask used in the picture monitor to which the essential information mask is to be applied. The middle boundary or rectangular area defines the size of the scanning raster. In the example shown, the size of the display is adjusted so as to show the corners of the raster on the picture monitor, for the reasons detailed in Sec. 2-6. The innermost oval defines the area of essential information. In applying this mask to a monitor, the innermost oval is usually removed (with a sharp knife) just inside the dotted lines. This results in an appearance on the monitor as shown in Figs. 7-1, 7-3, and 7-4. The masks may be applied to the monitors with clear double-surfaced (both sides adhesive) pressure-sensitive adhesive tape.

By keeping all important action and essential copy within the area defined by the dotted oval, the broadcaster has reasonable assurance that it will be reproduced on the average television receiver and will not be cropped by the several frame-size reductions encountered in the television system.

**7-7. Standard Gray Scale.** A standard gray scale in step-wedge form is an invaluable tool in any television studio where scenery preparation and set lighting are undertaken on a systematic basis. Since efficient operation requires a scientific rather than a haphazard approach to these activities, the need for calibrated gray scales is practically a prerequisite for economical operation. As compared to the motion-picture industry, the appetite of a television studio for sets is enormous. Furthermore, their useful life is relatively short, sometimes being used for a single half-hour program and never again. Under these circumstances, the sets as originally prepared in the scenery painting department must arrive at the studio with correct gray-scale tonal values since time (and attendant expense) seldom permit last-minute corrections of scenery painting errors. Experience has shown that, if the staging and lighting practices outlined heretofore (see Secs. 7-3 and 7-4) are intelligently applied, there will be few occasions where the monochrome reproduction on a picture monitor will prove disappointing. However, several of the recommended practices require the availability of a calibrated gray scale as an aid to achieving the desired results.

The specifications for the RTMA television test chart (see Sec. 16-6) include a gray scale "composed of ten steps varying in an approximate

logarithmic manner from maximum white brightness to approximately  $1/30$  of this value." Unfortunately, in practice, it is found that many of the commercially available copies of this chart are made by a printing process that fully justifies both uses of the word "approximate" in the specification just quoted. As a result, for serious measurements it is advisable to make use of accurately calibrated gray scales in place of the approximate ones on the test charts that are normally available. The standard gray scale need be no more than an inch wide and a foot or so long. When held alongside a 3- by 5-in. paint sample and viewed through a television system, the gray-scale step corresponding to the paint color under test is immediately discernible.

In addition, at least one large television production center (CBS) has found it advantageous to make use of a 10-step gray scale with each step related to its neighbor by a factor equal to the square root of 2. This 10-step scale has a total contrast range of 22 to 1 which, for all practical purposes, may be considered as being 20 to 1. Actually, this is not a major departure from the standard RTMA test chart, since by employing 11 steps, each equal to the square root of 2, a scale having a range just slightly in excess of 30 to 1 is obtained. In some respects, however, the square-root-of-2 scale is more convenient than the odd-valued RTMA steps (1.6 to 1) since with the former the ratio between alternate steps is exactly 2 to 1.

## Projector Camera Chains

ASIDE FROM THE TELEVISION TRANSMITTER ITSELF, the projector camera chain is, without doubt, the most important equipment in a television broadcasting station. With these two elements a station is in a position to begin and to continue broadcasting. To be sure, if a station had to rely completely upon film and stills for all its program material, it might be somewhat handicapped in the timeliness, popularity, and variety of its program. Nevertheless, the fact remains that television stations have begun their operations with no local program origination facilities available other than a projector camera chain and associated projectors.

**8-1. Projector Camera Applications.** Film and still projectors and the accompanying projector camera chains are the television counterpart of the transcription turntable and its associated audio facilities. Many an aural broadcasting station owes its success to the availability of transcriptions and phonograph records, and some have built remarkable reputations by intelligent programing that made extensive use of these sources of program material. In television, unfortunately, there is not yet available the wealth of program material in the form of films that is accessible to the aural broadcaster in the form of recordings. Nevertheless, the average television station will probably derive more revenue from its film and still camera chains than from any other single source of program material available to it. Since, in this country, most television stations depend upon their earnings in order to continue in business, their projector camera chains are a very important part of their plants. Bearing this in mind, it goes without saying that a television station's projector camera chains and the associated projectors should be of the best quality available and deserve all the attention necessary to maintain them in the best possible working condition.

**8-2. Projector Camera-chain Types.** Together with the flying-spot scanner, the image orthicon, the iconoscope, and the vidicon are used for projector chain service. Each type of pickup device has its advantages and its disadvantages. At the present state of the art, it cannot be said that

any one of the four types of pickup devices named is outstandingly superior to the others for *all types* of projection material handled by a television broadcasting station. The flying-spot scanner, while theoretically capable of outstanding performance, faces certain practical difficulties (see Sec. 8-12) which stand in the way of its being universally used. As a matter of fact, except for a few cases, the flying-spot scanner is used in this country only for the transmission of stills, and even in this service it is not in extensive use.

The image orthicon camera tube offers certain benefits for film projection applications but, because of the image retention problem (see Sec. 2-6), cannot be used for still projection if the subject material is to be held stationary for any appreciable length of time. The iconoscope tube, on the other hand, can be used for both still and motion-picture projection work. It may be argued that, theoretically, the flying-spot scanner or the image orthicon tube is better than the iconoscope tube for one type of projection service or another. Nevertheless the fact remains that, from a practical standpoint, the iconoscope still offers certain advantages. For one thing, it can be used for both still and motion-picture projection; for another, its cost of operation is considerably less than for an image orthicon (on an hourly basis, about one-sixth as much). Both factors are important, particularly to the television station that wishes to operate with a minimum investment in equipment and with a minimum operating cost.

**8-3. Iconoscope Camera Tube.** The iconoscope camera tube, like the image orthicon which it preceded, employs the principle of light storage and thereby effectively utilizes all the light that falls upon the mosaic rather than only that which is present at the instant the scanning spot passes over a given element of the mosaic upon which the image is focused. The general appearance of an iconoscope tube extensively used

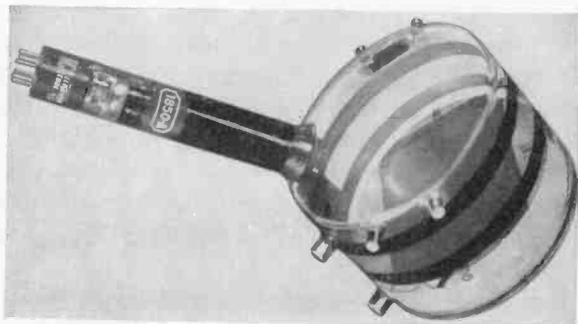


FIG. 8-1. An iconoscope tube of a type that is used extensively in film cameras. The cylindrical glass envelope is approximately 7 in. in diameter and equally long. (Courtesy of Radio Corporation of America.)

in television projector cameras is shown in Fig. 8-1. The offset neck contains an electron gun while the main portion of the highly evacuated glass bulb contains a mosaic and a collector ring. The gun assembly supplies a focused stream of electrons which, by means of magnetic deflection coils, are made to scan the mosaic. To the extent that both the image orthicon and the iconoscope tubes employ light-storage principles and electronic scanning, they are alike. Here, however, the resemblance between the two camera tubes more or less ends.

**Mosaic Construction.** A schematic sketch of an iconoscope tube is shown in Fig. 8-2. The subject matter to be televised is optically focused upon the face of a photosensitive mosaic. The basic material upon which the mosaic is constructed is usually a uniform plate of mica, approximately 0.001 in. thick.<sup>1</sup> After a thin, finely sifted coating of silver oxide powder is applied to the mica, the mosaic is baked in an oven. The heat reduces

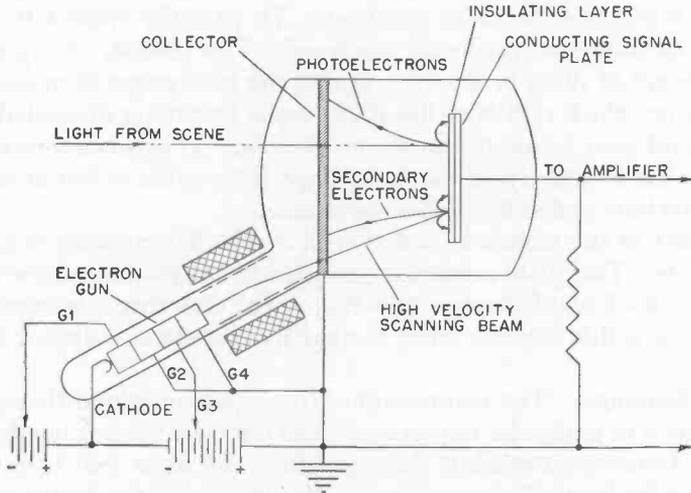


FIG. 8-2. The elements of an iconoscope camera tube and the basic circuit in which it is used.

the silver oxide to pure silver and, on cooling, the silver forms into extremely minute globules. Each globule is separated from its neighbors and is insulated from them by the mica support. This process results in each incremental area of the mosaic becoming an individual storage capacitance. Precautions must be taken during the remainder of the processing of the mosaic to ensure that the minute silver islands remain insulated from each other. Unless this is done, any charge configuration which

<sup>1</sup> Janes, R. B., and W. H. Hickock, Recent Improvements in the Design and Characteristics of the Iconoscope, *Proc. IRE*, Vol. 27, No. 9, p. 535-540 (September, 1939).

is subsequently formed on the surface of the mosaic would tend to spread transversely and thereby degrade the image definition.

The nominal size of a typical mosaic is  $3\frac{9}{16}$  by  $4\frac{3}{4}$  in. By careful control during manufacture, the distribution of globules may be quite uniform over this entire area. Although there may be some local irregularities in the surface, the individual globules are so small compared with the area of the electron scanning beam that their number in any given picture element may be considered essentially the same for any portion of the mosaic.

The pure silver globules are made photosensitive by exposing them to cesium vapor in the presence of a glow discharge in an atmosphere of oxygen. A surface consisting of silver oxide, cesium oxide, and pure cesium is formed on the silver globules. By this process, minute photosensitive islands are formed on the mica base.

The type of mosaic described is predominantly sensitive in the red and infrared regions of the color spectrum. To partially correct this shortcoming, an additional process is employed. This consists of vaporizing a small amount of silver in the tube, during the final stages of manufacture, in a manner which results in the silver vapor becoming deposited on the mosaic, and then rebaking the treated mosaic. This procedure not only increases the sensitivity of the iconoscope but results in better response toward the blue end of the visible spectrum.

The back of the mosaic is coated with a colloidal graphite to form the signal plate. This plate is capacity-coupled to the photosensitive surface, with the mica base of the mosaic acting as the dielectric. In some iconoscope tubes a thin ceramic sheet is used for the mosaic support in place of mica.

**Glass Envelope.** The construction of the glass envelope that encloses the mosaic is of particular importance since it must contain a nondistorting optically transparent window through which the scene that is to be televised may be focused precisely upon the mosaic of the iconoscope. A cylindrical glass envelope is employed since it offers several advantages from both an optical and a constructional viewpoint. The optical image passes through a front faceplate which would have to be relatively thick to withstand the pressure developed on this 8-in.-diameter surface if it were an optically flat plate as in the image orthicon tube. However, by employing ground and polished faceplates that are cut from a section of a sphere having a small curvature, it becomes possible to use thinner glass.

**Scanning Section.** Unlike the photocathode of the image orthicon tube, the iconoscope mosaic is not transparent. Consequently, the side of the mosaic upon which the optical image is focused is the side that must be scanned by the electron beam. Because it is impractical for the axes of

both the electron gun and the lens to be at right angles to the mosaic simultaneously, the gun is mounted to one side.

The electron gun which produces the scanning beam is similar to the electron gun employed in conventional television picture tubes. It consists of an indirectly heated cathode, a control grid, an accelerating electrode, a focusing electrode, and a collector. The collector is actually formed by a metalized coating on the inner surface of the glass tube. Not only does it serve to accelerate the electrons toward the mosaic but, in addition, it serves to collect the secondary electrons emitted from the mosaic. In this action it is aided by the collector rings which are narrow metalized coatings inside the large-diameter portion of the glass bulb, as shown in Fig. 8-1.

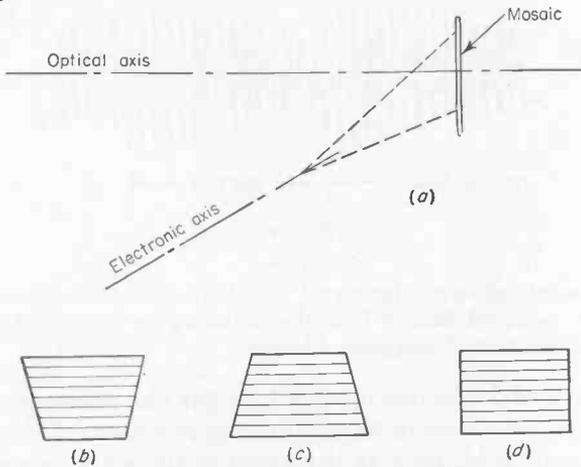


FIG. 8-3. The offset relationship between the mosaic of an iconoscope and its electron gun as shown at (a) results in a keystone-shaped raster (b) when constant angular deflection is used throughout the field. This may be corrected by producing a scanning raster which would look like (c) on a surface normal to the electron beam but which on the iconoscope's offset mosaic becomes rectangular as at (d).

The electron beam is caused to scan the entire surface of the mosaic systematically by magnetic fields that are set up by horizontal- and vertical-deflection coils which are mounted externally around the neck of the iconoscope. Saw-tooth scanning currents of correct frequency and waveform are passed through the coils to produce linear scanning in both vertical and horizontal directions.

As is evident from Fig. 8-1, the axis of the electron gun is at an angle approximately 30 degrees with a normal to the face of the mosaic. As a result, a horizontal scanning beam of given angular deflection will lay down a raster that is wider at the top than at the bottom, as shown in

Fig. 8-3. This results from the fact that the top of the mosaic is farther from the electron gun than the bottom; consequently, for a given angle of beam deflection, the sweep at the top of the mosaic is longer than at the bottom. To correct for this keystone effect, it is necessary to increase the amplitude of the horizontal scanning saw-tooth waveform as the scan progresses from top to bottom of the mosaic. This may be accomplished by modulating the output of the horizontal saw-tooth generator with a saw-tooth waveform so that the amplitude of the scanning current is increased linearly from the beginning to the end of each field, and the process repeated at the field frequency or 60 cps, as shown in Fig. 8-4.

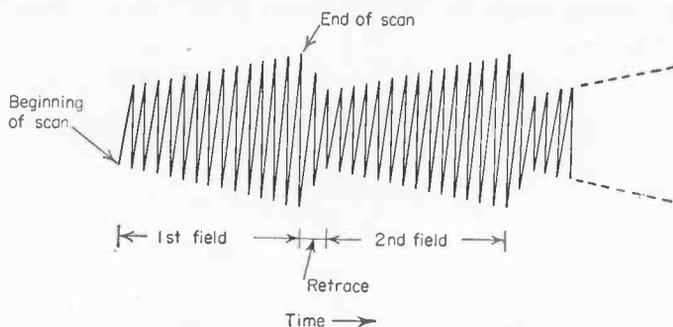


Fig. 8-4. The amplitude of the horizontal scanning waveform used in an iconoscope camera must be increased linearly from the beginning to the end of each field, as shown here in schematic and exaggerated form.

The offset axis of the iconoscope electron gun also presents a problem in keeping the electron beam in focus from top to bottom of the mosaic. An electrostatic focus field, such as is formed in the electron gun, provides correct focus for only one particular distance from gun to target. Therefore, the focus electrode potential must also be modulated by a saw-tooth voltage of correct amplitude and phase in order to maintain sharp electronic focus from top to bottom of the mosaic.

**8-4. Iconoscope Operation.** In spite of its relatively simple construction as compared to that of the image orthicon camera tube, the mode of operation of the iconoscope is somewhat complex. To a certain extent, the complexity stems from the fact that the relationship between the light input and the signal current output of the iconoscope is a function of the brightness or contrast range and the scene content of the image focused upon the tube's mosaic. In other words, the transfer characteristic of the iconoscope is a dynamic one and cannot be determined or portrayed by a static characteristic.<sup>2</sup>

<sup>2</sup> Grimwood, W. K., and T. G. Veal, Dynamic Transfer Characteristics of a Television Film Camera Chain, *J. SMPTE*, Vol. 57, No. 3, p. 249 (September, 1951).

**Theory of Operation.** When light strikes the photosensitive globules on the surface of the mosaic, they give off electrons in an amount proportional to the light intensity. Since each globule is insulated from its neighbor, it will hold its resulting positive charge until discharged by the electron scanning beam. The signal plate on the back of the mosaic acts as one plate of a capacitor, the mica or ceramic base of the mosaic as the dielectric, and each globule on the face of the mosaic as the second plate of a minute capacitor. Thus, when a scene is focused upon the mosaic, the millions of capacitors become charged up in a pattern that corresponds to the variations in brightness of the subject matter.<sup>3</sup>

However, when the scanning beam strikes the mosaic, it causes the emission of secondary electrons, some of which will have sufficient initial velocities to permit them to reach the collector rings. Others will become deposited on the glass walls of the tube, and still others will return to the mosaic in a more or less random fashion. These latter become superimposed upon the electric charge resulting from the photoemission effect which is being created by the light image projected upon the mosaic. Because of the shower of secondary electrons, all parts of the mosaic, except that immediately under the scanning beam, are charged more or less negatively. Those parts of the mosaic which are not illuminated will not have lost photoelectrons and will, therefore, be more negative than those parts that are illuminated. The illuminated areas, having released photoelectrons, will be less negative than the dark areas. As a result, when the scanning beam releases secondary electrons, those starting from dark areas will have a greater initial velocity than those coming from illuminated areas. Consequently, more secondary electrons from dark areas will reach the collector rings than from light areas. Thus, the signal current is greater for dark portions of the scene than for illuminated portions. Conversely, the output current decreases in amplitude when a light portion of the mosaic is scanned. Accordingly, the output signal developed across a load resistor connected to the signal plate will become more negative (with respect to ground) as the picture becomes darker. The iconoscope, therefore, produces a black-negative signal.

**Spurious Signal.** The secondary electrons which fall back on the mosaic create a spurious signal that manifests itself in the resulting picture by the uneven shading of large areas of the picture. Not only does this phenomenon create brightness variations in the reproduced picture that were not in the original but, in addition, it prevents the automatic establishment of a black level. Literally, black level can be almost anything, depending only upon the distribution of light intensities in the scene being televised

<sup>3</sup>Zworykin, V. K., G. A. Morton, and L. E. Flory, Theory and Performance of the Iconoscope, *Proc. IRE*, Vol. 25, No. 8, p. 1071 (August, 1937).

and upon the characteristics of the particular iconoscope being used. Fortunately, the uneven shading problem lends itself to correction by the introduction of equal amplitude and opposite polarity signals into the video circuit at a point following the pickup tube. In practice, a combination of parabolic, saw-toothed, and sine-wave-shape waveforms of proper amplitude, polarity, and frequency will largely eliminate the effects of the spurious signal. Furthermore, by employing modern high-gain triodes in direct plate-to-cathode coupled "cascode" video amplifier circuits incorporating feedback, the beam current of an iconoscope may be kept sufficiently low to largely eliminate both the spurious signal and the need for shading.

**Edge Flare.** A second type of spurious signal, which manifests itself in the form of edge flare, also results from the fact that the number of secondary electrons that fall back upon the mosaic greatly influences the resulting picture signal. The scanning process is such that, at the end of each horizontal line and at the end of each field, the electron beam is abruptly and completely cut off by blanking signals. If this were not done, the mosaic would be discharged by the electron beam during its retrace back to the starting point for the next scan. Under these circumstances, the border areas of the mosaic immediately adjacent to the point where the beam is cut off are not subjected to so great a shower of secondary electrons as are centrally located areas. These border areas are less negatively charged than the remainder of the mosaic and, if allowed to remain in this condition, will result in a smaller signal current from these areas than elsewhere. This results from the fact that the secondary electrons starting from the less negative areas will have a smaller initial velocity, and fewer will reach the collector than if the reverse were the case. As explained under *Theory of Operation*, the polarity of the output signal of the iconoscope is such that a maximum signal corresponds to black areas. Consequently, a reduction in signal, as from the border areas under discussion, results in a picture signal in the white direction. Thus, along the side borders and, in an even more pronounced manner, along the lower edge of an iconoscope picture, there is often a definite white flare.

Any process resulting in the deposition of more electrons in the border areas will tend to eliminate the flare, of course. The simplest way to do this is to illuminate the mosaic in the areas outside of the raster, immediately adjacent to the place where the scanning beam is blanked off. The supplementary light falling on these areas causes the emission of photoelectrons which perform the same function the secondary electrons would have performed had they been released by the scanning beam. In this way all traces of edge flare are eliminated, and the shading of border areas of the iconoscope made similar to that of the centrally located areas.

It is the customary practice to provide edge or rim lighting systems that preferably illuminate all four edges of the mosaic or at least the right- and the left-hand edges and the bottom of the picture. A U-shaped band of light therefore may be employed, as illustrated in Fig. 8-5. The inner edge of this band of light must necessarily be very sharply defined in order that it may be located immediately adjacent to the end of the raster. As a rule the edge light is aligned so as to be between  $\frac{1}{16}$  to  $\frac{1}{8}$  in. inside the edge of the mosaic itself. The scan is adjusted so as to approach as close as possible the inner border of the edge lighting. Depending upon the stability and preciseness of the scanning, it can usually be held to within better than  $\frac{1}{32}$  in. of the edge of the lighting band.

It is to be noted that the edges of the projected picture itself have no bearing upon the position of the edge lighting bands. The relationship is determined entirely by the position of the scanning raster. To be certain, in order to avoid cropping the picture, it should be focused upon the raster so as to just touch the border of the edge lighting bands. However, except when the picture content happens to be white along the borders, it contributes little to overcoming edge flare.

Although it is not important to focus the outer edges of the edge light beam sharply, its width should be kept to the minimum consistent with generating a sufficient number of photoelectrons for neutralizing the edge flare. During the manufacture of the iconoscope, a sufficient amount of photoemissive material becomes deposited upon the mounting strips just outside the exposed mosaic area so as to make them also capable of emitting photoelectrons when exposed to light. Therefore, if the edge

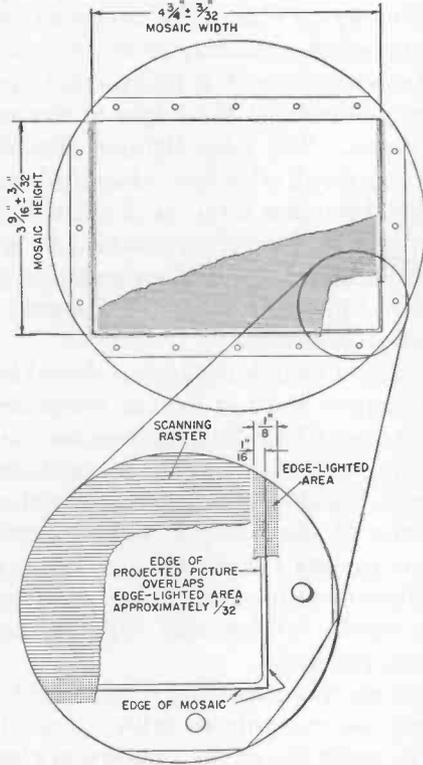


FIG. 8-5. A recommended relationship between the projected picture, the scanning raster, and the edge lighted area of the mosaic of an iconoscope. The dimensions indicated are such that close tolerances must be maintained for optimum results.

lighting extends over into this area, additional photoelectrons will become available for reducing edge flare. On the other hand, the wider the edge lighting band, the greater the problems with spurious light reflections. The ideal solution is to maintain the edge lighting band just wide enough to cover entirely the narrow strip of mosaic reserved for this purpose, with a little margin on the mounting strip side, and then to use sufficient light intensity to obtain the necessary number of photoelectrons. Since the number of secondary electrons created in scanned areas is a function of the beam current, it follows that the number of photoelectrons that must be produced at the edges of the scan is also proportional to the beam current. The edge lighting should therefore be sufficiently intense to eliminate all edge flare when the beam current is adjusted for the optimum signal-to-noise ratio, as detailed in Sec. 8-6. The most critical test for edge light intensity is obtained by scanning the mosaic with normal beam current but with no illumination on the mosaic. With a properly adjusted edge lighting system, there should be no flare discernible under these severe conditions.

The edge lighting system should be sufficiently intense to permit the use of narrow strips of light as recommended and, in addition, to provide for the use of light filters to remove the infrared radiation.<sup>4</sup> Filters, such as Corning 9780 or 9788 in 3-mm thickness, are effective for this latter purpose, but their use results in a reduction of the edge light intensity by a factor of about 30 per cent. Nevertheless, because of the improved picture quality (in the form of better contrast) that is obtained by the removal of infrared radiation from the edge lighting, the efforts necessary to obtain full-intensity edge lighting without infrared components are fully justified.

Even when the band of edge light is limited as described, some difficulty may be encountered with so-called "flags" that appear on the mosaic. The outer rim of the iconoscope glass envelope where the front spherical faceplate is joined to the cylindrical section of the envelope forms a bead that acts as a lens. This "lens" has the annoying property of focusing much of the light that falls upon it directly onto the mosaic. This stray light manifests itself in the picture as a white signal, and it frequently has the appearance of a small cirruslike cloud that is shaped so as to suggest the folds of a group of flags standing side by side on tightly spaced poles. Stray light may be prevented from entering the iconoscope in this manner by masking the front rim of the tube and thereby preventing the light from being focused upon the mosaic and creating the spurious flags. On the other hand, by restricting the width of the edge light beam as much as

<sup>4</sup> Grimwood, W. K., and T. G. Veal, Use of Color Filters in a Television Film Camera Chain, *J. SMPTE*, Vol. 57, No. 3, p. 259 (September, 1951).

is feasible, difficulty from this source of light is minimized. This procedure also eliminates the possibility of stray light being reflected from various other parts of the iconoscope and ultimately finding its way to the mosaic to the detriment of the contrast range of the resulting picture.

Edge lights should be operated from a d-c source to avoid hum pickup in the picture signal. Further, they should be of sufficient intensity to completely eliminate edge flare in the final picture. Any residual edge flare in the television picture is evidence of inadequate or improperly adjusted edge lighting.

**Back Lighting.** Some of the secondary electrons released from the mosaic are neither deposited on the mosaic nor find their way to the collector; instead they settle on the inner glass walls of the iconoscope tube. This results in a negative charge on the walls of the tube which effectively decreases the potential difference between the collector ring and the mosaic. This is detrimental to the desired tube operation since secondary electrons released from the mosaic will not be accelerated toward the collector ring with as much velocity as they would be were this unwanted charge absent. Under these circumstances, those electrons whose initial velocity is just a trifle too small to permit them to reach the collector ring will be lost in so far as the picture signal is concerned. Fortunately, a means is available for at least partially overcoming this difficulty.

During the process of manufacture, the inner glass walls of the iconoscope inevitably become coated with a small amount of cesium oxide and are thus photosensitized. By illuminating these walls with light from a controlled source, they may be caused to emit photoelectrons, and the unwanted charges on the walls may thereby be reduced. This increases the effective difference in potential between the collector ring and the mosaic and results in a better collection of secondary electrons. This, in turn, improves the efficiency of the iconoscope and produces a greater output signal for a given range of illumination of the mosaic or, conversely, for a given output signal, increases the sensitivity of the tube. Back light, when properly applied and adjusted, can increase the sensitivity of the iconoscope by as much as 2 to 1 and at the same time reduce the spurious signal and its attendant shading problems. In addition, back lighting assists in reducing any flicker which may occur in pulsed light projectors (see Sec. 9-7, *Gas-filled Flash Tube*). This flicker will be a minimum at the highest possible setting of the bias light. Whenever it is found that an abnormally great amount of back light is required for a particular iconoscope, it is almost assuredly an indication that the tube has reached the end of its useful life.

Back lighting is often obtained by the use of a number of small incan-

descent bulbs located behind the mosaic in a manner which results in their light falling upon the walls of the tube but not on the mosaic. Furthermore, just as in edge lighting, the use of filters to remove infrared components from the back-lighting source produces improved pictures by increasing the contrast range. In addition, for best results it is essential that the intensity of the lights be adjustable and that the lamps be heated from a source of direct current rather than from alternating current. The latter, in an iconoscope chain having good low-frequency response, will introduce unnecessary a-c hum in the picture signal. In film camera-chain applications the amount of back lighting that can be used is determined almost entirely by the need for eliminating the effects of the so-called "application bar" signal (see Sec. 8-6, *Application Bar Elimination*).

In the application of back lighting, care must be taken to avoid light falling upon the face of the mosaic by virtue of internal reflections in the tube. In addition to the judicious placement of the edge lighting bulbs, a ground or opal glass is often used to diffuse the light before it strikes the iconoscope. In many instances it has been found that the placement of a sheet of translucent diffusing material over the rear faceplate of the iconoscope provides the amount of diffusion necessary to avoid any concentrated reflections on the face of the mosaic.

**8-5. Iconoscope Application.** An iconoscope projector camera chain is capable of very good quality reproductions of motion pictures, transparent slides, opaque sketches, photographs, and other material. However, serious degradation of picture quality can readily occur if proper maintenance of the equipment is not carried out and if skillful and careful adjustment of the numerous controls is not undertaken.

The instructions furnished by an equipment manufacturer normally contain enough information to make possible reasonably good picture reproduction. On the other hand, a great many of the adjustments are covered rather briefly, and the exact manipulation and the resultant effects are left up to the operator's discretion. Consequently, included in the following paragraphs there are suggestions that endeavor to emphasize and describe in greater detail the operating adjustments which mean the difference between average picture quality and the best obtainable from the iconoscope camera chain.

**Scanning of Mosaic.** The iconoscope mosaic should always be scanned to full size. This type of operation will make it possible to obtain the maximum resolution and the best signal-to-noise ratio. Full-size scanning will also result in the minimum possible mosaic grain structure. Under these circumstances, with an iconoscope in good operating condition and with the *proper* potentials applied to the various electrodes, neither the

electron beam size nor the physical structure of the mosaic is a limiting factor.

Uneven edges of the raster may occur as the result of hum or other low-frequency disturbance being coupled into the scanning or the keystoneing circuits. When this occurs, it can usually be readily corrected by removing the circuits responsible for the pickup from the offending field or vice versa.

Another type of disturbance sometimes visible on the raster has the appearance of one or more narrow horizontal bars. These are also usually caused by transient disturbances coupled into the iconoscope circuits. In this instance, however, the video circuits are the ones responsible for the pickup. Certain types of d-c power supplies have been found to create transients in the high-voltage rectifier circuit and to feed this disturbance back onto the a-c line. These transients, which are readily visible on an oscilloscope connected across the a-c line, are sometimes picked up in the video circuits and manifest themselves as very narrow "hum" bars. Careful isolation of all video circuits, particularly the low-level ones, from all a-c circuits, including those carrying filament power, will usually eliminate this disturbance.

**Resolution.** In an iconoscope that is in good condition and proper adjustment, the diameter of the electron beam is about 0.0045 in. As a result, detail as fine as this dimension can just be resolved but no finer detail will be visible. Since the height of the mosaic in the iconoscope tube illustrated is  $3\frac{3}{16}$  in., this particular tube should be capable of about 800-line resolution. In practice, assuming correct operation of the iconoscope, it is found that the limitation to resolution in the vertical direction is not the iconoscope but the number of active scanning lines. Furthermore, it is customary to design video amplifiers for television service with bandwidths of approximately 8 Mc, and this limits the horizontal resolution to about 640 lines which is less than the capabilities of the iconoscope tube described.

As an iconoscope ages, the video output drops and the resolution decreases. The former results from the globules losing their photosensitivity and the latter from a reduction in the transverse resistivity of the mosaic. Migration of the cesium, the cesium oxide, or the silver oxide from the surfaces of the globules into the crevices of the mosaic accounts for the reduced insulation properties between globules. When this occurs, the charge configuration on the mosaic tends to spread out laterally and thereby degrade the resolution capabilities of the tube.

**Light-storage Properties.** Like the image orthicon tube, the iconoscope employs the principle of "light" storage (actually, storage of the electric charge created by the light) and, therefore, is able to make use of all the

light that falls upon the mosaic between scanning periods. When used for direct pickup applications in the field or studio, this characteristic of the iconoscope was used to full advantage because the image was focused upon the mosaic at all times. In projector camera applications, the same type of operation may be utilized when stills are being televised but not when motion pictures are being projected unless a continuous-type projector or one having a relatively fast (approximately 1 millisecond) pull-down is used. In the more usual case intermittent projectors with relatively slow (7- to 14-millisecond) pulldowns are used, and the image can be projected upon the mosaic only during the vertical blanking period whose duration is between 0.8 and 1.3 milliseconds.

The reasons why this type of operation is necessary are detailed in Sec. 9-6. For the present it is sufficient to note that, were it not for the light-storage characteristics of film camera tubes, they would be unsuitable for use with intermittent-type projectors. Such being the case, the ability of the camera tube to hold its electric charge for the entire period between light pulses is very important. Since light pulses occur at field frequency, or once every  $\frac{1}{60}$  second, the charge must persist, substantially unchanged, for at least twenty times as long as the duration of the light pulse.

If the storage properties of a film camera tube become impaired, there will be an objectionable difference in output level from the tube as the scanning progresses from the top of the picture to the bottom. The signal at the top of the frame will be greater than that at the bottom since, at the top, the raster is scanned immediately after the target or mosaic has been illuminated, whereas the bottom is not scanned until almost  $\frac{1}{60}$  second later. Poor storage properties in film camera tubes therefore manifest themselves by the need for shading in the vertical direction. Iconoscope film camera chains provide controls for adjustment of the vertical shading since a certain amount is usually needed to cope with the spurious signal with which this tube is afflicted. However, if the storage properties of a tube become sufficiently poor, the amount of shading required may exceed the capabilities of the equipment. Furthermore, the signal-to-noise ratio of the resulting picture is quite likely to suffer.

The loss of storage ability in a film camera tube is caused by leakage of the charge pattern across the surface of the mosaic. This, of course, also results in a loss of resolution. Consequently, any camera tube whose storage ability is impaired to the extent that it is unsatisfactory from this viewpoint will usually be quite poor from a resolution standpoint also.

**8-6. Iconoscope Operating Techniques.** In the foregoing sections many of the idiosyncrasies of the iconoscope tube have been described, and the operating techniques required to cope with them were presented. In the following paragraphs there are discussed several additional operat-

ing techniques including the adjustment of (a) beam current, (b) shading waveforms, (c) image size and centering, and (d) streaking controls.

**Beam-current Adjustment.** The beam current of an iconoscope is a measure of the number of electrons in the scanning beam that is directed toward the mosaic. Control of the beam current is effected by adjustment of the bias of the control or No. 1 grid. Adjustment of the beam current of an iconoscope for optimum picture signals is an exceedingly important operation and one which requires that consideration be given to the following four factors: (a) the light intensity of the scene focused upon the mosaic, (b) spurious signal generation, (c) the signal-to-noise ratio, and (d) the mosaic grain.

The spurious signal increases with increased beam current since it is the result of the excess secondary electrons (released by the scanning beam) returning to the mosaic in a nonuniform manner. As a result, the greater the number of electrons flowing to the mosaic, the greater will be the spurious signals generated in the iconoscope. This, in turn, complicates the shading problems. It is desirable, therefore, to employ as low a beam current as possible and thereby simplify shading considerations.<sup>5</sup> In addition, low beam current reduces the tendency for excessive edge flare and thus makes the control of this spurious signal easier also.

On the other hand, if the beam current is too low, the signal-to-noise ratio will suffer. Furthermore, the contrast range of the picture will be reduced under these circumstances. Therefore, the optimum amount of beam current is that value where the noise no longer decreases appreciably with further increase of current. For the type 1850 iconoscope, beam currents in the vicinity of 0.10 microampere usually produce the best results, assuming use is made of a low-noise video amplifier, e.g., a high-gain triode cascode circuit with feedback.

As an iconoscope reaches the end of its useful life, it may be necessary to use excessive beam current in order to keep the noise at an acceptable low value. This type of operation will be accompanied with loss of definition and contrast range. Furthermore, excessive beam current tends to emphasize the grain structure of the mosaic and results in the appearance of the picture being projected upon a coarse-grained screen. An iconoscope should, of course, be discarded long before its performance degrades to this extent.

**Shading Waveform Adjustment.** The spurious signals created by the redistribution of secondary electrons upon the mosaic of the iconoscope are counteracted by mixing, with the video output signal from the tube, potentials of opposite polarity and equal amplitude. The waveforms most

<sup>5</sup> Benson, K. B., and A. Ettlinger, Practical Use of Iconoscopes and Image Orthicons as Film Pickup Devices, *J. SMPTE*, Vol. 57, No. 1, p. 9 (July, 1951).

commonly used for this purpose are (a) saw-tooth signals at both vertical and horizontal frequencies, (b) parabolic shaped waveforms also at vertical and horizontal frequencies, and (c) occasionally sine-wave signals at both frequencies. Where the full complement of shading signals is made available, there are, therefore, a total of eight controls necessary for the shading operation alone (the sine wave is usually adjustable in amplitude and phase, all others in amplitude only). Although the spurious signal generated in an iconoscope is a function of the scene content, it is found in practice that, when *adequate edge lighting* and *correct beam current* are employed, relatively little shading is required even with marked changes in scenes. On the other hand, if the two conditions stipulated are not met, a great deal of shading will be found necessary to produce an acceptable picture.

Both picture and waveform monitors are useful in determining the correct adjustment of the shading controls. Neither monitor can be very well dispensed with in favor of the other, although, in the final analysis, of course, the appearance of the picture as seen on the picture monitor is all-important. On the other hand, the eye cannot detect errors in shading so readily on the picture monitor as on the waveform monitor. On the picture monitor, the net results of the spurious signal and the compensating shading signal manifest themselves as tones of gray, *i.e.*, as degrees of shading—whence the name. The incremental difference in gray scale that is necessary before it becomes discernible depends upon a great number of factors including the ambient light falling upon the face of the picture tube, the brightness of the reproduced picture, eye fatigue, the acuity of the observer, and the nature of the scene. On the other hand, the waveform monitor displays all signal amplitudes as displacements from a reference line. Under these circumstances, many of the ambiguous factors that are present, when only picture monitors are used for shading adjustments, may be eliminated. In practice, the judicious use of a picture monitor, in conjunction with both vertical and horizontal waveform monitors, usually results in the best over-all performance.

The vertical and horizontal saw-tooth waveforms are probably the most useful ones. By observation of both the picture and the vertical waveform monitors, the vertical saw-tooth signal is adjusted so that the field from top to bottom of the picture (left to right on the waveform monitor) is approximately even. This control is therefore used primarily to correct the shading at the top of the picture with respect to the bottom, or vice versa. The horizontal saw tooth is adjusted in a similar manner except here the field is made approximately even from a left to right viewpoint; *i.e.*, the horizontal saw tooth corrects the right side of the picture with respect to the left, or vice versa.

The vertical parabolic shading waveform darkens or lightens the center of the picture with respect to the top and bottom. It is used to correct shading of the picture at the top and bottom simultaneously with respect to the center, or vice versa. The horizontal parabolic shading waveform darkens or lightens the center of the picture with respect to the edges. It may, therefore, be used simultaneously to correct the side of the picture with respect to the center, or vice versa.

The vertical sine-wave shading signal, if used, darkens or lightens the picture in a sinusoidal fashion from top to bottom. In addition to its amplitude, the phase of this waveform can usually be adjusted and thereby permit vertical shift of the sinusoidal shading. The horizontal sine-wave shading signal darkens or lightens the picture in a sinusoidal fashion from left to right. The phase of this signal can also be adjusted so as to shift the shading effects from left to right. In some instances a master shading control is provided in order to permit the over-all adjustment of the amplitude of the combination of all shading voltages that are applied to the picture signal.

**Application Bar Elimination.** In televising motion-picture film it is customary to flash the picture on the mosaic of the iconoscope for only a very short time during the vertical blanking period (see Sec. 9-6, *Pulldown and Projection Cycles*). This procedure results in a large pulse of light falling on the mosaic at field frequency. This, in turn, gives rise to a large signal pulse that may drive the grids of video amplifier tubes positive and cause grid current to flow. Should this happen, the operating points of the amplifier tubes affected will be changed with a corresponding change in their gain and transfer characteristic. Fortunately, the effects of this so-called "application bar" can be largely eliminated by the use of a feedback preamplifier and by adjustment of the back light on the iconoscope tube. Just the right amount of back lighting will largely eliminate the application bar. Too much back light, on the other hand, will reverse the polarity of the signal pulse. The limit in the back or bias light intensity is reached when a dark shading bar begins to appear across the top of the picture—an indication that the polarity of the signal has reversed. The magnitude of the application bar signal and, therefore, the amount of back light required to annul its effects, are functions of the average density of the film in the gate of the projector. Thus, it is found that, for optimum cancellation of the application bar, slight adjustments of the back lighting intensity must be made with each change in the average brightness of the picture.

**Image Size and Centering.** The importance of having the edge lighting come up to the very edge of the scanned raster was pointed out in Sec. 8-4). The edge light position on the iconoscope mosaic is normally ad-

justed during installation of the tube and does not lend itself to ready adjustment during normal operations. Accordingly, in order to produce a picture with the least edge flare, it is very important that the scanning be adjusted so as to stop as close as possible to the band of edge light. Adjustment of the raster size and centering can usually be readily accomplished since the controls for this purpose are entirely electronic and generally easily accessible.

By the same token, care must be taken to carefully center the scene that is being projected on the mosaic of the iconoscope so as to place it just tangent to the bands of edge lighting. This procedure will ensure the minimum of cropping of the edges of the picture by the scanning process. In general, it is preferable to permit the scanning raster to define the edges of the transmitted picture since this usually results in cleaner and better defined edges than is the case when the edges of the projected material are permitted to show in the television picture. It is to be noted, however, that in some instances the aspect ratio of the projected material may not conform to the standard television ratio of 3 to 4. Under these circumstances, when it becomes necessary to crop in the vertical direction, it should almost always be done at the bottom rather than the top of the picture for the reasons given in Sec. 7-5, *Framing of Action*.

**8-7. Iconoscope Camera Optics.** Because of its physical configuration, the iconoscope tube presented a number of difficulties, in so far as lenses were concerned, when it was used for field and studio camera applications. Fortunately, these problems do not exist when the iconoscope is used as a projector camera tube. Here, as contrasted to studio camera use, the film or stills usually used are all smaller than the iconoscope mosaic and, therefore, some magnification rather than a reduction in size is required. Consequently, it is simply necessary to equip the projector with a lens that produces the correct picture size when the machine is located the desired distance away from the iconoscope tube.

As a rule, in the interest of as compact an arrangement as possible, the projector is located as near to the camera tube as feasible. The minimum distance is determined, of course, by the physical size of the iconoscope camera and the projector. Convenience in operation and multiplexing considerations (see Sec. 9-11), however, often dictate a distance somewhat greater than the minimum. Upon taking these matters into account, the *exact* distance between the projector and the camera is finally determined by the availability of lenses. It is obviously desirable to make use of the lens that comes closest to fitting requirements than to have a special lens designed and manufactured.

By neglecting the distance between the nodal points of a projection lens (which data are seldom readily available in a practical case), the focal

length of a lens and the distance from the object to the image may be reduced to the following simple formula:

$$f = \frac{D \times m}{(m + 1)^2}$$

where, as shown in Fig. 8-6,

$f$  = focal length of lens, in inches.

$D$  = distance from film or slide to camera-tube screen, in inches.

$m$  = magnification required =  $h_i/h_o$ .

Conversely, the necessary distance between the object and the image for a lens of given focal length is:

$$D = \frac{(m + 1)^2}{m} \times f$$

Attention is called to the fact that the distance  $D$  in the above equations is *not* the distance from the front of the projector to the front of the camera. Rather, it is the distance from the plane of the material being projected to the plane of the camera tube's mosaic or photocathode. Inevitably this latter distance is longer than the minimum clearance between the projector and the film camera.

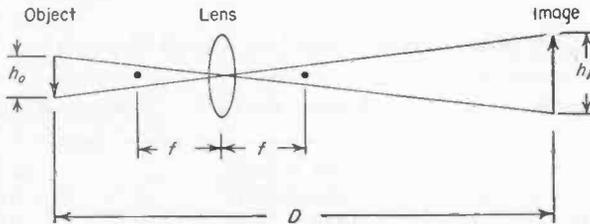


FIG. 8-6. The geometry of the optics used for the projection of film.

Furthermore, the above simplified (but practical) formula results in a calculated projection distance that is from 1 to 2 in. greater than that actually found in practice (depending upon the design of the particular projection lens involved) as shown by the typical examples given in Table 8-1. If this is kept in mind, the simplified formula will be found sufficiently accurate for any normal design work since, in the final analysis, the exact position of a projector is determined by trial before it is permanently fastened in place.

The required magnification,  $m$ , depends upon the size of the material being projected, since the size of the camera tube's mosaic is fixed. The nominal size of an iconoscope's mosaic is  $3\frac{9}{16}$  by  $4\frac{3}{4}$  in., but, in practice, it is usually desirable to allow a  $\frac{1}{32}$ -in. border all around the projected picture on the mosaic, as shown in Fig. 8-5. Under these circumstances,

the nominal dimensions of the net area of the projected image become  $3\frac{1}{2}$  by  $4\frac{11}{16}$  in.

The standard areas of 16- and 35-mm projector apertures, of 2- by 2-in. slides, and opaques suitable for use in the telop (Sec. 9-4) projector are also listed in Table 8-1. The magnification required for the different types of material when projected on an iconoscope camera tube is given also.

TABLE 8-1. ICONOSCOPE CAMERA OPTICAL RELATIONSHIPS

a. Projection Distances (Throw) of Typical Film Projector Lenses

<i>Film projector</i>	<i>Projection lens, focal length (in.)</i>	<i>Calculated throw* (in.)</i>	<i>Actual throw † (in.)</i>
16 mm.....	3	43	39½-42½
16 mm.....	3½	50	47⅝-48
16 mm.....	4	57½	56 -56¾
35 mm.....	6½	52	50 -51⅞

\* Based upon simplified formula given in text.

† Based upon manufacturers' published data.

b. Magnification Required for Typical Projectors

<i>Projector</i>	<i>Aperture size (in.)</i>	<i>Required magnification ‡</i>
16-mm film .....	0.284 × 0.380	12.3
35-mm film .....	0.612 × 0.816	5.7
2- by 2-in. slide.....	0.844 × 1.125	4.15
4- by 5-in. opaque.....	3 × 4	1.17

‡ For coverage of iconoscope mosaic within  $\frac{1}{32}$  in. of all borders, *i.e.*, net area of  $3\frac{1}{2} \times 4\frac{11}{16}$  in.

In setting up an iconoscope camera for projector service, care must be exercised that stray light does not enter the camera and fall upon the surface of the mosaic. Should this happen, it may adversely affect the resulting picture signal in several ways. For example, if the light is from an a-c source, it can introduce hum in the outgoing signal. In this respect fluorescent lamps are worse offenders than incandescent lamps because of the higher flicker amplitude of the former. Both, however, can cause serious degradation of picture quality. Furthermore, any stray light on the surface of the mosaic, whether from outdoors or from lighting fixtures, will result in a reduction in the effective contrast of the projected scene. This,

also, results in degradation of the transmitted picture signal, assuming that the contrast range of the original material was correct for television transmission.

In shielding an iconoscope from sources of stray light, it is necessary to take into consideration the possibility of light being reflected into the camera from the white clothing of an occupant of the telecine room. Further, if the room has any outside windows, the amount of light coming into the room at various times of the day and different seasons of the year must be given due consideration. Finally, it is advisable to guard against light reflections from the inside of the camera housing itself from internal sources such as back lights and edge lights.

**8-8. Iconoscope Camera Circuits.** The appearance of a typical iconoscope film camera is shown in Fig. 8-7. The unit shown weighs 60 lb and is 14 in. high, 15 in. wide, and 17 in. deep. Contained within the housing are the iconoscope camera tube, a video preamplifier, and a blanking circuit chassis. Supporting circuits for the iconoscope camera illustrated are located in an associated camera-control unit and an equipment rack, which units are described in the following section.

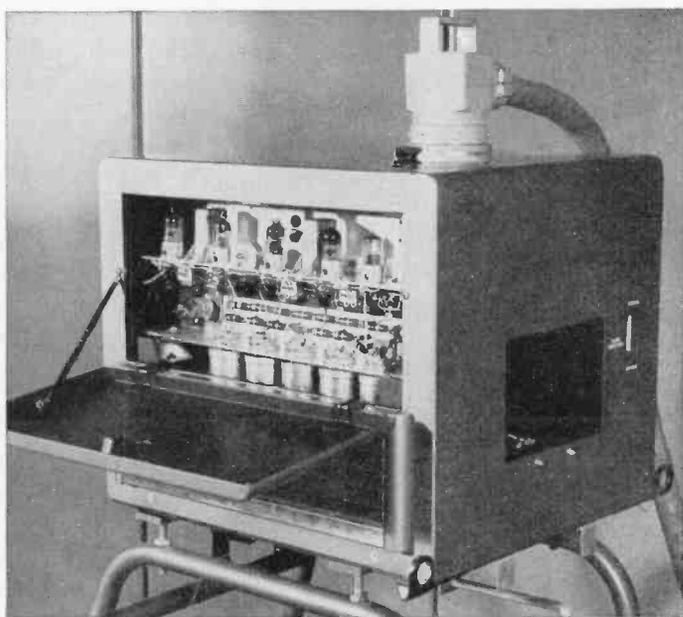


FIG. 8-7. In this film camera an iconoscope tube is mounted internally with its mosaic aligned with, and normal to the axis of, the rectangular port seen at the right. An associated video preamplifier chassis is at the left and a camera cable connector on the top of the case. (Courtesy of General Electric Company.)

The film camera shown in the photograph has one of its side covers open to show the video preamplifier chassis which is shockmounted within the unit. The chassis containing the blanking circuits occupies a similar position on the opposite side of the camera. The "front" of the camera is the face toward the right of the photograph which contains a rectangular opening through which the picture to be televised is projected. No lens system is incorporated in the film camera itself since reliance is placed on the optical systems in the associated film, slide, or opaque projectors (see Chap. 9) to focus the image directly on the mosaic of the iconoscope. Immediately below the afore-mentioned opening are two warning lights which are illuminated when the film camera is in operation.

The large plug at the top of the unit provides a means for connecting all signal, blanking, driving-pulse, and power circuits in the film camera to the supporting equipment in an associated rack and camera-control unit. The connector is similar to a camera cable connector (see Sec. 15-4).

The iconoscope camera tube together with its deflection yoke is mounted in the center of the housing, between the video preamplifier and the blanking chassis, with its mosaic parallel to and aligned with the rectangular opening in the cabinet. Adjustable edge lights capable of directing a sharply defined beam of light on the mosaic of the iconoscope are mounted on the bottom of the cabinet immediately inside the picture opening. The back light for the iconoscope is mounted on the inside of the rear door to the cabinet.

A schematic block diagram of the iconoscope film camera described is shown in Fig. 8-8. The video output signal of the iconoscope is applied to the grid of the first amplifier stage, V1, which uses a relatively high grid load resistor in order to secure a good signal-to-noise ratio. This arrangement, however, results in high-frequency attenuation for which compensation is introduced farther along in the amplifier. On the other hand, this problem can be avoided by incorporating inverse feedback in the iconoscope preamplifier. Under these circumstances the feedback loop may be arranged so that its frequency characteristic is also determined by the nature of the input circuit. Since this feature may be employed to control, in a compensating manner, the over-all frequency characteristic of the preamplifier, the need for further high-frequency equalization may be avoided.

The second video amplifier, V2, is a conventional shunt-peaked stage whose output drives the third video amplifier, V3. The signal level at this point is sufficiently high so that the equalization required to make up for the high-frequency losses incurred at the input of the amplifier may be introduced without degrading the signal-to-noise ratio. Accordingly the

plate circuit of video amplifier V3 contains an adjustable high-frequency peaking circuit.

The fourth and fifth video stages, V4 and V5, are conventional shunt-peaked stages and are followed by an output stage which supplies a 0.1-volt peak-to-peak, black-negative signal from its cathode circuit when a positive image is projected upon the mosaic of the iconoscope. When negative film is projected, the polarity of the resulting video signal may be reversed by the expedient of obtaining the output signal from the plate rather than the cathode circuit of the output stage, V6. Under these cir-

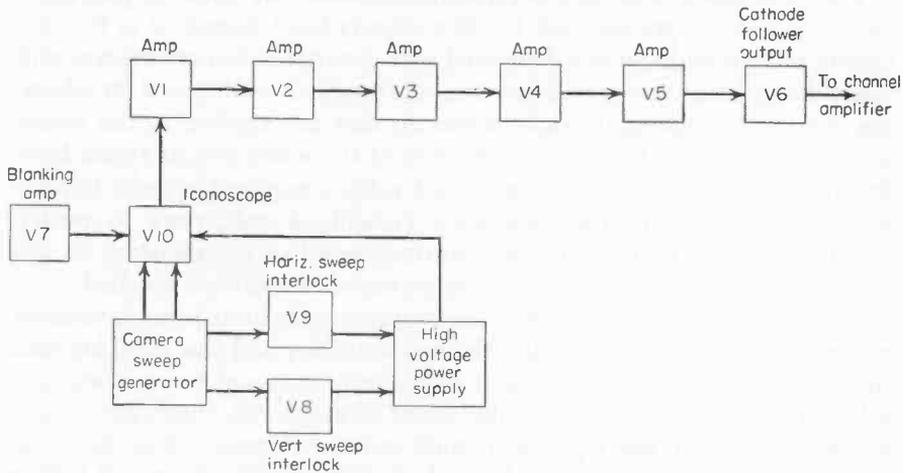


FIG. 8-8. A schematic block diagram of the video preamplifier, blanking amplifier, sweep interlock circuits, and high-voltage power supply that are contained in the iconoscope film camera shown in Fig. 8-7.

cumstances, a black-negative video signal is again obtained, and thus negative film may be used and a conventional picture produced on picture monitors and receivers. For convenience in accommodating either positive or negative film in actual operations, the switch for selecting either plate or cathode output from the final stage is located on top of the camera, to one side of the cable connector, as shown in Fig. 8-7. Thus, at the turn of a switch, either positive or negative originals may be employed to produce normal picture signals.

The blanking circuits contained in the film camera illustrated consist simply of a single-stage blanking amplifier, V7, which is arranged to clip off the base of composite (horizontal and vertical) blanking pulses obtained from a blanking generator located external to the film camera (see below). After amplification, these blanking pulses are applied to the grid

of the iconoscope to bias off the scanning beam during both horizontal and vertical retrace periods.

Two additional tubes, V8 and V9, are contained on the blanking chassis in order to provide a protective circuit to prevent damage to the iconoscope should either the vertical or the horizontal sweep circuit fail. In operation, the tubes amplify and rectify a sample of the respective sweep voltages and, via a relay control tube, permit application of the high voltage to the iconoscope only when adequate sweep voltages are present.

**8-9. Camera-control and Supporting Circuits.** In order to provide a complete film camera channel, the film camera head described in the preceding section must be supplemented with a suitable camera-control unit containing picture and waveform monitors together with means for adjusting the various potentials and waveforms that are applied to the iconoscope. In addition, further amplification of the video output signal from the film camera head (approximately 0.1 volt) is required in order to raise it to the standard transmission level (usually 1 volt, peak to peak). Finally, blanking and shading waveform generators are required, as are power supplies for all the elements in the entire film camera channel.

It is common practice to mount the power-supply units in an associated equipment rack while the video channel amplifier and the blanking and shading generators may be located either in the base of the control console or in an equipment rack. The former arrangement somewhat simplifies installation of the equipment and conserves space. The latter or equipment rack arrangement, although requiring more space and longer interconnection cables, provides better ventilation for the equipment and greatly facilitates its adjustment and maintenance.

Typical film camera-control units are shown at the extreme left end of the array in Fig. 6-4 while an individual unit is shown in Fig. 8-9. The unit at the top of the assembly contains a combination picture and waveform monitor (see Sec. 6-8) while a film camera-control panel is located in a horizontal plane flush with the desk top. This panel contains all the controls which may require adjustment during normal operational use of the film chain. These include means for adjusting video gain, blanking level, electronic focus, centering of vertical and horizontal sweeps, beam current, back light intensity, and shading waveforms. The particular equipment illustrated has individual controls for adjustment of the polarity and amplitude of four shading waveforms: horizontal saw-tooth, vertical saw-tooth, horizontal parabola, and vertical parabola waveforms.

A typical rack-mounted assembly of the supporting equipment for an iconoscope film camera is shown in Fig. 8-10. In this particular assembly a blanking and shading generator chassis is mounted at the top of the rack,

followed by a sweep generator chassis, a video channel amplifier, and then a series of power-supply units for the afore-mentioned equipment and the camera head itself.

The function of the channel amplifier that is associated with the film camera head is to mix the shading and blanking signals with the video output of the film camera and to amplify the combination in order to provide signals suitable for program transmission and monitoring purposes.

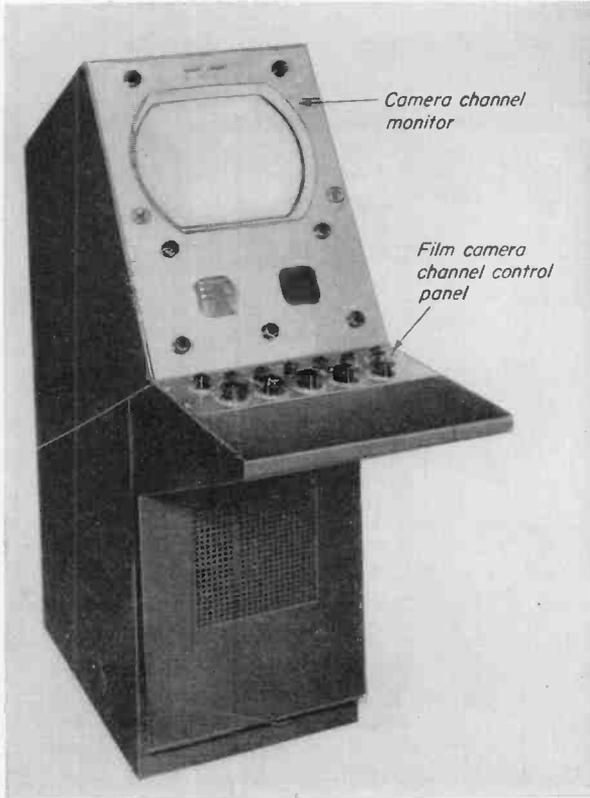


FIG. 8-9. An iconoscope film camera-control console containing a picture and waveform monitor in the upper portion and a camera-control panel on the shelf top. (Courtesy of General Electric Company.)

This particular unit consists of a six-stage video amplifier capable of providing an over-all gain of from ten to fifteen times and having uniform transmission over a bandwidth in excess of 6.5 Mc. The amplifier incorporates a specially arranged clamper that automatically sets the reference black level to the blackest part of the picture. In addition, a conventional keyed clamper is employed to remove hum and low-frequency micro-

phonics and to correct for deficiencies in the low-frequency response of preceding portions of the system.

The four types of shading pulses mentioned above are obtained from the shading generator (Fig. 8-10), which is driven by horizontal and vertical synchronizing pulses, and by means of suitable circuitry develop the waveforms required for shading purposes. In addition, this unit develops the signals necessary for blanking the camera output during the vertical and horizontal retrace periods.

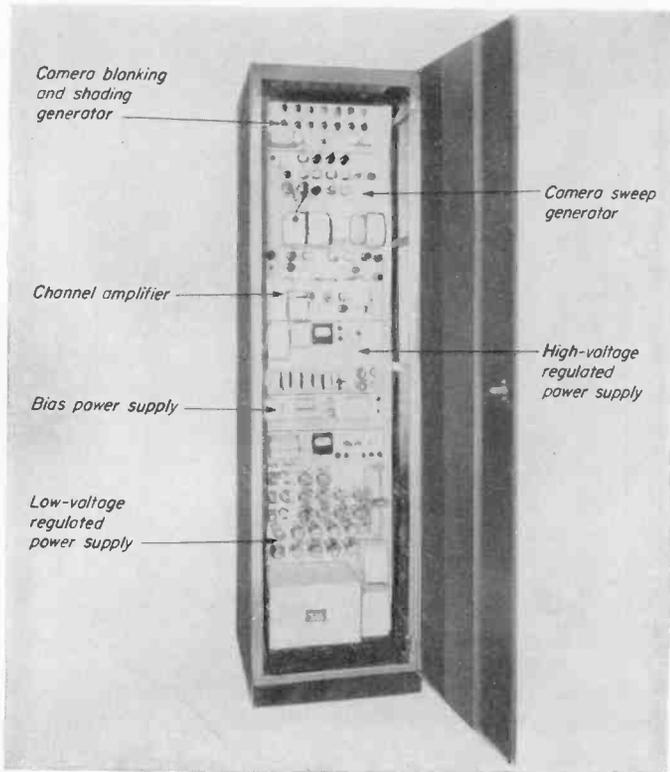


FIG. 8-10. Rack-mounted supporting equipment for the iconoscope film camera and associated control unit shown in Figs. 8-7 and 8-9. (Courtesy of General Electric Company.)

The sweep generator chassis produces the horizontal and vertical sweep signals required for controlling the deflection of the iconoscope scanning beam. Vertical and horizontal driving pulses from a synchronizing waveform generator are applied to the sweep generator unit where they are processed to develop the desired waveforms. As explained in Sec. 8-3, the amplitude of the horizontal scanning waveform must be increased in

a predetermined manner during each field in order to overcome the key-stoning effect that would otherwise result because of the offset electron-gun structure of the iconoscope. In addition, provisions are made for the usual adjustment of vertical and horizontal size and linearity of scanning.

As expected, iconoscope film camera chains of different manufacturers differ considerably in the methods employed to generate and process the numerous waveforms required to operate an iconoscope tube. In addition, the packaging of the various units varies over wide limits. In the final analysis, however, much the same functions must be performed since all manufacturers employ the same type of iconoscope tube in their film camera. The performance of the various chains differs, of course, depending upon the skill of the equipment designer, the manner in which a given chain has been adjusted and maintained, and the aptitude of its operator.

**8-10. Image Orthicon Film Camera Chain.** Because of its picture retention difficulties (see Sec. 2-6), the image orthicon when used for projection purposes can be safely employed only for motion-picture film applications. Slides may be projected upon the photocathode of the image orthicon tube, without fear of picture retention, only if held for not more than a few seconds. This operation is so hazardous, however, that image orthicons are not normally employed for this service.

**Advantages and Disadvantages.** The image orthicon tube can be compared directly with its predecessor, the iconoscope, for film projection applications. The transfer characteristics of both tubes are a function of the potentials applied to their electrodes. In addition, the transfer characteristics of both tubes are determined by the average level of light flux on their targets or mosaics. However, the shapes of the transfer characteristics of the two tubes are different from each other, as is the manner in which the transfer characteristics are influenced by the control potentials and the average light intensity of the scene.

Although the target size of the image orthicon tube is considerably smaller (1.6-in. diagonal) than the mosaic size of the iconoscope (5.9-in. diagonal), nevertheless the resolution of both tubes, in so far as commercial television applications are concerned, is limited in the horizontal direction largely by the pass band of the associated video amplifiers which seldom exceed 8 to 10 Mc. Accordingly, resolution in the 600-odd-line region may be obtained from either tube. In the vertical direction, the resolution is limited by the number of scanning lines and the accuracy of the interlacing of these lines.

The nature of the noise coming from image orthicon and from iconoscope camera chains not being alike, the signal-to-noise ratios obtained from the two tubes are not directly comparable in a quantitative way. The relative amount of noise that each tube contributes to a picture signal

must be judged on a subjective basis in order to obtain a meaningful comparison. In the image orthicon tube, the depth of modulation of the scanning beam determines the signal-to-noise ratio, while in the iconoscope camera the noise originating in the grid circuit of the first video amplifier is usually the limiting factor. Taking all factors into consideration, it is usually found in practice that, for film having a limited contrast range, the nature and the amount of noise originating from an image orthicon film chain are less objectionable than those from an iconoscope camera. On the other hand, for normal film where the contrast range is large, the iconoscope is capable of delivering a picture signal that is singularly free from noise.

The image orthicon film camera chain has an advantage over the iconoscope chain in that neither back lighting, edge lighting, nor shading operations are necessary. On the other hand, the image orthicon tube is critical as regards the intensity of the highlights projected upon the photocathode, and careful adjustments must be made to compensate for any changes in highlight brightness of the different scenes of a film. Finally, it is subject to the many vagaries detailed in Sec. 7-2, including black halos, image orthicon ghosts, clouding, and streaking.

**Camera Circuits.** There is very little difference between image orthicon cameras used for live pickup applications and those used for film chain work. The major differences include horizontal and vertical deflection reversal, ability to reverse signal polarity, improved low-frequency response, and the use of a so-called close-spaced (target-to-screen) image orthicon tube.

If the beam of light from the film projector is focused directly upon the photocathode of the camera tube, the image will be reversed from left to right as compared to that encountered in live camera applications. Under these circumstances, it is necessary to reverse the direction of the horizontal scan in order to compensate for the picture reversal. On the other hand, if a mirror diplexer is used between the projector and the camera tube, as is often the case, then the image will be in the same sense as when the camera is used in the studio or field, and reversal of the scanning circuit is not necessary. In any event, the image projected upon the photocathode from the film will always be upright rather than inverted as is the case when the camera is used for direct pickup. Accordingly, the direction of vertical scan must be reversed for film applications. Provisions for reversing the scan of both the horizontal and the vertical scan can be made by the simple process of installing double-pole double-throw switches in the leads to the two deflection yokes involved. The method whereby this may be accomplished in a typical image orthicon camera is shown in Fig. 8-11.

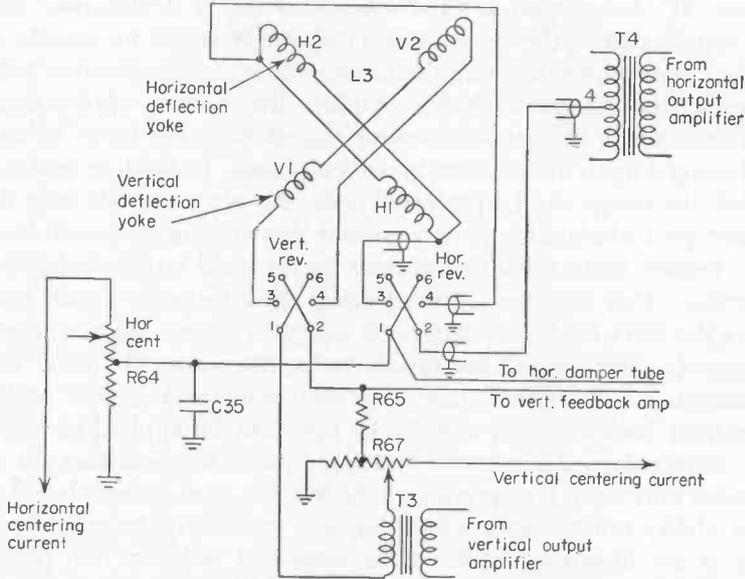


FIG. 8-11. Circuit modifications for an image orthicon camera to provide for reversal of both horizontal and vertical scanning directions in order to adapt it to film pickup applications.

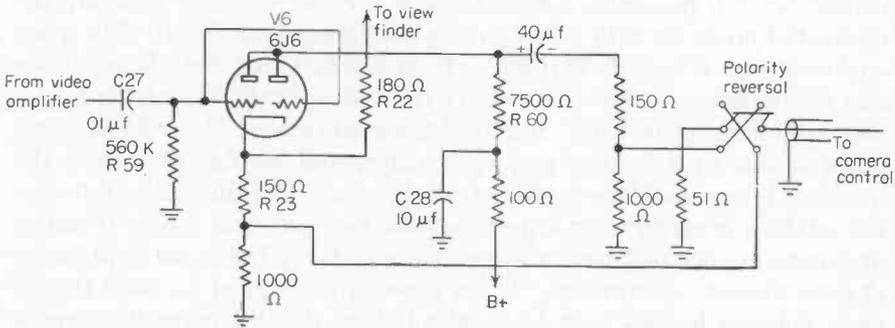


FIG. 8-12. Circuit modifications for an image orthicon camera in order to provide means for coping with the transmission of both negative and positive film.

In television film applications, in addition to the projection of conventional prints, it is often advantageous to be in a position to accommodate negative film. This can generally be accomplished by relatively simple changes in the output stage of the image orthicon camera, as shown in Fig. 8-12. In this typical unit, a dual triode tube, with both sections connected in parallel, is normally used as a cathode-coupled output stage. By the addition of five resistors whose values are shown but which do not

carry an "R" designation, a 40- $\mu$ f condenser and a double-pole double-throw toggle switch, the output stage may be arranged to provide either cathode or plate coupling and, therefore, output signals of either polarity.

**Close-spaced Image Orthicon.** Unlike live pickup applications, an image orthicon in film camera service cannot have the scene being projected imaged upon the photocathode at all times. Instead, as explained in Sec. 9-6, the image can be projected upon the photocathode only during the short vertical-blanking period. Under these circumstances, it is necessary to employ an image orthicon tube having good target-charge storage properties. This requires a tube having close target-to-screen spacing, such as the 1854 tube. Close-spaced image orthicons have an apparent decrease of sensitivity and are unable to handle scenes of widely varying illumination levels. The former is of no consequence in film projection applications because, even though the light can be applied in only relatively short pulses, the sensitivity of the tube is so great that for direct projection only very low-intensity light sources need be employed. The lack of ability to cope with wide ranges of scene brightness while undesirable is not insurmountable. As a matter of fact, for film projection service, this limitation is not so severe as would be the case were a closed-spaced tube to be used for outdoor pickup use.

**8-11. Image Orthicon Camera Optics.** When the image orthicon tube is used for film projection applications, it may be necessary to equip the associated projector with a lens having a different focal length than when an iconoscope is used.<sup>6</sup> This stems from the fact that the photocathode size of the image orthicon is smaller than the mosaic size of the iconoscope, by a factor of 3.65. Bringing the camera tube closer to the projector results in a smaller projected image, and by this procedure the resulting image could be made the correct size. Unfortunately, this simple solution is usually not a practical one because most lenses found in projectors are not suitable for projecting a high-resolution flat-field image at short throws. Accordingly, lenses especially designed for short throws (*e.g.*, enlarger lenses) must be substituted for the lens normally encountered in the television film projector. The magnifications required for 16- and 35-mm film projectors are given in Table 8-2.

Another very important consideration enters into the selection of a lens for a projector to be used with an image orthicon tube. It will be recalled that the photocathode of the image orthicon is semitransparent. As a result, care must be taken that the light that passes through the photocathode does not strike the side walls of the image orthicon or parts of its internal structure other than the target. Should this happen, light reflec-

<sup>6</sup> Benson, K. B., and A. Ettlinger, Practical Use of Iconoscope and Image Orthicons as Film Pickup Devices, *J. SMPTE*, Vol. 57, No. 1, p. 9 (July, 1951).

tions may be experienced that will "fog" or otherwise degrade the picture. Flare light of this nature can be avoided by selecting a lens of sufficiently long focal length so that the width of the light beam is sufficiently narrow to avoid the difficulty cited. In practice, lenses having focal lengths of 3 and 5 in. are usually found suitable for 16- and 35-mm film projectors, respectively, when the latter are used with image orthicon tubes.

TABLE 8-2. IMAGE ORTHICON CAMERA OPTICAL RELATIONSHIPS

## a. Projection Distances (Throw) of Typical Film Projector Lenses

<i>Film projector</i>	<i>Projection lens focal length (in.)</i>	<i>Calculated throw* (in.)</i>
16 mm .....	3	17¼
16 mm .....	3½	20
16 mm .....	4	23
35 mm .....	4	17
35 mm .....	5	21¼

\* Based upon the simplified formula given in the text.

## b. Magnification Required for Typical Projectors

<i>Type of film</i>	<i>Aperture size (in.)</i>	<i>Required magnification †</i>
16 mm .....	0.284 × 0.380	3.4
35 mm .....	0.612 × 0.816	1.6

† For image having 1.6-in. diagonal on photocathode of image orthicon camera tube.

Image orthicon projector cameras are even more susceptible to picture-signal degradation because of stray light than is the iconoscope camera. This results from the markedly higher sensitivity to light of the image orthicon tube. Accordingly, the amount of light required from the projector is proportionally less and, therefore, a given amount of stray light becomes a larger percentage of the total light on the photocathode. As a matter of fact, the sensitivity of the image orthicon tube is so great that it is advisable to exclude *all* light completely other than that directly from the film being projected. Fortunately, since the image orthicon tube does not require back lights or edge lights, there is no danger of stray light from internal camera sources such as these. In practice, stray light is often eliminated by the use of a light shielding tube between the lens on the projector and the photocathode of the image orthicon tube.

**8-12. Flying-spot Scanner.** The scanning of a subject with a spot of light for the purpose of creating a picture signal was the basic method used by the earliest workers in the television field. By converting the reflected light (or in the case of transparencies, the transmitted light) into electrical waves, a signal was created that was representative of the subject being scanned. The first television systems employing the flying-spot system utilized mechanical methods of scanning. Modern flying-spot scanners employ electronic methods for accomplishing the same fundamental process. Cathode-ray tubes having very short persistence screens are employed for the light source, and electron-multiplier phototubes are used to convert the reflected or transmitted light into picture signals. Flying-spot scanners do not lend themselves to the pickup of live talent for many reasons. However, they are useful for the transmission of transparencies and opaques.

**Motion-picture Film Transmission.** The transmission of motion-picture film with a flying-spot scanning device requires the availability of a special type of projector. As mentioned heretofore (Sec. 8-5, *Light-storage Properties*) and as detailed in Sec. 9-6, when conventional projectors are used for the television transmission of film, the picture is momentarily imaged upon a storage-type camera tube only during the vertical blanking time. This mode of operation has been adopted in order that the film may be moved to the next frame during the relatively long interval while the target or the mosaic of the camera tube is being scanned and the projector light source is extinguished. In a flying-spot film scanner, on the other hand, the film image is dissected line by line, and the only time that would be available for pull-down is the relatively short time allowed for vertical retrace (between 0.8 and 1.3 milliseconds). Although projectors with pull-down times as short as this are not impossible to build, they may put an excessive strain on the film, particularly the 35-mm size. As a result, it is generally considered desirable to make use of a motion-picture projector capable of continuous motion rather than intermittent motion where a flying-spot scanner is to be used for the conversion of the film image into television signals. Continuous-motion film projectors have been built for experimental purposes (see Sec. 9-1, *Nonintermittent Projectors*), but do not, as yet, enjoy wide application in the television broadcasting stations of this country. The use of the flying-spot scanner for motion-picture film offers several attractions, and it is to be expected that it will find commercial application in the television field.

**Transparent and Opaque Stills.** The use of a flying-spot scanner for the transmission of opaques and transparencies in the form of slides does not involve any of the projector problems that attend film transmission. Several flying-spot scanners for stills are therefore commercially available.

Although not so versatile as the telop and similar types of projectors for transparencies and opaques (see Chap. 9), nevertheless the flying-spot scanner offers the attraction of requiring a smaller investment than is represented by a telop (or other still projectors) and its associated projector camera chain. Furthermore, its cost of operation is less, since less expensive tubes are used than in a projector camera. Finally, the flying-spot scanner avoids the numerous and complicated adjustments required with most projector camera systems. It must be noted, however, that blemish- and grain-free flying-spot tubes are not always readily available.

**Scanner Design.** A practical adaptation of the flying-spot scanner principle for television applications is shown in Fig. 8-13. This unit<sup>7</sup> employs a 10-in. short-persistence cathode-ray tube as the source of the flying spot of light. The tube is mounted face up in the center portion of the equipment assembly, and a raster is formed on its face by conventional magnetic deflection methods. The light from this raster is focused upon a transparent 2- by 2-in. slide by a suitable lens, the transmitted light collected by a condenser lens system and projected upon the photocathode surface of an electron-multiplier phototube, as shown diagrammatically in Fig. 8-14. The resulting video signal is amplified, passed through a stage that modifies the transfer characteristic, has blanking and synchronizing pulses added, and is finally delivered at the output terminals as a composite television signal.

Details of the scanning circuits are given in Fig. 8-15. Negative horizontal and vertical driving pulses from a synchronizing generator are clipped by their respective amplifiers to ensure noise-free signals. The differentiated leading edges of each of these pulses are used to generate saw-tooth waveforms for application to deflection amplifiers. A standard

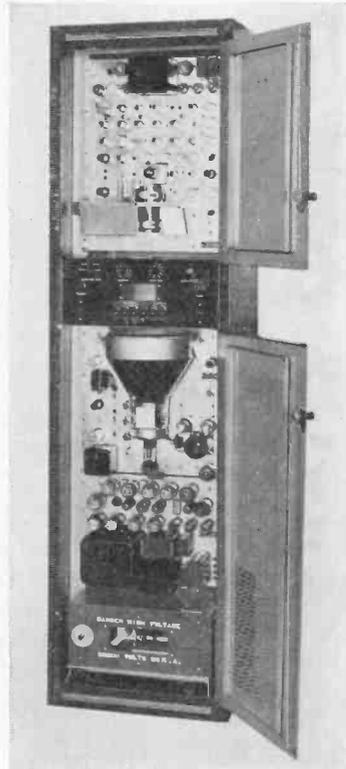


FIG. 8-13. A flying-spot scanner designed to handle the transmission of 2- by 2-in. slide transparencies. (Courtesy of Allen B. Du Mont Laboratories, Inc.)

<sup>7</sup> Thompson, R. D., Television Pickup for Transparencies, *J. SMPE*, Vol. 53, No. 2, p. 137 (August, 1949).

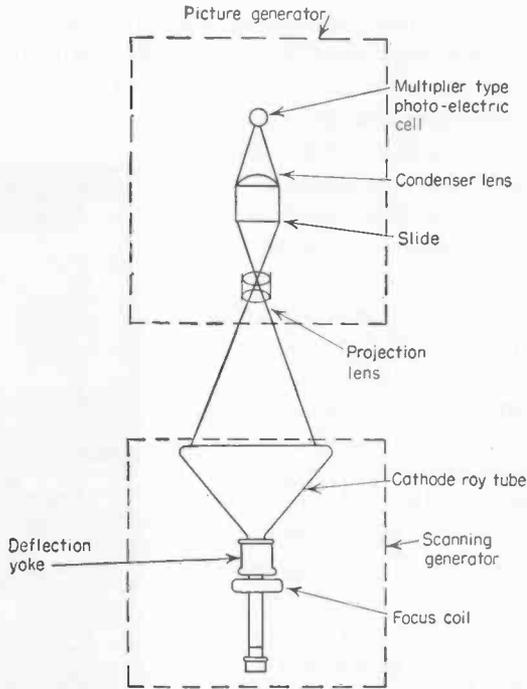


FIG. 8-14. A schematic drawing of a flying-spot scanner showing the cathode-ray tube upon which a scanning raster is produced, the optics for focusing the raster on a slide or film transparency, the light collector lens and photoelectric cell for converting the modulated light beam into electrical impulses.

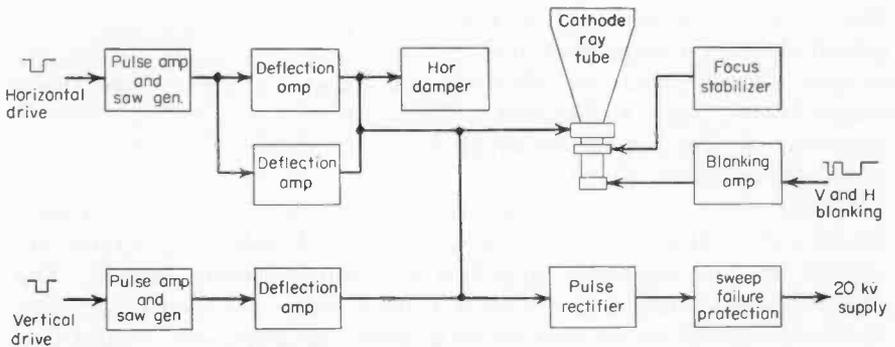


FIG. 8-15. A schematic block diagram of the circuits supporting the cathode-ray tube in a flying-spot scanner.

negative blanking pulse, consisting of both horizontal- and vertical-frequency components, is also obtained from a synchronizing generator and applied to a blanking amplifier which clips and amplifies the signal and then utilizes it to extinguish the scanning spot during the retrace periods. A pulse rectifier applies a positive voltage to a sweep-failure protection tube. The resulting plate current closes a relay whose contacts complete the cathode circuit of the cathode-ray tube only when the voltages across the secondaries of both deflection transformers are normal.

The focus-coil current is stabilized by means of a pentode which is capable of maintaining correct focus for a-c line-voltage variations of  $\pm 10$  per cent. The voltage impressed upon the grid of this tube is derived from both a regulated and an unregulated d-c source, the former acting as a reference and the latter as an indication of the line voltage. The plate current of the pentode flows through the focus coil and, in this way, automatic compensation for a-c line-voltage changes is obtained.

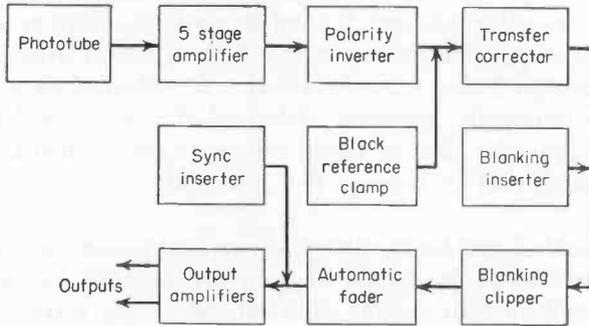


FIG. 8-16. A schematic block diagram of the circuits associated with the photoelectric cell in a flying-spot scanner.

The video amplifier and associated circuits are shown in Fig. 8-16. The output of the photo-multiplier tube is amplified by a five-stage frequency-compensated video amplifier which is followed by a unity-gain stage which acts as a polarity inverter in order that either positive or negative transparencies may be accommodated by the equipment.

The transfer characteristic of a photo-multiplier tube is essentially linear; *i.e.*, the output voltage is proportional to the input light intensity. In television applications it is the standard practice to employ a transfer characteristic wherein the output voltage is proportional to the logarithm of the subject brightness. A device to change the transfer characteristic of the flying-spot scanner is therefore necessary to make its output conform to the accepted standard. A remote cutoff pentode is used in the unit illustrated for this purpose, as shown in Fig. 8-16. By properly

choosing the operating conditions for this tube, a reasonably close approximation to an ideal transfer characteristic is obtained.

Since the flying spot is blanked off during retrace, there is no output signal from the phototube during this interval. This automatically results in a reference signal that bears a constant relation to black level. This reference signal is clamped in the grid circuit of the transfer-characteristic corrector stage, thereby ensuring that all signals are applied to the grid of this tube at the selected operating point. The desired relation between reference black and blanking level is achieved by means of a blanking inserter (operating in the plate circuit of the transfer-characteristic corrector stage) and a blanking clipper. The amount of inserted blanking and the blanking clipper are adjusted until the resulting signal is in accordance with the transmission standards that are in use.

An electronic fader stage is used just prior to the output amplifier in order to provide means for fading out one slide and fading in the next. The slides that are to be used are held in a supply hopper, and a solenoid-operated reciprocating plunger is used to push the bottom slide of the stack into proper position for scanning. The transition from one slide to another is accomplished in 0.2 second so that the effect of an instantaneous changeover is obtained. However, if desired, the electronic fader may be employed to fade the picture signal automatically to black just before the slide change and to fade in the next slide immediately after the change.

Standard vertical and horizontal synchronizing pulses may be added to the picture and blanking signals to form a composite television signal. This is accomplished by means of a synchronizing waveform inserter stage connected into the plate circuit of the fader amplifier. However, if the output from the flying-spot scanner is to be fed to a switching and mixing console, it is customary to add the synchronizing waveforms after the signal mixing operations are performed (see Sec. 6-5, *Remote Inputs*). Under these circumstances, no use is made of the synchronizing waveform inserter stage in the flying-spot scanner.

Two cathode-follower output stages are employed, one for feeding the program line and the other for a picture monitor. Both outputs are intended to feed into a 75-ohm resistive load and to provide a 2-volt peak-to-peak black-negative signal.

Although intended primarily for the reproduction of black-and-white slides, the flying-spot scanner described is able to handle color slides for monochrome reproduction. Although the cathode-ray tube output and the phototube sensitivity are confined largely to the green portion of the spectrum, the result is not adversely affected except in one way. Because of the limited contrast range in the greens of many color slides, the

signal-to-noise ratio that is obtained is inferior to that which results from the use of good black-and-white slides.

The equipment described is capable of 500-line resolution in the horizontal direction, while the vertical resolution is limited by the number of raster lines and the accuracy of interlace.

**8-13. Monoscope Tube.** The monoscope tube and its associated "camera" may be considered a specialized type of projector camera chain. This device is capable of producing a picture signal only of the one fixed pattern that is built into the tube. In spite of this, when available in a television broadcasting station, this camera is likely to be in use more hours per day than any other single camera. This is a consequence of the practice in television broadcasting stations of transmitting test patterns prior to regular program operations and of making the signals available on a continuous basis in their control rooms and shops for routine maintenance and test purposes.

**Construction.** The monoscope tube is similar to the iconoscope in so far as general construction and method of operation are concerned. It does not have a photosensitive mosaic, however, and since it is unnecessary to focus an optical image upon the tube, there is no need for the offset neck construction for locating the electron gun to one side of the target. In the monoscope, an aluminum plate takes the place of the mosaic in the iconoscope. The fixed pattern desired is printed upon the surface of this plate with carbon ink. Upon being bombarded with electrons from the electron gun, those portions of the aluminum that are clear will emit more secondary electrons than the areas which contain a surface coating of carbon. The secondary electrons are collected by a collector electrode just as in the iconoscope. Thus by scanning the target in a systematic manner, a picture signal is obtained.

The aluminum pattern electrode is placed in the large end of the mono-



FIG. 8-17. This monoscope tube is approximately 5 in. in diameter and 12½ in. long overall. (Courtesy of Radio Corporation of America.)

scope tube and the electron gun in the small end (Fig. 8-17). Magnetic deflection of the scanning beam in both the vertical and the horizontal directions is achieved in a conventional manner by placing deflection coils over the neck of the tube.

**Output-signal Polarity.** The output signal appears across a load resistor connected between the collector and the metal target. The polarity of the signal is the reverse of that of the iconoscope, however. Since the aluminum emits most secondary electrons from the clear metal (or white) areas, the signal current of the monoscope is largest for white and a minimum for black. Accordingly, the signal developed across the load resistor becomes more negative (with respect to ground) as the pattern becomes more white; *i.e.*, the output is a white-negative signal. In order to obtain an output signal of the same effective polarity as from an iconoscope, it is customary to print the desired pattern on the face of the aluminum target as a negative. Another procedure, of course, is to use an odd number of stages in the monoscope video amplifier. Either procedure will result in a final signal that is in accordance with the industry standard calling for a black-negative signal for transmission purpose.

**Resolution.** The scanning spot in any picture-tube device has a finite size, and obviously detail smaller than the dimensions of the spot cannot be resolved. For the monoscope illustrated, this limitation establishes a minimum element size on the pattern electrode in the order of 0.0045 in. Since the height of the pattern electrode is 2.25 in., this limits the resolution of the monoscope tube under discussion to about 500 television lines. In order to obtain higher resolution, it is necessary either to decrease the size of the scanning spot (by redesign of the electron gun) or to increase the size of the pattern electrode.

**Pattern Limitations.** In laying out patterns for incorporation in custom-built monoscopes, it is necessary to observe certain precautions. For example, for the particular tube described above, it is evident that no detail smaller than approximately  $\frac{1}{500}$  of the picture height can be resolved. In designing a monoscope pattern, this limitation must be kept in mind, particularly with respect to the width of lines used to create the design.

The limitation imposed by the finite size of the scanning beam also makes the use of half tones to obtain shades of gray rather unsatisfactory. This stems from the fact that the element size needed in the half tones to form the desired shades of gray are smaller than can be resolved. This is not a serious limitation, however, since curved or straight lines separated by corresponding spaces, both of varying width, may be used very effectively to create various shades of gray (see Fig. 8-18). The line and space widths used to create the shaded effects must, of course, be carefully

dimensioned so that the resolving capabilities of the scanning beam, in relation to line or space widths, result in the shading tone desired. When the line and space widths are properly determined, they can be seen on the picture tube at close viewing distances. However, at normal viewing distances, they appear to merge to give a half-tone effect. This effect can be readily observed by viewing Fig. 8-18 both at close range and at a distance.

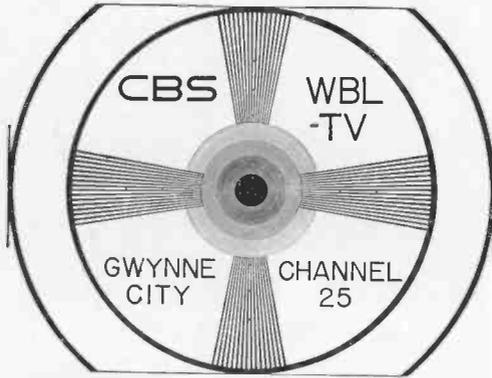


FIG. 8-18. The centrally located circles of this typical monoscope tube pattern illustrate the use of lines of various widths and spacing to create the appearance of various shades of gray.

**8-14. Monoscope Camera.** The monoscope camera is a complete television camera which produces a picture signal that may be used interchangeably in a television system with the output signals of field, studio, and projector camera chains. However, the picture signal is limited to the one pattern incorporated in the monoscope tube that is a part of the monoscope camera. When used to generate test-pattern signals, the monoscope camera supplies a video signal of known quality that may be used in place of a regular camera-chain signal. A complete camera chain is relatively expensive, and a monoscope camera provides an economical way of having available at all times a test pattern for equipment maintenance and broadcasting purposes.

**Description.** A monoscope camera consists of a monoscope tube, vertical and horizontal scanning generators, a video amplifier, blanking circuits, and the necessary power supplies. In the unit illustrated in Fig. 8-19, the monoscope tube is mounted in a vertical position at the left of the chassis (which is intended for rack mounting). The upper part of the monoscope is enclosed in a mu-metal shield, and the magnetic deflection coils are mounted within this shield.

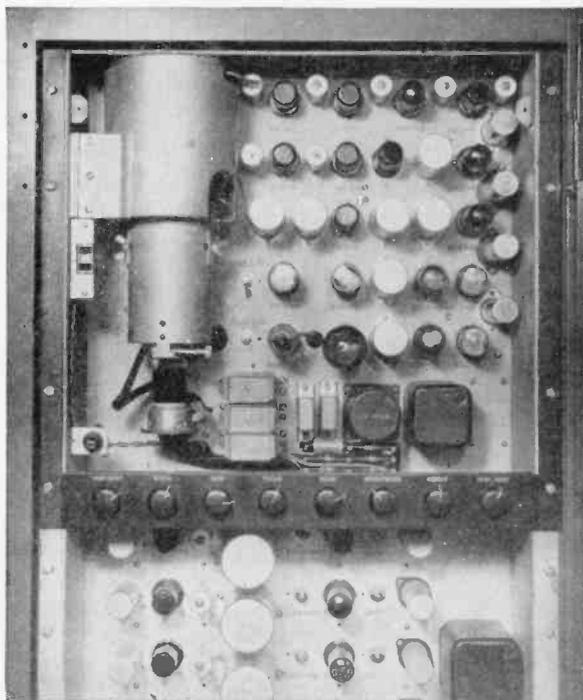


FIG. 8-19. The upper chassis in this equipment rack is that of a monoscope camera. The monoscope tube itself is mounted vertically within the tube shield at the left. (Courtesy of Radio Corporation of America.)

**Circuits.** A schematic block diagram of a typical monoscope camera is shown in Fig. 8-20. The vertical deflection circuit consists of four tubes and their associated circuits. A negative, vertical driving signal from a synchronizing generator is applied to the first tube which amplifies this signal and generates a saw-tooth voltage wave which is amplified by the second, third, and fourth tubes. The output of the last tube is applied directly to the vertical deflection yoke. Negative feedback is employed in the amplifier to improve scanning linearity.

The horizontal deflection circuit also requires a negative driving pulse. The first tube in this section of the unit amplifies the driving pulse and generates a horizontal saw-tooth voltage which is then amplified by two additional tubes and fed to the horizontal deflection coils of the monoscope tube.

The blanking amplifier consists of one tube and utilizes a negative blanking signal. The amplified blanking pulses are coupled into one of the video amplifier tubes to produce a combined picture and blanking signal.

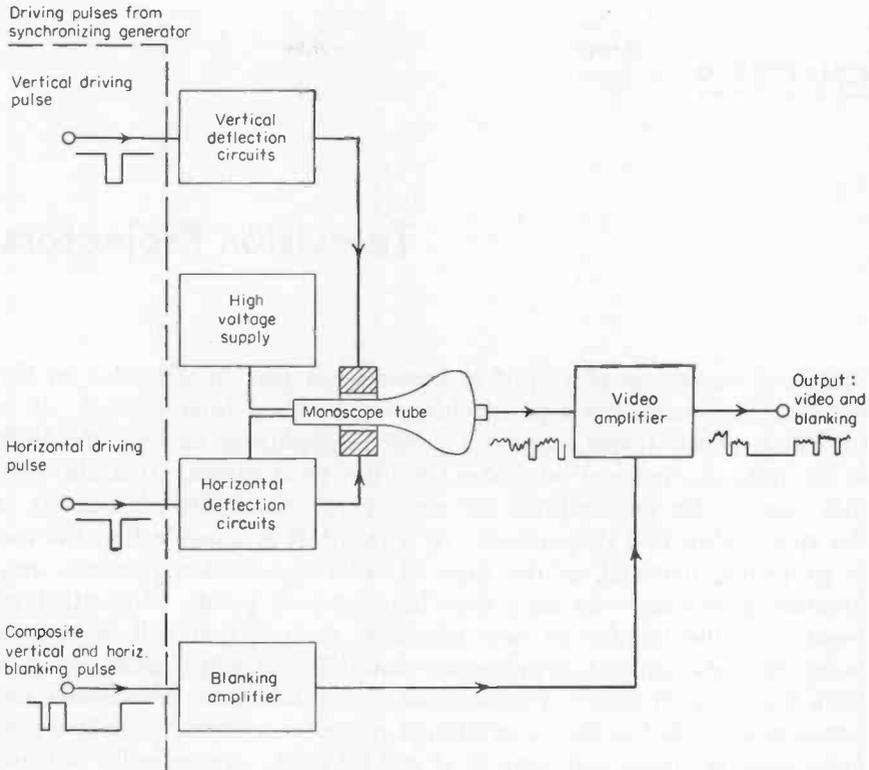


FIG. 8-20. A schematic block diagram of the circuits in a monoscope camera.

The video amplifier consists of a six-stage frequency-compensated amplifier that has reasonable uniform transmission to 8 Mc. The output signal from the monoscope is fed directly into the first stage of this amplifier, and the afore-mentioned blanking signal is introduced in the output circuit of the fourth stage. The output of the fifth stage, which contains both video and blanking signals, is fed to a clipper stage which adjusts the height of the blanking signal. The clipper feeds an output stage consisting of two tubes with their grids in parallel but with their plate circuits separate. This provides two separate outputs from the monoscope camera: one for regular transmission and the other for monitoring or other purposes. The maximum output potential is 1.5 volts, peak to peak, black negative, into a 75-ohm resistive load impedance.

## Television Projectors

THE FILM PROJECTOR plays just as important a part in television as the turntable and magnetic tape machines do in aural broadcasting. It is true that, at the major television program-producing centers, the bulk of the program material originates from live productions. It is also true that one of the justifications for employing video network circuits is the spontaneity that they afford. As a result, it is possible that the use of projection material, in the form of stills and motion pictures, may diminish percentagewise on a time basis at such points. Nevertheless, because of the number of new television stations that will come into being, the total amount of projection material used will steadily increase for a long time to come. Furthermore, as the television broadcaster becomes more skilled in the integration of projection material with live program material, more and more of it will be used. Numerically at least, the number of times projection material is used is bound to increase as television program directors take full advantage of the capabilities of the system that is available to them for creative expression. Even in those studios where live program production outweighs film programing, telecine (a contraction of the term "television cinema") room operations still bulk large since there is hardly a studio program that does not require the use of a still projector for titling or a motion-picture projector for inserting outdoor or other scenes into the studio production.

**9-1. Projectors for Television.** In television applications use can be and is being made of projectors for handling original material in several forms. Still projectors are used for both transparent slides and opaque materials. Motion-picture projectors are used for both 16- and 35-mm film. On the other hand, use has not been made of 8-mm film because its resolution capability is not commensurate with that of the television system and, in addition, it is not normally available with an accompanying sound track.

**Slide Projectors.** Assuming that a suitable slide projector is available, any size slides may be used for television purposes. From a practical

viewpoint, however, there is little need for employing slides larger than the standard sizes having over-all dimensions of 2 by 2 in. and  $3\frac{1}{4}$  by 4 in. The resolution capabilities of properly made slides of this size are generally adequate for television broadcasting purposes. To facilitate rapid handling of transparent slides, it is usually desirable to make use of a dual projector setup or some form of rapid-change mechanism that, in effect, permits instantaneously changing from one slide to another.

In addition to conventional individual slides (that are usually mounted in glass), some use has been made of transparencies made up in the form of individual frames on a continuous strip of motion-picture film. Projectors with instantaneous-change solenoid-operated automatic framing devices have been made available for handling this kind of slide film. This type of material lends itself to often-repeated slide sequences and has the advantage that the picture portion of the entire production is contained on one small roll of film. The disadvantages of the slide film include the inflexibility as to the order in which the material is presented and the relatively high cost of preparing the material. With individual slides not only can the material be assembled in any desired order but, if time should run out, any designated slides may be omitted from the presentation. Furthermore, all the slides are available individually for future use in building new programs.

**Opaque Projectors.** Opaques of any practical size may also be used for television purposes, provided only that a suitable opaque projector is available. Actually the size of copy used is largely a matter of convenience in preparation and handling. The smaller the copy size, the easier it is to illuminate the entire area uniformly. Balanced against this is the question of handling small cards. The best compromise seems to be to use an over-all size in the vicinity of 4 by 5 in. When opaques are used for television purposes, it is necessary to provide means for rapidly switching or fading from one display to another, just as with transparencies. This generally calls for a dual projector arrangement. Furthermore, the copy size is usually comparable to that of the mosaic of the camera tube so that relatively little magnification is required. In addition, the distance from the object to the image is relatively short as compared to conventional opaque projector applications. Because of these factors, regularly available opaque projectors do not lend themselves to television applications. Units especially designed for broadcasting are therefore generally used in the television studio plant.

**16-mm Projectors.** Intermittent-type motion-picture projectors for television applications differ in three major respects from those used for conventional screen-projection purposes. First, means must be provided for running the film at its normal speed of 24 frames per second while arrang-

ing to broadcast a television picture at 30 frames per second. Second, the operating mechanism of the television projector must be synchronized precisely with the synchronizing waveform generator in the television studio plant. Third, the film *projection* cycle must be adapted to the peculiar needs of the television system.

In addition to these major items, the television projector must be equipped with a lens system suitable for a relatively short throw and with only a moderate magnification. Finally, it is exceedingly important that the sound-reproducing system be of the highest possible quality. This last requirement stems from the fact that, in television broadcasting, a motion-picture presentation often follows or immediately precedes a studio production. Under these circumstances the audience can make a seriatim comparison of live and recorded sound. Whether this comparison is made consciously or not, the results are likely to be unfavorable unless the sound track on the film is a good one and it is properly reproduced. It is to be noted that a direct comparison of this kind, which is experienced continuously in television, is seldom encountered elsewhere. This, no doubt, accounts for some of the complacency that exists in the 16-mm motion-picture production, film-processing and -equipment manufacturing fields.

**35-mm Projectors.** The 35-mm projector designed for television applications differs from the conventional theater projector in much the same way as does the 16-mm machine. The same problem of converting from 24- to 30-frame projection exists, together with that of synchronization with the television system, and of providing a lens system commensurate with the short-throw and small magnification requirements. In addition, the arc-light source with which theater projectors are normally equipped is usually replaced with a flash-tube light source. This device is capable of supplying the intense light of very short duration that is required in a television film projector. Although not mentioned above, flash-tube light sources are sometimes used in 16-mm projectors in place of the more common incandescent source.

**Nonintermittent Projectors.** In addition to the conventional intermittent type of film projectors, several types of nonintermittent projectors have been proposed for television application.<sup>1,2,3</sup> As contrasted to conventional projectors, the film in nonintermittent devices moves through

<sup>1</sup> Bamford, H. S., A Non-intermittent Projector for Television Film Transmission, *J. SMPE*, Vol. 31, No. 5, p. 453 (November, 1938).

<sup>2</sup> Goldmark, P. C., A Continuous Type Television Film Scanner, *J. SMPE*, Vol. 33, No. 1, p. 18 (July, 1939).

<sup>3</sup> Jenson, A. G., R. E. Graham, and C. F. Mattke, Continuous Motion Picture Projector for Use in Television Film Scanning, *J. SMPE*, Vol. 58, No. 1, p. 1 (January, 1952).

the film gate continuously and at a uniform rate rather than intermittently. Furthermore, by means of suitable optics unique to each design, the film image is projected continuously upon the photosensitive surface of the associated pickup tube, rather than intermittently (*e.g.*, see Fig. 9-1).

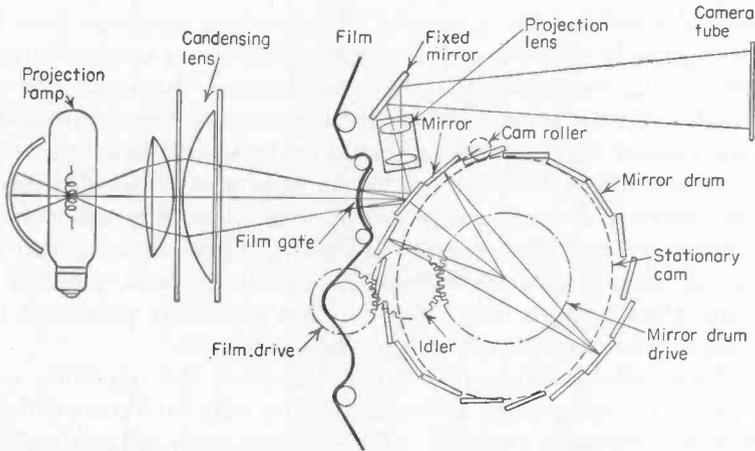


FIG. 9-1. In this nonintermittent motion-picture film projector, mirrors mounted on the surface of a rotating drum are tilted by a cam in a manner that exactly compensates for the film motion, with the result that a stationary image is projected upon the camera tube. By substituting a cathode-ray tube for the camera tube and a photoelectric cell for the projection lamp, a flying-spot scanner type of film pickup system is obtained. (*Courtesy of Bell Telephone Laboratories, Inc.*)

Nonintermittent film projectors offer several potential advantages for television applications. For example, either storage or nonstorage types of camera tubes may be used since, with the image present at all times, it is not imperative that storage principles be utilized as is the case for conventional intermittent projectors (see Sec. 9-6, below). Furthermore, the need for accurately synchronizing the operation of the film projector with that of the synchronizing waveform generator is also obviated. This results from the fact that, with the film continuously imaged on the camera tube, there is no need for any particular relationship being precisely maintained between film projection and television scanning rates.

The most important advantage of nonintermittent projectors is the potentialities they offer for using flying-spot scanner techniques (see Sec. 8-12) for film transmissions. However, because of construction, operation, and maintenance difficulties, nonintermittent projectors have not found general application in commercial broadcasting establishments in this country although they are employed abroad.

**9-2. Projection of Stills.** In television stations use is continuously made of projection equipment to handle stills for station identification purposes, for test patterns, for title cards, for program and commercial announcements, for displaying the time of the day, the weather, and late news reports and for a myriad of other applications. Although material of this type is generally used for short presentations between programs or for opening titles and credits, a number of interesting programs have been presented entirely with the aid of either a slide or an opaque projector. Illustrated talks, employing photographs, sketches, diagrams, and other visual material, may be presented to the television audience in essentially the same manner that they are presented in the lecture hall and with the added attraction that everyone can have a good seat and readily hear the lecturer. News and weather reports may frequently be greatly enhanced with a visual presentation consisting of maps, diagrams, numerical tabulations, and photographs. The results of sporting events, political elections, and other contests may often be more effectively presented if the verbal report is supplemented with a visual tabulation.

By taking full advantage of the capabilities of the television system when projecting stills, many interesting effects may be obtained that are not otherwise normally available. For example, with suitable projection equipment, two or more slides or opaques may be superimposed upon each other to create a montage. At will, one or the other of the displays may be faded in and out or still another substituted in place of one of the original presentations. In this fashion, otherwise inanimate displays can be given a degree of action and motion and thereby made to recapture some of the capabilities of the television system which, after all, is intended to convey action pictures rather than stills.

**Transparent Slides.** From the viewpoint of equipment size, availability, simplicity, and initial cost, the transparent slide projector has much to offer (see Sec. 9-3). On the other hand, the preparation of a slide entails a process that not only takes time over and above that necessary for the preparation of the original art work but, in addition, is one that is not usually available within the television broadcaster's organization. Furthermore, the 2- by 2-in. slides that are frequently used are small and a little difficult to handle rapidly unless an automatic device is used to feed them to the projector from a supply hopper. Flexibility is lost with this type of operation, however, since the slides must be presented in the order in which they are stacked, and when a given slide is to be repeated, duplicates must be placed in the pile in the proper sequence. Because the slides are small and transparent, the process of ascertaining the content of each is a relatively slow process. Further, since they are usually mounted in glass, they are subject to breakage during handling. In spite of these

shortcomings and because of the relatively small initial investment in equipment, the slide projector has found its way into many television stations. The unit having once been put into service, the subsequent acquisition of a large collection of slides inhibits abandonment of the equipment in spite of its inconvenience and the relatively high cost of preparing the slides themselves.

There are two applications where transparencies may be used to advantage. One is in flying-spot scanners (see Sec. 8-12) where in both monochrome and color-television applications the small copy size and the potentially relatively high light transmission of the transparent slide alleviate both the optical system requirements and those of the source of light that creates the flying spot. The second application where transparent slides are useful is in the creation of still projector material for color-television use. Here the small size helps to reduce the cost of slide production which can become a considerable item if large quantities are involved. However, all the problems attending the handling of the slides because of their small size still prevail in either case.

**Opaque Copy.** Under the classification of opaque copy are included photographs, photostats, line drawings, airbrush work, printed matter, and illustrations in any other form suitable for direct viewing. Since, with the exception of photographic negatives, practically all illustrations and reading matter originate in one or the other of these forms, it is evident that opaques are more universally available than transparent slides. Any of this material may be used in an opaque projector, provided only that it is the right size and that the range of gray-scale tonal values is in keeping with the transmission requirements of the television systems.

Opaques for television projector use are usually printed or mounted on heavyweight paper, equal in thickness to double-weight photographic paper, for example. The size of the copy varies with projectors but usually is in the vicinity of  $3\frac{1}{4}$  by 4 or 4 by 5 in. overall and with useful areas ranging from about  $2\frac{1}{4}$  by 3 in. to 3 by 4 in.

Art work, titles, sketches, and other material that is to be worked up for this type of projection are relatively easy to prepare. Paste-ups of printed material clipped from any convenient source may also be used for preparing the original. In monochrome work where the original material is not of the exact size required, it may be enlarged or reduced by means of the photostat process. If the paste-up is of the correct size, it can be used directly, otherwise the finished material may be reduced by one method or another. Even when the original paste-up is the correct size, it is usual to make a photostat copy for actual broadcasting purposes since paste-ups are likely to dry out and fall apart at inopportune moments. Furthermore, ragged edges, trim lines, and other imperfections can be

largely eliminated, if not entirely removed, in the process of preparing a final copy with the aid of photostats. Photostats are potentially capable of reproducing a 15-to-1 contrast range which is usually adequate for the purpose in hand.

In the final analysis, the nature of the copy to be produced, the number of copies required, the time available for its preparation, and similar considerations will largely determine the manner in which material is prepared for opaque projection. In any event, opaques of the size described are easy to handle during the process of preparing for a broadcast and when actually in use in the telecine room. This stems from the fact that they are large enough to be readily identified at a glance, there is no breakage hazard, they may be readily mailed without special packing, and they are easy to file for future use.

**Clocks.** Rightfully, running clocks do not come under the heading of *still* projection but, since they are commonly used with still projectors, they are described here. The clocks used for these purposes are ordinary electric clocks equipped with properly proportioned and suitably styled hands and face. As a rule, the faces are prepared in exactly the same way that opaques are prepared for projection purposes. As a matter of fact, clocks are sometimes incorporated as a part of a station identification slide. In selecting a clock for this purpose, the smallest mechanism is entirely satisfactory since, at most, the hands will probably not be more than  $1\frac{1}{2}$  in. in radius (the area of the entire display being perhaps 3 by 4 in. as detailed above). A clock with a second hand is usually preferred in order to present readily discernible motion. Some projectors are designed to receive copy only in a horizontal plane, and some clocks are not designed to run in this position. However, it is usually possible either to obtain a clock that does perform satisfactorily in this position or to modify one that is intended primarily for operation in an upright position.

**Ticker-type News Tapes.** News dispatches presented on horizontally moving ticker-type tapes are also not really in the category of still projection. But, since a still projector is commonly employed for projecting this type of material on the camera tube, ticker tapes are being covered here. Paper tape,  $\frac{5}{16}$  in. wide, is usually employed for this application with a 12- or 14-point medium or bold gothic type being used for the lettering.

News tapes lend themselves readily to superimposition on regular station identification signs, test patterns, or other displays since they occupy relatively little space. On the other hand they are much more difficult to read than teletype page style copy since the reader must adapt himself to the speed of the moving tape and he cannot look back more than a word or two if he wishes to refresh his memory as to a name, figure, or

other fact that has been presented. In practice, a speed of about 1 to 2 in. per second has been found suitable for news copy.

**Teletype News Presentations.** The teletypewriter presents its copy just as does an ordinary typewriter except that long rolls of paper are used rather than individual sheets. For television applications, news bulletins are sometimes presented in this manner. The width of the page is limited, however, by the size of the copy that the projector is designed to accept. In practice the page width is generally 3 to 5 in. so that the material is actually in the form of wide tape. Normally this tape moves in an upward direction at a speed of perhaps 1 ft per minute and displays approximately 10 lines of reading matter on the picture tube at any given time.

When the material is presented in page form with many lines visible at any given moment, a viewer can, to some extent, read at the rate to which he is accustomed. The process is further enhanced by the fact that the rate at which the material is moving is relatively slower than with a ticker-tape type of presentation even though the same amount of material is presented in a given time interval. Furthermore, with a page of material in view at all times, the reader may glance back to read again a name, number, or other fact that sometimes takes on added significance after further information has been presented.

Wide tape may also be used to advantage in presenting titles, cast lists, author, producer, and similar credits, and other types of information as is often done prior to and at the end of a dramatic performance. In this application the speed with which the material moves upward will depend largely upon the style and size of type or lettering used for the presentation.

**9-3. Slide Projectors.** Almost any *well-designed* slide projector may be adapted to television service, provided the lens is capable of producing a sharp image at the relatively short projection distance usually employed.

TABLE 9-1. DIMENSIONS OF TV SLIDES AND OPAQUES

Over-all size	Copy area (in.)	
	Total	Useful, i.e., scanned
Preferred sizes:		
2- by 2-in. slide .....	$2\frac{9}{32} \times 1\frac{11}{32}$	$2\frac{7}{32} \times 1\frac{1}{8}$
4- by 5-in. slide or opaque.....	$3\frac{3}{16} \times 4\frac{1}{4}$	$3 \times 4$
Other sizes:		
$3\frac{3}{4}$ - by 4-in. slide or opaque.....	$2\frac{3}{4} \times 3$	$2\frac{1}{16} \times 2\frac{3}{4}$
8- by 10-in. opaque.....	$7 \times 9$	$6 \times 8$

Where slides are used in television applications, they usually are of the 2- by 2-in. and occasionally of the 3¼- by 4-in. size. However, the size of the mask opening normally employed for photographic applications is not in accordance with the standard television 3-to-4 aspect ratio. Consequently, an industry standard has been proposed covering the slide dimensions for television applications as detailed in Table 9-1.

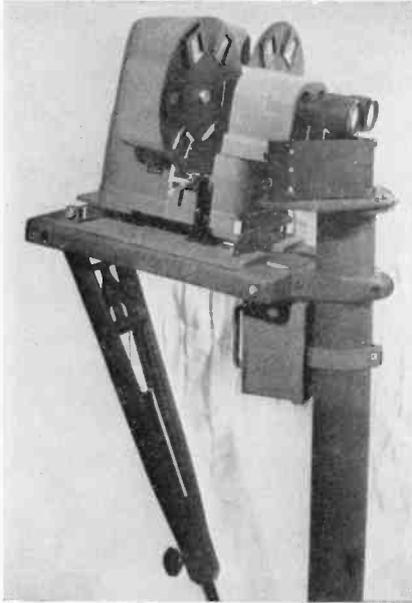


FIG. 9-2. This dual 2- by 2-in. television slide projector incorporates means for remotely controlling the selection of slides and for dissolving from one slide to another. In addition, the optical system employs matched lenses in an adjustable mounting that permits precise registration of the images from both apertures upon the mosaic of the associated camera tube or flying-spot scanner. (Courtesy of Gray Research and Development Co.)

Commercially available magazine types of slide projectors, with manual or remote control of the slide-changing operation, have not always proved entirely satisfactory in broadcasting applications. Depending upon the condition of the slides and of the slide-changing mechanism, units of this type sometimes fail to handle the slides reliably. However, mechanisms have been especially designed to meet the need in television of completely reliable operation, *e.g.*, the unit shown in Fig. 9-2.

Where a slide projector is used primarily for test-pattern transmission, the better grade, commercially available manual-changer types are usually satisfactory. Projectors of this type, equipped with a 150-watt projection lamp, supply more than ample light for most television needs. For iconoscope applications, a projection lens having a 5-in. focal length is usually correct for the image size and the throw involved. Its flatness of field under actual operating conditions should be carefully scrutinized however.

Heat-absorbing glass for protecting the slides is generally incorporated in projectors of this type and is particularly important where a given slide is to remain in place for more than a few seconds. Furthermore, as detailed in Sec. 10-8, when an iconoscope camera tube is involved the use of infrared absorption filters materially improves the contrast range, the image sharpness, and the signal-to-noise ratio while reducing the shading requirements.

Commercially available magazine

**9-4. Telop Projector.** A versatile projector for handling all types of still material is the television optical projector (telop) shown in Fig. 9-3. This unit has provisions for projecting transparent slides, opaques, clocks, horizontally moving narrow tape, and vertically moving wide tape. Furthermore, it has four "input" ports where the copy may be placed for projection purposes. Two of these are associated with an upper channel and two with a lower channel. Either one or the other of the two ports

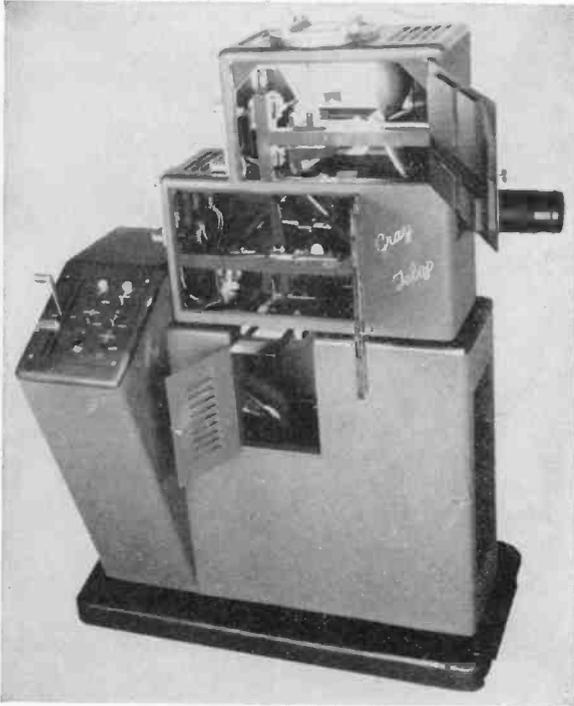


FIG. 9-3a. A television optical projector (telop) capable of handling opaque and transparent copy in the form of slides, scrolls, and tape. Side doors are open to show interior construction. (Courtesy of Gray Research and Development Co.)

associated with the upper channel may be used at a given moment. A similar arrangement prevails for the lower channel. However, by an ingenious arrangement of full and semimirrors, material from both the upper channel and the lower channel may be superimposed simultaneously on the mosaic of the camera tube. On the other hand, material inserted in one of the upper ports may be faded out and that in a lower port faded in, or vice versa. Dissolves, laps, and quick switches from one channel to the other can be accomplished to simulate the effects obtainable with

the switching and control consoles associated with studio camera channels (see Sec. 6-5).

**Optical Design.** The optical portion of the telop is contained in the upper portion of the unit, while blowers and other accessories are contained in the base. The electrical control circuits are contained in the pedestal at the left which also carries the electrical control panel. As shown in Fig. 9-3, at the very top and outside of the main housing of

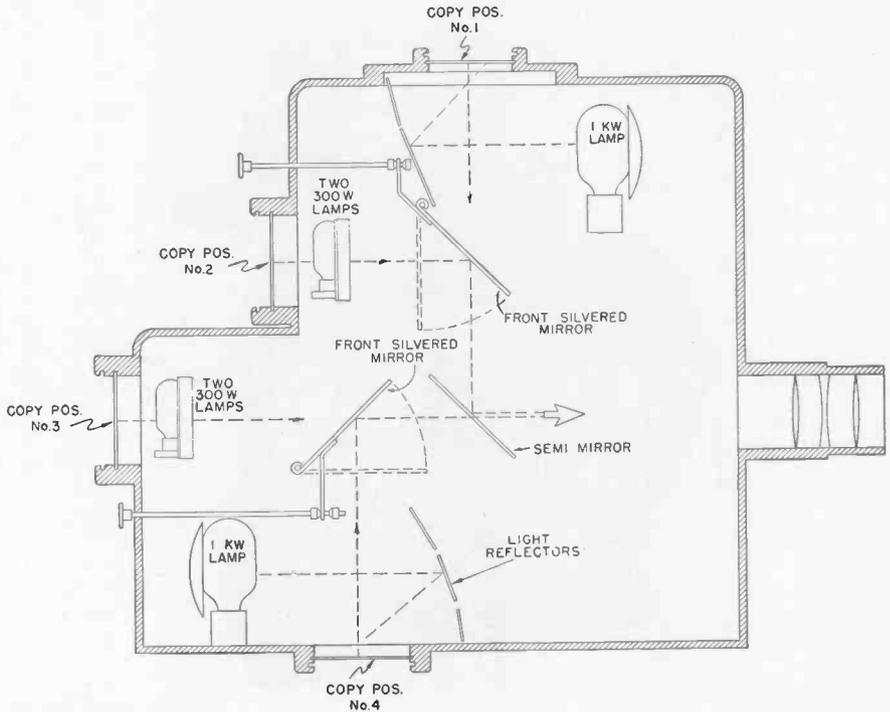


FIG. 9-3b. Cross section of the telop showing the manner whereby opaque or transparent copy may be introduced at four different points and imaged upon a film camera tube by means of a common lens system.

the telop, there is located a horizontal slide holder which has slots at two levels. The lower set of slots accommodates a metal slide holder with provisions for carrying five opaques, each accurately centered and properly oriented, as shown in Fig. 9-4. A slide holder of similar design but slightly different dimensions is used for handling transparent glass slides. In this instance, the upper set of slots is used to support an incandescent source of light which, of course, must come from the back of a transparent slide.

A second port, also associated with the upper portion of the telop, is in a vertical position at the left or back side of the projector. This port may also be used to accommodate either opaques or transparencies. In addition, there are extra slots which may be used to mount the familiar push-pull type of slide carrier used in conventional slide projectors. With this accessory in place and a light box mounted back of it, the telop may be used in exactly the same manner as regular slide projectors.



FIG. 9-4. The telop at the left is handling opaque copy in its top and bottom ports and projecting the material onto an iconoscope camera tube contained in the housing at the right.

A third port, also in a vertical position, is associated with the lower portion of the projector. A fourth port is located at the bottom of the unit in a horizontal position. Both ports may be used in exactly the same manner as their opposite numbers in the upper part of the device.

Opaque material placed in either the upper or the lower horizontal ports is illuminated by means of 1,000-watt projection-type lamps. A reflector back of the lamp and auxiliary reflectors opposite the lamp direct the light upon the copy and illuminate it in a uniform manner. Blowers, located in the base of the telop, supply air through an internal duct system both to the projection lamps and to the copy in order to keep both at safe operating temperatures. Opaque material used at the rear ports is illuminated by means of two 300-watt lamps and associated reflectors at each port.

The control shaft seen protruding at the left of the upper part of the housing, just above the upper vertical port, may be used to swing a first surface mirror into or out of the path of light from the upper horizontal port. In the position shown, this mirror is *intercepting* the light from the upper horizontal port; however, it is in position to *reflect* the image from the upper rear vertical port downward toward a fixed semimirror immediately below the front silvered mirror. Upon striking the semimirror the light from the upper channel is reflected into the projection lens and thence upon the mosaic of the camera tube.

A movable front-silvered mirror is also used to select one or the other of the two ports that are associated with the lower channel. In this instance, the lower vertical port projects directly to the semimirror when the front-silvered mirror is swung down out of the way. In the position shown, however, the light from the vertical port is intercepted and that from the lower horizontal port is being reflected *through* the semimirror and the associated lens system. The reason for the fixed semimirror thus becomes evident. It is so positioned that it *reflects* the light from the upper channel through the lens system and at the same time transmits light from the lower channel *through* itself and thence to the lens system.

In this manner, images from both the upper channel and the lower channel may be simultaneously projected upon the mosaic of the camera tube thus creating a superimposition of two sets of copy.

Either the horizontal or the vertical port in the upper channel may be used at any given time, but not both simultaneously. A similar restriction applies to the lower channel. However, the port selected for use with the upper channel may be combined at any time with the port selected for the lower channel. Furthermore, the selection of ports is done instantaneously by operation of the handles connected to the two movable mirrors.

Provisions have been made in the design of the telop to obtain perfect registration from all four of the ports that are used for copy. Thus, with identical material inserted at all ports, it is possible to switch from one to another without the viewer's being aware of a change. Naturally, in practice, the feature of exact registration would not be used in this way. However, it may be used to provide a degree of animation to stills that are projected by the telop. Or, it may be used to add words or objects to an initial display either by switching to another port or by superimposing the material from two ports. This latter may be done with complete confidence in the registration of the various parts, provided the original copy is accurately prepared and carefully centered when placed in the associated slide holders.

It will be observed, upon examination of Fig. 9-3, that the images from both the upper and the lower horizontal ports are both reflected by one mirror before being projected by the lens system. On the other hand, the image from the upper vertical port is reflected twice while that from the lower vertical port reaches the lens system direct. Under these circumstances, the images from the horizontal ports will be reversed with respect to those from the vertical ports. Accordingly, copy placed in vertical ports must be the reverse of that placed in horizontal ports if it is all to appear upon the mosaic in the same manner. To a degree this restricts the usefulness of the vertical ports but not so seriously as to warrant a more complicated design that would result in the addition of a reflecting surface to two of the four light paths.

As a matter of fact, the vertical ports lend themselves to use for fixed displays that are required frequently. For example, station identification signs are usually called for at least once every 15 to 30 minutes. By permanently placing one of these in a vertical port, it is available at all times for instant projection. Similarly, a test pattern, a clock, or any other often used display may be placed in the other vertical port. It is no great hardship to prepare this more or less permanent copy in a reverse manner for use in these ports.

In the design of the optical system of the projector illustrated, it would have been possible to associate one lens with the upper channel and another with the lower channel, and eliminate the semimirror described above. In effect, this would be simply two separate projectors. This more prosaic design is not so satisfactory as the one illustrated because the object-to-image distances involved are such that parallax or keystoneing problems are encountered. With the single lens system actually employed, there is no possibility of difficulty on this score.

**Electrical Features.** Switches are provided to control the light sources associated with the four ports. By this means the art work positioned in any given port may be essentially instantaneously projected upon or removed from the mosaic of the camera tube. The control panel also contains two 2-kw faders, each of which is operated by a conveniently large, push-pull handle. One fader is used to control one or the other of the two light sources in the upper channel, the selection being made by a switch. The other fader serves a similar purpose for the lower channel. Thus a dissolve from one piece of copy to another may be effected by fading up the light in one channel while dimming it in the other. By stopping part way, a superimposition is created. Since the light for each channel is individually controlled, the intensity of the picture from the two stages may be balanced until exactly the desired result is obtained.

**Slide Holders.** The required speed of operation in a fast-moving television program is such that individual slide holders usually prove to be entirely inadequate. Furthermore, when a large number of slides are handled individually, it becomes a major problem to keep them in the proper sequence. All these difficulties are overcome in the telop by the simple expedient of providing slide holders capable of carrying five slides at a time. A number of these holders, designed to handle 4- by 5-in. opaques, are shown in Fig. 9-4. These holders may be placed into any one of the ports and then moved through from slide to slide. As each of the five openings in the slide holder approaches the port, a detent arrangement snaps it into exact registration. The normal method of operation is to project the first slide from the upper channel, the second from the lower, and so forth, fading from one to the other on cue.

One of the great advantages of the multiple slide holder is the fact that copy for an entire day's work may be inserted in a series of holders in exactly the order in which they will be used. This can be done in the program production art department away from the confusion that is often characteristic of a busy telecine room. The copy may be accurately centered, placed right side up, and otherwise arranged at leisure. Hundreds of slides, all in their proper order, all properly oriented and carefully centered, may thus be contained in an armful of slide holders. When, during the press of a program production, the slides are needed, an absolute minimum of time is necessary for finding the proper slide, getting it into the projector right side to and right side up since they are all grouped in the correct order and can be placed in the projector only in the correct orientation.

**Wide-tape Carrier.** The transport mechanism for handling wide tape shown in Fig. 9-5 is typical of the kind of accessories that can be used with the telop unit described. The device illustrated accommodates 5-in.-wide roll stock which is pulled in an upward direction. A speed control permits selection of any speed from 0 to 90 in. per minute. The tape carrier is mounted by slipping it into one of the sets of slots provided at each port for receiving accessories of this kind.

**Narrow-tape Carrier.** A unit for transporting  $\frac{5}{16}$ -in.-wide tape horizontally across the screen is shown in Fig. 9-6. The position of the tape on the screen may be adjusted in a vertical direction so as to be placed in a suitable position with respect to any other copy that may be simultaneously displayed. A news tape, for example, may be superimposed upon a test pattern, a clock, a weather report, or other appropriate copy which may be originated in the same or another stage of the telop. The speed of tape transport is adjustable from approximately 0 to 15 in. per second.

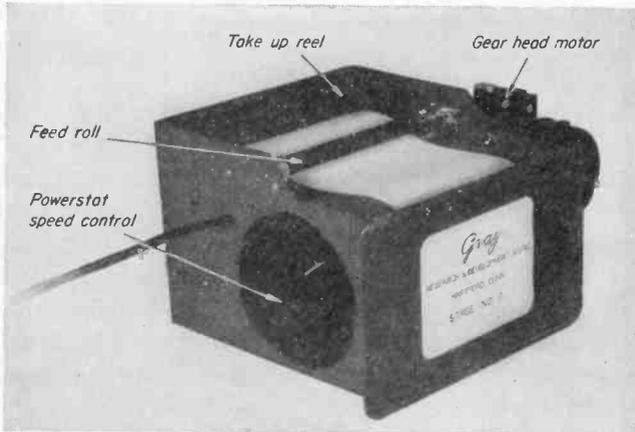


FIG. 9-5. This telop accessory transports 5-in.-wide tape (upon which news, titles, or author, cast, and other credits may be printed) in an upward direction on the picture screen. (Courtesy of Gray Research and Development Co.)

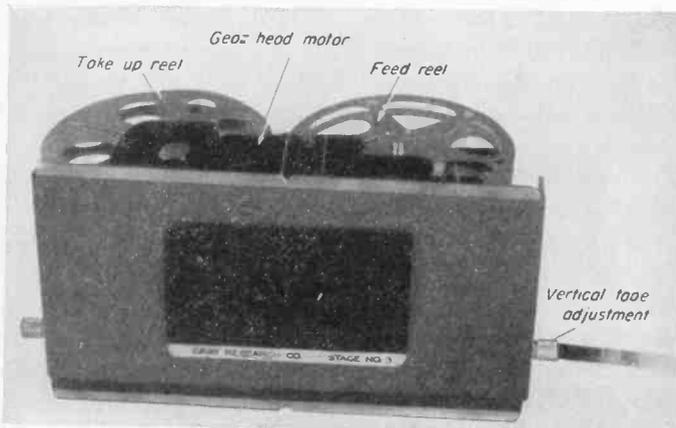


FIG. 9-6. A telop accessory that draws news ticker tape horizontally across the screen, the position on the screen being adjustable in a vertical direction in keeping with the requirements of other copy upon which the news tape may be superimposed. (Courtesy of Gray Research and Development Co.)

**9-5. 16-mm vs. 35-mm Film.** In television broadcasting stations 16-mm motion-picture film is used much more extensively than 35-mm film. This results from a number of factors. First, since all 16-mm motion pictures are on safety base film, building codes usually do not require the observance of the many safety precautions that attend the use of 35-mm projectors. Next, the cost of 16-mm film is considerably less than that of the 35-mm product. For example, neglecting entirely the greater cost of

the 35-mm cameras and projectors, the cost of the film alone (together with its processing) for a program of given length is approximately four times as much in 35-mm as in 16-mm film.

The bulk and weight of 35-mm film as compared to 16-mm film are also of importance where transportation and storage are factors. The ratio of weight and volume of the two films for a given running time is 5.5 to 1. The bulk of 35-mm film is also an important consideration in the operation of television stations since the common program unit is 30 minutes in duration. Television projectors for 16-mm film are built to handle enough film for a program of this length or even longer. Machines for 35-mm operation, however, are seldom so constructed since 35-mm film is normally handled in 2,000-ft reels which run for approximately 20 minutes. Under these circumstances, in order to produce a 30-minute program from 35-mm film, it is sometimes necessary to use two projectors or to modify a conventional unit to accommodate somewhat more than 2,700 ft of film. Even in the latter case, the film as normally received would have to be spliced together and placed on special large reels. Furthermore, in some cities local ordinances prohibit the use of reels of 35-mm film more than 2,000 ft in length. The storage problem posed by both the greater bulk and the stringent building code requirements (see Sec. 10-13) is also a major consideration if any appreciable library of 35-mm film is to be kept on hand.

There is no question, of course, but that 35-mm film is capable of producing a higher quality picture and sound track than can 16-mm film. After all, the picture area of 35-mm film is 4.6 times that of 16-mm film, the sound-track area is more than three times as great, and the linear film speed (which, of course, has a great influence upon the sound quality) is 2.5 times as great. Furthermore, the television system is potentially capable of transmitting the picture quality that is possible with 35-mm film, and the television sound-transmission system far exceeds the capabilities of the 35-mm sound track. In spite of this, because of the relatively great expense and the inconveniences of 35-mm film, it is not widely used for television applications. There is little question, of course, that as television broadcasting matures consideration will be given to the more extensive use of 35-mm film. Balanced against this, however, is the possibility of improved quality of 16-mm motion-picture films and projectors with time.

Although 16-mm film may leave something to be desired, it is also true that it has not always been treated with the respect that it deserves. In fact, in some quarters it is still regarded as an amateur film and handled accordingly. Because of this, both the picture and the sound qualities of some 16-mm sound films are often subject to improvement. Until re-

cently, projector designers and manufacturers were prone to stop with a de luxe amateur projector and make no effort to produce a machine whose performance was in keeping with professional requirements. Under these circumstances it is difficult to escape the conclusion that, as far as professional applications are concerned, the possibilities of 16-mm film have yet to be fully exploited.

**9-6. Film Projectors for Television.** The use of standard sound-motion-picture film for television transmission purposes creates a number of special problems as enumerated at the beginning of this chapter. In the following paragraphs, these factors are covered in detail and the methods employed to adapt standard motion-picture film to television transmission standards explained.

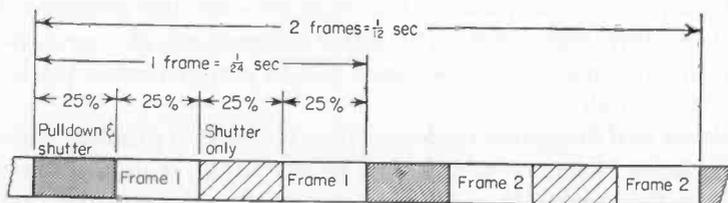


FIG. 9-7. The pull-down and projection cycles of a conventional 35-mm theater-type projector, as shown, usually allocate 25 per cent of a frame period to pulling the film into place. Furthermore, in order to increase the flicker frequency, each frame is projected twice, with each showing amounting to 25 per cent of a frame period.

**Conversion from 24 to 30 Frames.** The standard speed for both 16- and 35-mm film is 24 frames per second. However, the normal method of projection is such that the projected light is interrupted twice per frame: once to permit pull-down to the following frame and once during frame time to give an additional interruption to the picture image. This double showing of each frame reduces the sensation of flicker to the eye by doubling the repetition rate of the flicker. Since each picture is actually seen twice, the flicker frequency is 48 times per second, which is high enough to give the illusion of no flicker at all at the picture brightness levels normally used for motion-picture projection.

This sequence of operation is shown diagrammatically for a 35-mm projector in Fig. 9-7. The first *unshaded* block represents the showing time; the next shaded block indicates the shutter-interruption time; the next unshaded block, the second showing time for the first frame; and the heavily shaded block, the shutter-interruption time during which pull-down takes place. In television terminology, each showing time is approximately equivalent to a field—not exactly, however, since in television any one field contains only one-half the total number of scanning lines.

In 16-mm projectors a similar cycle of events takes place except that the time necessary for pulldown is less, and the dark or shutter-interruption periods can therefore be shorter. This permits the image to be projected upon the screen for the maximum amount of time consistent with avoiding flicker, thereby obtaining maximum utilization of the available light.

In television, for the reasons explained in Sec. 1-4, the frame rate is 30 per second and the field rate is 60 per second. This presents the problem of converting standard motion-picture film made at 24 frames per second to the 30 frames per second required for television transmission. The method employed to accomplish this consists of projecting alternate frames twice and the remainder three times. In this way 60 fields per second are produced in place of the usual 48 while the average speed of the film remains unchanged. This latter is necessary, of course, in order to keep the action at the proper pace and to permit normal pitch of the reproduced sound.

**Pulldown and Projection Cycles.** There is a second problem peculiar to the application of motion-picture film to television. The time devoted to scanning a field amounts to 92 to 95 per cent of the time of each field (see Sec. 1-8, *Vertical Blanking Pulses*). If the projected image is to be thrown upon the camera tube at all during the scanning time, it must be held there for the entire period. If this is not done, all parts of the area will not be subjected to the same amount of light and an uneven picture will result. However, operation in this manner leaves only the vertical retrace time in which to pull down the film to the next frame. The retrace time amounts to the remaining 5 to 8 per cent of the time of one field or between 0.8 and 1.3 milliseconds. Pulldown times within the upper limit mentioned have been achieved in both 16- and 35-mm projectors but, because of the rapid accelerations and decelerations required for this type of operation, the film and the mechanisms may be subject to considerable strain, wear, and instability of registration.

One method commonly used to overcome this difficulty with intermittent projectors is to make use of the storage properties of iconoscope, image orthicon, and similar tubes. The frame of film in the aperture of the projector is imaged upon the camera tube with very intense illumination only during the vertical retrace time or while the scanning beams of both the camera and the picture tube are blanked off. The light beam is then turned off and the picture tube scanned without the presence of any optical image from the film. The signal generated during scanning is the result of the charges stored upon the mosaic or the target of the camera tube by the preceding flash of light. By this "full-storage" mode of operation, the light is turned off during the relatively long period corre-

sponding to the scanning period (almost 16 milliseconds), and this entire time then becomes available for pulling the film down to the next frame.

As already indicated, alternate frames of film are allowed to remain in place for two flashes of light and the remainder for three. This implies an uneven gait for the pulldown process and, in fact, 35-mm projectors are so designed. The timing cycles for a typical 35-mm projector are shown in Fig. 9-8. This particular projector takes full advantage of the time interval available for pulldown and utilizes approximately 14 of the 16 milliseconds available to perform the operation. Since nothing is to be gained by a faster pulldown (unless it were very much faster), the maximum time possible is used consistent with the film's coming to rest in time for the light pulse that occurs during the vertical blanking period.

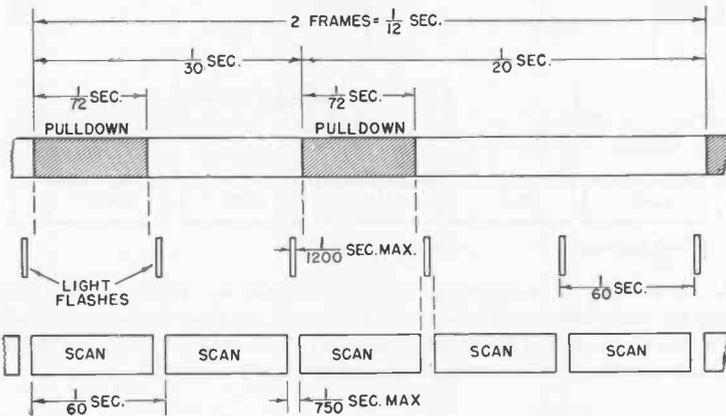


FIG. 9-8. The relationships existing in a 35-mm television film projection system between the pulldown and the dwell time of the film, the projection thereof upon a storage-type camera tube, and the scanning of the mosaic or target of the camera tube.

As shown by the illustration, upon being pulled down into place, the first frame remains stationary for two light flashes or two projections of the image upon the screen of the camera tube. The second frame is then pulled into place and remains stationary for a longer period during which three light flashes take place. The third frame is then pulled down and projected twice, as was the first one. The cycle continues in this 2-3-2-3-... manner, every other cycle having a period of  $\frac{1}{20}$  second and the remaining ones  $\frac{1}{30}$  second. Thus two successive cycles amount to  $\frac{1}{20}$  plus  $\frac{1}{30}$  or  $\frac{1}{12}$  second, the exact time for two complete frames projected at the standard motion-picture rate of 24 frames per second.

In 16-mm projectors very much faster pulldown times are practical, and the timing is such that, if the projector can complete its pulldown cycle in

less than approximately 7 milliseconds, then an evenly gaited projector can be designed. As shown in Fig. 9-9, with a short pull-down time it is possible to illuminate the first frame twice, the second frame three times, the third frame twice, etc., while still keeping the pull-down cycle  $\frac{1}{24}$  second for all frames. This makes it possible to utilize a standard 16-mm projector having a moderately fast pull-down time for television applications by the simple expedient of changing the shutter and driving it with a synchronous motor.

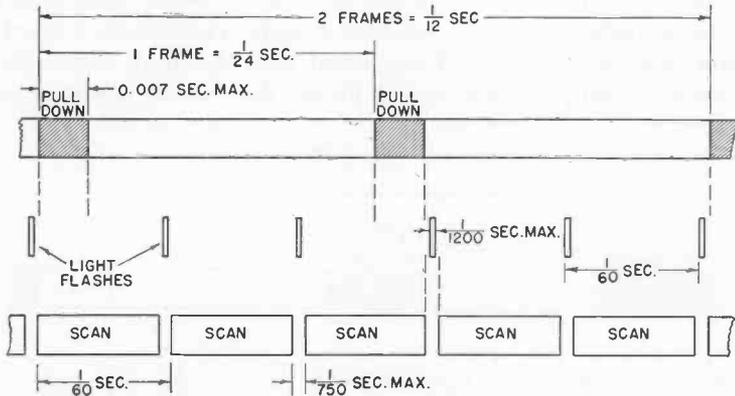


FIG. 9-9. As contrasted to 35-mm projectors, the pull-down time of 16-mm machines can readily be made fast enough to permit either two or three properly phased flashes of light to take place during the dwell time of a frame. Thus a 2-3-2-3 type of intermittent is not necessary when storage-type camera tubes are used.

**Projector Synchronizing.** It is evident from the preceding discussion that the film pull-down, the flashing of the film image upon the screen of the camera tube, and the scanning process within the tube must all be very accurately synchronized. If an incandescent lamp is used for the source of light, it can be interrupted with a shutter which may be mechanically geared to the intermittent pull-down mechanism and accurate synchronism maintained in this manner. This is the method used in many projectors. On the other hand, separate synchronous motors can be used for the shutter and the intermittent drives, provided suitable arrangements are made to obtain the proper phase relationships between the two driven elements.

In any event, in order to synchronize the projector with the television scanning process, it is necessary to lock in the television synchronizing waveform generator with the projector. Not only must these two units be locked together as far as their operating cycles are concerned but, in addition, they must be accurately phased with respect to each other. Syn-

chronization may be accomplished by driving the projector with a unique-phase synchronous motor and by simultaneously locking the television synchronizing waveform generator to the a-c power supply. The special motor must meet two requirements: (a) it must lock in with the power-line frequency and (b) since ordinary synchronous motors can do this at either one of two positions, the special motor must always select the proper lock-in position. If the motor were to lock in 180 electrical degrees out of phase, then the picture would be projected upon the camera tube during scanning time. To avoid this possibility, a unique-phase synchronous motor is generally used. Motors of this type have wound rotors and d-c field coils so that they will lock in with the a-c line for only one phase relationship. The motor should also be designed so that there are only small changes in torque angle with variation in load so as to avoid any tendency to hunt with changes in film or projector load during operation.

There is one case where a unique-phase synchronous motor is not required for projector operation. When a pulsed light source employing a flash tube is used (see Sec. 9-7) an ordinary synchronous motor may be used to drive the projector. This is possible because, in this instance, there is no shutter in the projector and the pulsing of the flash tube is controlled by the synchronizing generator. Under these circumstances, the light flashes are always in the proper phase relation. This type of operation may be thought of as one employing an electronic shutter since the flashes of light are controlled directly by the synchronizing generator rather than through the medium of a motor and the a-c power-supply frequency.

Regardless of whether regular or unique-phase synchronous motors are employed for maintaining synchronism of television motion-picture projectors, it is also necessary carefully and accurately to adjust the phase of the projectors with respect to that of the synchronizing waveform generator. As a rule, this operation need be performed only during installation of the equipment since, once undertaken, there is no reason for the relative phase relationship of the two units to change, barring, of course, any slippage of mechanical parts. Correct phasing of the projector is usually accomplished by mechanically changing the position between the motor shaft and the intermittent drive shaft by one means or another. In some projectors this is accomplished by rotating the entire motor about its own axis and clamping it into the correct position. In other machines, a set-screw-secured coupling between the motor and intermittent shafts must be shifted. On still others, gears must be disengaged and reengaged in the proper relation to each other. In the last instance, fine adjustment of the phase (less than that afforded by shifting the gears by one tooth) is usually obtained by rotating the motor slightly in its cradle.

The second requirement, that of also locking the television synchronizing waveform generator in with the a-c power line, is accomplished by the methods described in Chap. 5.

**Picture Steadiness.** One of the most annoying and most readily perceived shortcomings of a film presentation is an unsteady picture. Good projection requires that a picture be steady within at least 0.2 per cent of its width in both the horizontal and the vertical directions. Even the most perfect film from a photographic viewpoint is detectable as film, rather than a live presentation, if the picture has excessive weave or jump. This shortcoming in a motion-picture presentation is analogous to wow and flutter in sound reproduction and just as obnoxious. The problem of picture steadiness is related to the camera and the film used for the original photography, the printers, the film stock used for the release print, and, finally, to the performance of the projector itself.

Film in good condition, properly processed from accurately manufactured raw stock, can be expected to give good results. Badly worn, poorly dimensioned film or improperly printed film may cause picture unsteadiness regardless of the precision with which the projector performs. However, the projector should be designed to minimize as much as possible any dimensional inaccuracies found in commonly available film and to introduce as little film wear as possible in doing so.

In a correctly designed projector, horizontal unsteadiness or weaving of the film is usually chargeable entirely to dimensional errors in the film. It can be minimized, however, by choosing the proper method of lateral guiding of the film. An important consideration in this connection is the fact that a great many of the regular 16-mm prints are made originally on 32-mm film and then slit down the center. This process affords certain economies during the processing of the film but, unfortunately, the slitting may be quite inaccurate. The slitting is always undertaken along the sound-track edge and, if the film is guided along this edge, the resulting picture may have excessive weave. Consequently, some 16-mm projectors laterally guide the film from the sprocket-hole edge.

Unfortunately, this philosophy of edge guiding is in conflict with that which results from consideration of the standards applying to 16-mm film (see Sec. 10-1, *16-mm Film*) wherein the sound-track edge is designated as the guided edge. In general, the edge which is the better one to guide depends upon the kind of film projected most. If prints on 16-mm film and on accurately slit 32-mm film are in the majority, then it is better to guide from the sound-track edge. If the bulk of the film to be projected is from inaccurately slit 32-mm film, it may be an advantage to guide from the sprocket-hole edge. It would seem reasonable to expect that, if the quality of 16-mm film work improves generally, more accurate slitting

machines will be employed and the need for guiding from the sprocket-hole edge will become less pronounced. In 35-mm projectors, a similar problem does not exist since no slitting operation by the processing laboratories is involved.

Steadiness in the vertical direction or film jump depends upon uniformity of sprocket-hole spacing and the accuracy of the intermittent movement in the projector. In 16-mm amateur projectors, a claw type of intermittent is generally used. It is relatively easy to obtain good vertical steadiness with this type of mechanism because the same mechanical parts are used for positioning each frame of film. Unfortunately, however, the claw action may cause excessive film wear since, under some conditions, the entry of the claw into the sprocket hole of the film may resemble the action of a drift punch in a rivet hole. For this reason the use of a claw pulldown in 35-mm practice is limited to cameras and similar equipment where the film is subject to only one passage through the device. The sprocket type of intermittent is preferred in both 16- and 35-mm projectors because of the increased film life that can be obtained by its use.

The sprocket type of intermittent is not an easy one to manufacture, however. Each tooth of the sprocket and each arm of the star must be very precisely indexed in order to achieve vertical steadiness of the picture. In addition, the design must be such as to compensate for wear on these parts. With the sprocket type of intermittent, the action of the tooth in entering a sprocket hole is gradual and similar to that of a pinion gear entering a rack. With a number of teeth simultaneously in contact with sprocket holes, a very favorable distribution of the stress is achieved.

The sprocket-type intermittent also operates more reliably than a claw type with badly damaged films. Several successive torn sprocket holes will often pass uninterrupted through a sprocket-type intermittent whereas they are almost certain to fail to do so with a claw-type intermittent.

**Film Gate.** The film gate of a projector usually consists of two main parts; a fixed aperture plate and a movable film shoe or pressure pad. The film shoe is pressed against the aperture plate with springs, and this pressure is usually adjustable. In any projector the film gate is one of the most critical parts in so far as film abrasion is concerned. This is particularly the case in a television projector because many are called upon to handle large quantities of television recording film (see Chap. 11), which may be comparatively unseasoned as compared to old film that has been projected many hundreds of times.

It is important, therefore, that the various parts of the film gate that come in contact with the film be given a very hard, mirror-smooth finish. Minute, almost imperceptible pinholes can serve as a collection point for particles of emulsion. As a result, castings are unsuitable for this service

no matter how well they may be machined. Hardened stainless-steel or hard chromium-plated machined parts should be used for both the aperture plate and the film shoe. When emulsion pile-up once starts, a minute speck of emulsion gouges additional emulsion from the film and, after the passage of only a few hundred feet of film, an amazingly hard deposit may result. This surface irregularity soon places a visible scratch upon the film, and it often becomes wide enough to enter into either the picture or the sound area of the film, or both. When the latter occurs, it immediately results in an increase in the background noise level since the film passes through the sound pickup head *after* passage through the film gate. (For preventive maintenance suggestions, see Sec. 10-11.)

In incandescent and arc projectors, the film gate becomes exceedingly hot and, besides gouging out the film, the little island of emulsion may press into the film during the short interval while the film is stationary in the gate. This results in pinpricks in the film, one per frame. When they occur in the sound-track area, they are reproduced by the sound pickup head and cause a sprocket-hole frequency modulation (24-cps for 16-mm film; 96-cps for 35-mm film) in the sound output.

In addition to having a very hard and smooth finish, the aperture plate and the film shoe should be undercut so that they bear only on those portions of the film that do not contain either the picture image or the sound track. As a matter of fact, all film supporting parts (sprockets, rollers, and associated parts) in the projector should be undercut so that there is only the very minimum of contact with vital areas of the film.

Standards have been established covering the location of film sprocket holes with relation to the image frame (see Figs. 10-1 and 10-4). In spite of this, film is sometimes encountered with sprocket holes that are improperly located. Adjustments are therefore required to bring the film into proper relation with the aperture in the film gate. Some projectors do this by shifting the gate aperture up and down and thereby also shifting the projected rectangle on the screen. This arrangement is unsatisfactory for television applications since it is the usual practice to fill the screen of the camera tube completely with the projected image. Therefore, if the projected rectangle is moved when framing the picture, the entire projector has to be moved in a compensating manner to retain the projected image centered on the screen of the camera tube.

The only satisfactory framing control for a television projector is one that moves the film with respect to a fixed picture aperture. This may be accomplished in several ways, and this feature should always be incorporated in a projector intended for television service.

**9-7. Projector Light Sources.** Two sources of light are used for television projectors: incandescent lamps and gas-filled flash tubes. As incan-

descent lamps are continuous sources of light, properly designed and synchronously operated shutters must be used with them in order to meet television projector requirements. The gas-filled flash tube, on the other hand, is a source of pulsed light which may be timed by the television synchronizing generator and which eliminates the need for a shutter in the television projector.

***Incandescent Lamps.*** Filament-type lamps used for projection purposes differ in a number of respects from those used for general lighting. Projection lamps usually employ tungsten filaments and are filled with an inert gas such as nitrogen or argon. The filament of a projector lamp consists of coils of wire arranged so as to secure the highest possible concentration of light. In the "monoplane" type of construction, a number of springlike coils of tungsten wire are arranged side by side in a plane oriented at right angles to the optical axis of the lighting system. In the "biplane" type of construction, additional coils of filament wire are arranged in a second plane, parallel to the first but back of it. The filaments in the second plane are staggered with respect to those in the first plane so that the light from all of them can be transmitted directly along the optical axis.

To augment the light that is transmitted directly to the film from the light source, it is customary to employ a reflector at the back of the source. This reflector is designed so as to collect the light from the rear of the light source and reflect it along the optical axis toward the film. The proportion of the total output of the light source collected by a reflector of given diameter depends largely upon the distance of the reflector from the light source. The closer the reflector is to the source, the greater the amount of light collected and reflected. For this reason, projection lamps are made as small in diameter as possible in order that the reflector may be placed as close to the light source as practical.

Furthermore, the bulbs of projection-type lamps (which are of clear glass) are made somewhat longer than may appear necessary. The extra bulb length is always located above the filament, and it is in this upper portion of the bulb that the blackening (caused by tungsten deposit from the filament) takes place. Thus the transmission of light through the bulb along the optical axis is not appreciably impeded during the useful life of the lamp. Some lamps are designed to operate with the base up and others with the base down. By the preceding explanation, one type of lamp can be distinguished from the other by noting the location of the filament with respect to the extra length of glass bulb. In addition, it becomes evident that a lamp designed for one operating position is not likely to perform satisfactorily in the other, even if the filament location should happen to be correct with respect to the optical axis of the projec-

tor. In this respect, projection lamps are usually of the prefocus base type and do not require any focusing adjustment when placed in service, assuming, of course, that the lamp socket is properly located initially.

Projector lamps of a given wattage are usually available in several different types, all at very much the same price, but each with a different rated life, e.g., 10, 25, and 200 hours. Unfortunately, however, this is not a case of getting something for nothing. The difference in the lamps is in the filament, the short-lived lamps delivering more light by virtue of operating at a higher filament temperature. The difference in light output is appreciable, increasing approximately 40 per cent in going from the 200-hour lamp to the 25-hour lamp and another 40 per cent in going to the 10-hour lamp.

In television service it is considered good practice to replace projector lamps on a regular basis so as to avoid the possibility of lamp failure during broadcasting operations. For example, lamps having a 25-hour rated life might well be changed at the end of 15 hours of service. If used for more than this period, approximately 10 per cent failures may be expected in attempting to extend their use up to the rated 25 hours.

In practice it is found that lamp failures often occur at the instant they are turned on, the failure being occasioned by the thermal shock received by the filament. To avoid these embarrassing failures, it is good engineering practice to operate projector lamps in a stand-by condition throughout the broadcasting day. This is done by running them at a cherry-red temperature when the machines are idle.

Incandescent lamps are used for light sources in many 16-mm projectors that have been adapted from regular projector service to television applications. Usually either 750- or 1,000-watt lamps are employed in this service. They are generally operated directly from the a-c power circuit, and means are sometimes provided for adjusting the filament potential as desired.

**Gas-filled Flash Tube.** The gas-filled flash tube consists of a tubular glass envelope filled with xenon gas and with an electrode sealed into each end of the tube (Fig. 9-10). The over-all length of the tube is approximately  $6\frac{5}{8}$  in. and its diameter  $1\frac{1}{4}$  in. Each electrode consists of a coiled tungsten wire encased in either a quartz or a ceramic shield. In operation, the electrode assemblies become red hot. This serves as a keep-alive arc and restricts arc wander to a negligible amount. It is important, of course, that the arc always occur in almost exactly the same spot since the alignment of the entire optical system associated with the light source is dependent upon a fixed location for the actual source of light.

In operation, the arc in the flash tube strikes between the two tungsten

alloy tips of the electrodes, approximately 6,000 volts being required to break down the gap. After the gas is ionized, it is necessary to supply sufficient energy to maintain the arc and then to cut off the light pulse at exactly the right time. A circuit arrangement <sup>4</sup> that may be employed to



FIG. 9-10. This film-projector flash tube is filled with xenon gas and employs coiled tungsten-wire electrodes encased in ceramic shields. A cigarette is included in the photograph for size comparison. (Courtesy of General Electric Company.)

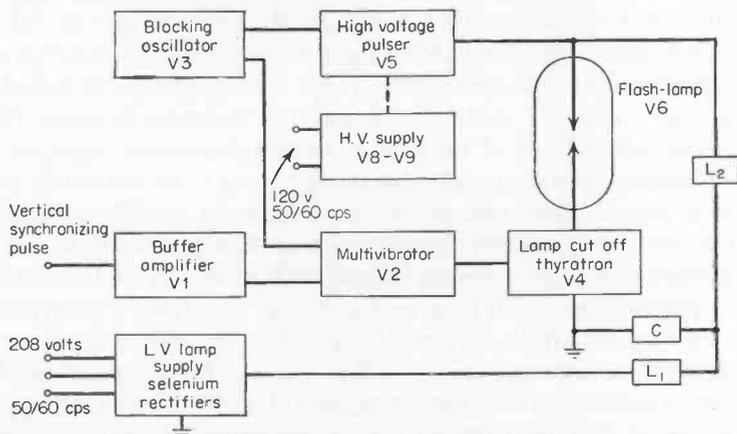


FIG. 9-11. A schematic block diagram of the circuits employed to actuate a film projector's flash tube at the television field-frequency rate.

accomplish this is shown in Fig. 9-11. Vertical synchronizing pulses from the television synchronizing waveform generator are fed through a buffer amplifier V1 and used to trigger a multivibrator V2, which, in turn, fires a blocking oscillator V3 and a thyatron V4. The pulse developed by the blocking oscillator is used to drive a high-voltage pulser tube V5. The output of the high-voltage pulser is an oscillatory wave having a peak-to-

<sup>4</sup> Downes, L. C., and J. F. Wiggin, Shutterless Television Film Projector, *Electronics*, Vol. 22, No. 1, p. 96 (January, 1949).

peak value of some 15,000 volts and a frequency of about 1 Mc, or a period of 1 microsecond. This voltage appears across the gap of the flash lamp V6, ionizes the gas, and strikes an arc.

Once the gas has been ionized, a much lower voltage, but a much higher current, is required to maintain the arc during the approximately 0.75-millisecond period of the light pulse. This is provided by a selenium rectifier power supply capable of delivering about 2 amperes of direct current at about 135 volts. Two resonant circuits are used in conjunction with this power supply in order to control the duration of the light flash and the shape of the light pulse. The resonant charging circuit  $L_1$  and  $C$  is so arranged that the capacitor becomes charged to 600 volts just before the high-voltage pulse is applied to the flash tube. This capacitor is then discharged through the discharge circuit consisting of  $L_2$ ,  $C$ , the flash tube V6, and the thyatron V4. This resonant discharge circuit is so designed as to maintain the light pulse for approximately 0.75 millisecond which is equivalent to 4.5 per cent of the television frame rate of  $\frac{1}{60}$  second. Since the minimum vertical blanking period is 5 per cent, this ensures a light pulse that is less than the lower limit of the vertical blanking period.

The thyatron V4 carries the full current that passes through the flash tube and acts as a diode to cut off the light pulse during the negative swing of the resonant discharge cycle. The shape of the light pulse is that of a half sine wave, and the peak current through the tube is about 70 amperes. Connecting leads of fairly heavy current-carrying capacity must therefore be employed if considerable energy is not to be lost in the wiring.

When a pulsed light source (or an efficiently cooled incandescent source) is used, it is entirely feasible to hold film stationary in the gate and to project one picture frame as long as desired. This feature has a number of advantages both from an operations and from a program production viewpoint. With a frame held stationary, the channel can be fully prepared for transmission with the shading, back light, edge light, optical and electronic focus, centering, and the video levels all adjusted before a foot of film has passed through the projector. From an operations viewpoint, the ability to hold the film stationary is very useful in news and similar programs where it may be desirable to stop the film momentarily in order to permit viewers a closer examination of some fleeting incident or to permit a more detailed description than would otherwise be afforded by the length of the film available.

The color of the light from a flash tube of the type described is predominantly blue, although the spectral energy distribution is a function of the loading. For best results, when used for monochrome transmission of either black-and-white or color film, light filters should be used as detailed in Sec. 10-8.

One feature of the gas tube that is of great importance in television applications is the fact that the tube is not likely to fail suddenly. Rather, it becomes unsuitable for further service when the glass bulb becomes so blackened as to reduce the light transmission below an acceptable amount. On the other hand, the necessary supporting circuits (Fig. 9-11) *do* contain a number of filament-heated tubes that can fail abruptly. Thus, there seems to be no advantage and several disadvantages (*e.g.*, higher initial and installation costs, greater maintenance expense and labor) in using gas-filled flash tubes for television film projector light sources where incandescent lamps will suffice.

**9-8. Film Projector Sound Pickup.** The sound pickup portion of a motion-picture film projector is located between the bottom of the film gate and the holdback sprocket that feeds the film to the take-up reel. It consists of a film transport mechanism and an optical system for generating an electrical replica of the sound track on the film. The function of the film transport system is to eliminate the intermittent motion imparted to the film by the pulldown mechanism and to transport the film past the optical system at a constant velocity and in a fixed plane.

In some sound-reproducing systems an exciter lamp (heated by a source of d-c or r-f current) illuminates a fine slit which, by means of a lens system, is projected upon the film as a greatly reduced slit image perpendicular to the direction of film travel. In other systems the slit is omitted, and with the aid of special optics an image of the exciter lamp filament is used directly. In any event, the width of the slit image in the plane of the emulsion should be as narrow as feasible since its width is the determining factor in so far as high-frequency response potentialities are concerned. The practical lower limit to the slit width is determined largely by the need for transmitting enough light to establish a satisfactory signal-to-noise ratio at the output of the photocell pickup.

An effective scanning slit width of between 0.00025 and 0.0005 in. (0.25 to 0.5 mil) is practical in television-type 16-mm projectors and certainly should be no wider than the latter figure.<sup>5</sup> The scanning loss for a slit of the smaller size mentioned is negligible at 8,000 cps, but that of the larger slit is almost 5 db at the same frequency. Assuming that film in good condition is available, and it is desired to obtain film sound reproduction that at least approaches the frequency range of live pickup sound, it is necessary to employ electrical equalization to compensate for the scanning loss of the 0.0005-in. slit. Of course, if the sound track on a particular film is of poor quality or limited frequency range, there is

<sup>5</sup> Proposed American Standard PH22.91, 16mm Motion Picture Projector for Use with Monochrome Television Film Chains Operating on Full-storage Basis, *J. SMPTE*, Vol. 59, No. 2, p. 144 (August, 1952).

nothing to be gained by maintaining flat response to even 8,000 cps. In fact, if the sound track is scratched, it may be necessary to employ a low-pass filter to reduce the noise level of the resulting reproduction.

In 35-mm projectors, it is customary to employ scanning slits having effective widths of between 0.001 and 0.0013 in. (1 to 1.3 mils). Since the ratio between the linear speeds of 35- and 16-mm film is 2.5 to 1, the slit widths mentioned for 35-mm projectors are effectively of the same order of magnitude as the 16-mm slits described above. Accordingly, the slit losses encountered are also of the same general magnitude.

Uniformity of illumination of the scanning slit image is also a matter of considerable importance, particularly in the reproduction of variable-area sound tracks. If the slit is not uniformly illuminated, the electrical waveforms that result from scanning of the sound track may not be exact replicas of the recorded sound. The extent of the distortion is a function, of course, of the nonuniformity of the scanning slit illumination. Projectors for 35-mm film, being built to professional standards, are usually capable of satisfactory adjustment of scanning-beam illumination. Naturally, whether or not a particular machine is in optimum adjustment is a function of the care it has enjoyed.

Unfortunately, the situation is not so satisfactory for all 16-mm projectors. This latter class of equipment, not having enjoyed a professional status for very long, is sometimes equipped with inferior sound optical systems. The better professional and television-type 16-mm projectors are capable of essentially uniform slit illumination and can be maintained well within the accepted practice<sup>6</sup> which calls for a variation of less than  $\pm 1.5$  db at any point along the length of the slit.

The hitherto nonprofessional status of 16-mm film also manifests itself in considerable amounts of film having a nonstandard emulsion position, particularly composite color duplicate prints. The accepted 16-mm standard (see Sec. 10-6) specifies that the emulsion of prints shall be toward the projection lens or the screen. When nonstandard emulsion positions are encountered, the situation can be compensated for by an alert projectionist *in so far as the picture is concerned* since the picture projection lens is adjustable. Such adjustment is a nuisance, of course, particularly if a 15- or 30-second film insert is all that is involved; nevertheless, the facility to make the adjustment is available.

The sound-system optics, however, sometimes do not lend themselves to easy refocusing to compensate for nonstandard emulsion positions. If the equipment is properly adjusted to reproduce standard film and is used for the reproduction of nonstandard film, there will be a loss in reproduc-

<sup>6</sup> American Standard Z22.80-1950, Scanning-Beam Uniformity Test Film for 16-mm Motion Picture Sound Reproducers, American Standards Association, Inc., New York.

tion of the medium-high and the high frequencies. The extent of the loss will be a function of the quality of the sound-system optics. If the optical system is focused upon one surface of the film, the accuracy with which the opposite surface will be in focus depends upon the depth of focus of the lens. With the *best* professional type of lens systems, the loss in response for a film with nonstandard emulsion position, as compared to film with standard emulsion position, may be as small as 1 db at 5,000 cps. On the other hand, with some allegedly professional sound-system optics, the loss may be as great as 20 db at 5,000 cps.

The better projectors cope with this situation by a lever adjustment that shifts the lens barrel just enough to change the focus from one surface of the film to the other. Another method, which is also satisfactory, is the incorporation of an extra "front" lens as a regular part of the projector and which may be moved into the light path to shift the focus by the required amount. It is preferable, of course, that the optical system be so good that there is little loss in response when film with a nonstandard emulsion position is running through the projector. Just as is the case of refocusing the picture optics, it is a nuisance to have to perform a similar operation for the sound optics, particularly when a number of short film inserts with varying emulsion positions are being handled.

**9-9. 16-mm Film Projector.** A 16-mm film projector<sup>7</sup> of professional caliber designed for television applications is illustrated in Fig. 9-12. It represents a new approach to the problem of film projection and incorpo-

<sup>7</sup> Fritts, E. C., A Heavy-duty 16mm Sound Projector, *J. SMPTE*, Vol. 55, No. 4, p. 425 (October, 1950).



FIG. 9-12. A 16-mm television projector whose projection light and film cooling systems are so efficient that film may be held stationary in the gate and a single frame projected continuously without damaging the film from excessive heat. (Courtesy of Eastman Kodak Co.)

rates a number of features not available heretofore in a 16-mm television projector.

**Projector Mechanism.** In the conventional motion-picture projector (both 16- and 35-mm types) a single motor is used to drive both the intermittent mechanism and the sound drive. The linking of these basically different types of motion (one which periodically moves the film and the other which requires as uniform motion as it is practical to achieve) has always been the source of difficulties. In order to minimize the flutter introduced into the motion of the film past the sound head, elaborate mechanical filtering arrangements are commonly employed.

In the projector illustrated, the usual mechanical coupling between the intermittent mechanism and the sound-system drive is replaced by an electrical linkage. This effectively prevents the shock forces unavoidably introduced by the intermittent mechanism from being transmitted to the sound drive. This independence is accomplished by individually driving each unit by its own synchronous motor. There is a temporary mechanical interlocking of the two systems during starting in order to keep them in step; however, when both motors reach synchronous speed, this temporary linkage automatically disengages.

A sprocket-type intermittent, which engages three film perforations simultaneously, is used in the projector illustrated. Thus, film with damaged or torn perforations is more likely to pass through this projector satisfactorily than through one using a single pulldown claw. The pulldown time is approximately 5 milliseconds.

The film gate and the pressure pad of the projector illustrated are constructed of hardened and lapped steel. These parts have a radius of 3 in., concave toward the projection lens as shown in Fig. 10-11. This longitudinal bending of the film is opposite to and counteracts the normal film curl and thermal distortion caused by the light beam, in those applications where an incandescent lamp or arc is used. Thus the film is held in the best shape to give good definition over the largest possible area of the picture frame. Side guiding of the film is employed with sapphire pads for long wear and with the fixed guide on the sound-track side of the film.

Framing is accomplished by a control knob that rotates the housing containing the Geneva star. Thus the film frames are shifted while the picture aperture remains fixed. Accordingly, the projected image remains properly centered upon the screen of the camera tube at all times.

**Light Source and Optical System.** The projector illustrated is available for television applications with an incandescent source of illumination and an associated rotating shutter. A separate synchronous motor drive is used for the shutter to avoid again any mechanical coupling between the various driving systems required in the projector. The incandescent lamp

system employs a base-up 1,000-watt lamp with an improved basing ring that provides accurate alignment of the filament, better maintenance of light output, and improved ventilation. A dual lamp arrangement permits a burned-out lamp to be instantly swung out of the way and the spare lamp brought into place without stopping the projector.

An unusual feature of this projector is the ability to hold a frame of film stationary in the gate without damaging it, in spite of the fact that an incandescent source of light is used. The ability to do this is attributable to a combination of features all reflecting a carefully considered design. First, the film illumination system is so efficient that it is possible to make use of an effective infrared filter between the lamp and the film. Second, an ample blast of air cools the film and the film gate. Third, the shutter and intermittent motors are independent, and the latter may be turned off while the former is permitted to run. When operated in this fashion, the incandescent light source provides most of the advantages of a pulsed light source without the need for a multitube high-voltage power supply for operation of the flash tube.

**Douser.** The light beam of the projector described may be cut off by a plane shutter located between the condenser lens system and the film gate. This shutter, usually called a douser (or dowser) is operated by means of a rotating solenoid type of mechanism and may be remotely controlled. In television applications it is customary to interlock the douser operation with the running of the projector mechanism itself. Thus, when the projector is started, the douser moves out of the way, and when the off-button is operated, the douser immediately moves back into place and cuts off the light beams even before the projector coasts to a stop. The operation is commonly known as dousing and undousing the projector.

**Sound System.** The sound optical system produces a scanning beam image 0.0003 in. (0.3 mil) wide at the surface of the film. A prism-lens system behind the film collects the light and directs it onto the cathode of a photocell. A multiple-element optical system of special design, employing among other items a highly corrected microscope objective, forms an image of uniform width and light intensity. An adjustment lever, with predetermined stops, accurately focuses the sound optical system on either surface of the film, as desired. Thus both standard and nonstandard emulsion positions are accurately accommodated. Means are also provided to undertake lateral positioning of the sound track and for azimuth adjustment of the scanning slit. The exciter lamp is heated from a source of direct current obtained from a self-contained selenium rectifier.

There is a free loop of film between the intermittent and the sound drum and another one between the sound drum and the take-up sprocket (Fig. 9-13). These loops protect the sound drum from disturbances

originating in both the intermittent and the take-up mechanism. A sound sprocket draws the film from the sound drum over a filtering idler carried on a swinging arm whose rotation is viscously damped by a film of silicone fluid. The tension developed by this filtering loop on the sound drum is balanced by a countertorque produced by an eddy-current drag between an aluminum disk on the sound-drum flywheel and a fixed permanent magnet.

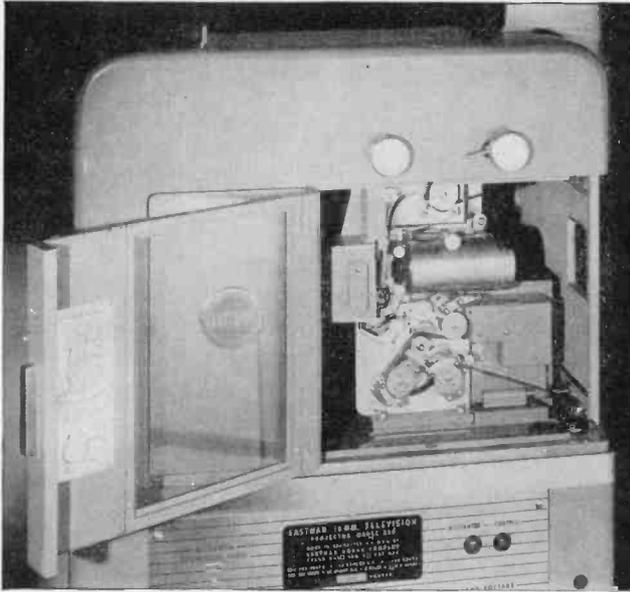


FIG. 9-13. A close-up of a 16-mm television projector showing the film path, the various guide, sound, and take-up sprockets, the sound drum, and the projection lens.

The output of the photocell pickup tube is fed directly into a preamplifier located on the projector head. As a matter of fact, the photocell is mounted within the preamplifier chassis itself so that no long connecting leads, requiring special handling, are involved. Accordingly, there is no loss in high-frequency response or in signal-to-noise ratio as sometimes occurs when the first audio amplifier tube is mounted at a distance from the photocell.

**9-10. 35-mm Film Projector.** A projector designed for the presentation of 35-mm sound-motion-picture film for television broadcasting purposes is shown in Fig. 9-14. The projector is mounted on a heavy metal pedestal which houses various accessories including a d-c power supply for the unique-phase synchronous driving motor. This projector employs a

pulsed-light source using a gas-filled flash tube (Sec. 9-7, *Gas-filled Flash Tube*) and consequently does not require a shutter.

**Projector Mechanism.** The projector mechanism, including the 2,000-ft supply and take-up reels, is entirely enclosed in a metal housing in keeping with the usual practice for 35-mm film projectors. Shatterproof glass windows permit viewing the operation of the mechanism while the machine is running and all doors are closed.

As shown in Fig. 9-15, film is fed from the upper (supply) magazine down through the film feed sprocket and thence through the film gate in the picture head. Unlike 16-mm film which has one sprocket hole per frame, 35-mm film has four sprocket holes per frame. In threading the machine, the sprocket holes must be correctly engaged so as to center the picture in the film gate. To facilitate this operation, the projector illustrated has an extra aperture (located exactly 5 frames above the regular picture aperture) which is visible even when the film gate is closed. A "framing" lamp, operated by a conveniently located switch, is provided back of the auxiliary aperture in order to illuminate the film frame in the auxiliary gate during the threading process.

In order to obtain a steady picture, it is necessary that the tension on the film in the film gate be correctly adjusted. Two controls are provided for this purpose in the projector illustrated. Simultaneous adjustment of three pressure pads is afforded by one control while the other controls the tension shoe for the intermittent sprocket. To reduce wear both on the film and on the film pressure shoe, it is advisable to run the film with the highest pressure possible consistent with projecting a picture free of jump or motion in a vertical direction during projection. Weave, or sideways motion, is reduced to a minimum by the use of conventional side guides for the film, together with guide rollers at the top of the film gate.

The pulldown mechanism in this projector, for the reasons detailed

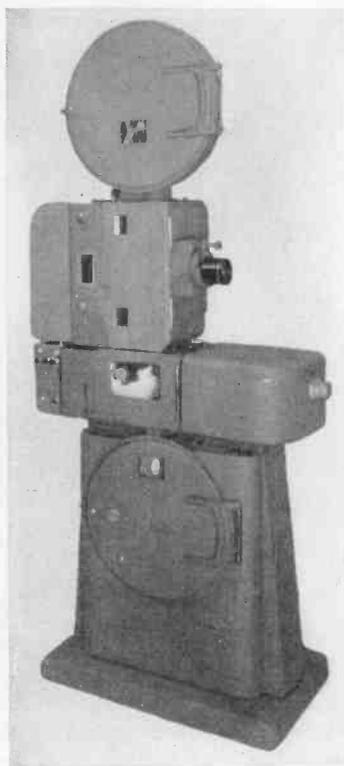


FIG. 9-14. A 35-mm television projector that utilizes a flash-tube source of light for projection purposes. (Courtesy of Radio Corporation of America.)

above (see Sec. 9-6, *Pulldown and Projection Cycles*) is designed so as to leave alternate frames in the aperture for three light pulses and the remaining frames for two.

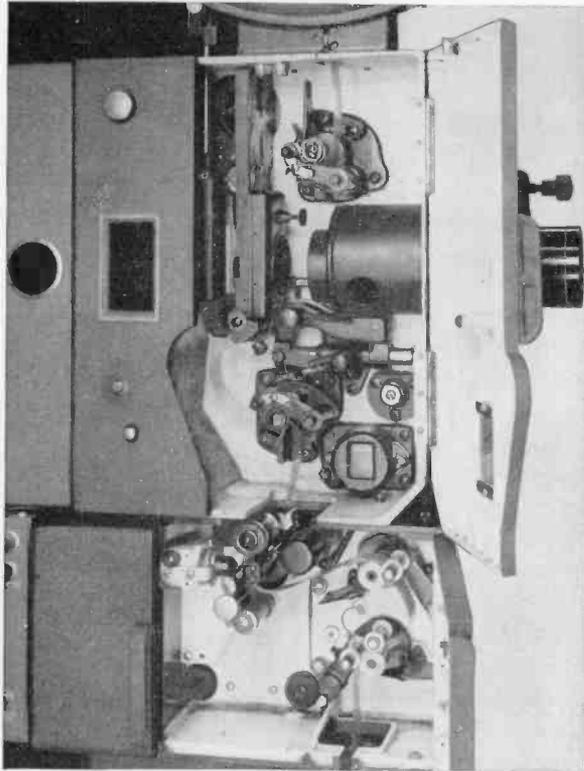


FIG. 9-15. A close-up of a 35-mm television projector showing the path of the film down through the film gate in the upper compartment and over a sound drum, constant-speed sprocket, and a holdback sprocket in the lower compartment on its way to a take-up reel. (Courtesy of Radio Corporation of America.)

**Light Source and Optical System.** A gas-filled flash tube with its associated optical system is mounted in a housing at the rear of the projector. The condenser lenses are mounted in a barrel at the front of the assembly. A front-surface mirror serves as the reflector for the illumination system and is located at the rear of the assembly. The gap lamp is supported on insulating blocks between the reflector and the condenser lenses. Provisions are made for both rotation and elevation of the gap lamp to position properly the light source with respect to the optical system. The high-voltage power supply and associated triggering circuits, described previously, are contained in a separate unit.

**Douser.** A shutter is provided in the projector illustrated in order to cut off the light beam from the camera tube whenever desired, without having to turn off the pulsed-light tube. This douser consists simply of a flat plate inserted between the condensing lens and the film aperture. The operation of cutting off the beam of light may be performed manually at the projector or by electrical control from a remote point.

**Sound Head.** The sound head used in the projector described is a modified version of a standard theater projector sound head. The unit operates in a conventional manner, employing an exciter lamp, an associated condenser lens, and a photocell for converting the modulated light beam into electrical waves. The exciter lamp requires 4.5 amp of direct current at about 9 volts. This is obtained from a full-wave rectifier whose output is well filtered to remove all power-supply ripple. In an emergency resulting from failure of the d-c supply, the exciter lamp filament may be heated with alternating current of the proper voltage by operating a switch incorporated in the equipment to handle this situation. Should it become necessary to operate the machine in this manner, there will be some a-c hum in the audio output, but this spurious signal is preferable to no audio output whatsoever.

A spare exciter lamp is mounted on the same bracket as the lamp that is in service, in order to cope with the possibility of failure of the exciter lamp itself during operation. Should this occur, an instant substitution of the lamps may be made by removing the bracket from the housing, reversing it, and reinserting the bracket. The exciter lamps are of the prefocused type, and when a replacement unit is installed, it requires no adjustment once it has been properly seated in its socket.

**Drive Motor.** A  $\frac{1}{8}$ -hp three-phase 208- to 230-volt, 1,800-rpm synchronous motor, employing d-c field excitation, is used to operate the projector illustrated. The use of this type of motor ensures automatic lock-in and phasing of the projector with the television synchronous waveform generator when both units are operated from the same source of a-c power. This motor drives both the film projector head and the sound head through suitable gear trains. To assist in obtaining uniform motion of the sound drum, a rotary stabilizer, or viscous damper, is mounted on the shaft carrying the drum. This aids in damping out the intermittent motion given to the film as it moves through the projector head.

**9-11. Projector Multiplexing.** Television projector cameras, unlike field and studio cameras, cannot be dollyed readily from one position to another and trained upon a new source of program material at will. Rather it is necessary to employ means that will ensure the accurate and rapid registration and focus of the image from a projector upon the screen of the camera tube.

A number of methods have been employed for multiplexing several projectors upon a single camera. Some involve moving the camera from one projector to another either by rotating the camera on a swivel or by moving it laterally on rails. Other methods employ either fixed or movable mirrors in the optical path of the projector in order to direct the image into the camera. It cannot be said that any one system has outstanding advantages over the other. Each has its good points and its drawbacks; the choice of multiplexing system will depend largely upon the operating requirements of the television station involved.

In the following paragraphs, the several basic systems are described. It is to be borne in mind that combinations of several systems can often be employed to advantage.

**Fixed-mirror Multiplexer.** One of the simplest methods of directing the image from two projectors into a single camera tube is by means of two mirrors set at approximately 90 degrees with respect to each other and at about 45 degrees with respect to the optical center lines of the projectors and the camera tube, as shown in Fig. 9-16. Obviously, angles other than those mentioned may be employed should there be any advantage in doing so.

The mirrors employed for this service are made of optically flat glass whose front surface is silvered. Preferably, they should be individually adjustable over a small range in all directions to facilitate initial line-up of the optics during installation. It is exceedingly important that the system employed for supporting the mirrors be such as to avoid placing strain thereon and creating optical distortions. The pedestal supporting the mirrors should, of course, be exceptionally rigid since any vibration in this unit will manifest itself as vibration in the image projected upon the camera tube.

In order to avoid reduction in the contrast range of the image projected upon the screen of the camera tube, the mirrors of a multiplexer unit should be shielded from stray light. Any light from a window or the general lighting used in the telecine room which falls upon these mirrors and is then reflected onto the camera tube may materially degrade the picture. However, even light that is not so unfortunately reflected may also be damaging if the surface of the mirrors is not spotlessly clean, since the scattered light from a dirty mirror will also reduce the picture contrast.

In some installations a slide projector is mounted just over the multiplexer mirrors and focused directly upon the tube in the camera. Typical installations of this type are shown in Fig. 14-2. When a slide projector is mounted in this manner, there is a slight amount of optical keystone present since the optical axis of the projector is not perpendicular to the

screen of the camera tube. Because of the small inherent depth of focus of most slide projector lenses, this may result in parts of the image being out of focus. This may be corrected by stopping down the lens to increase its depth of focus. However, slide projector lenses are not normally

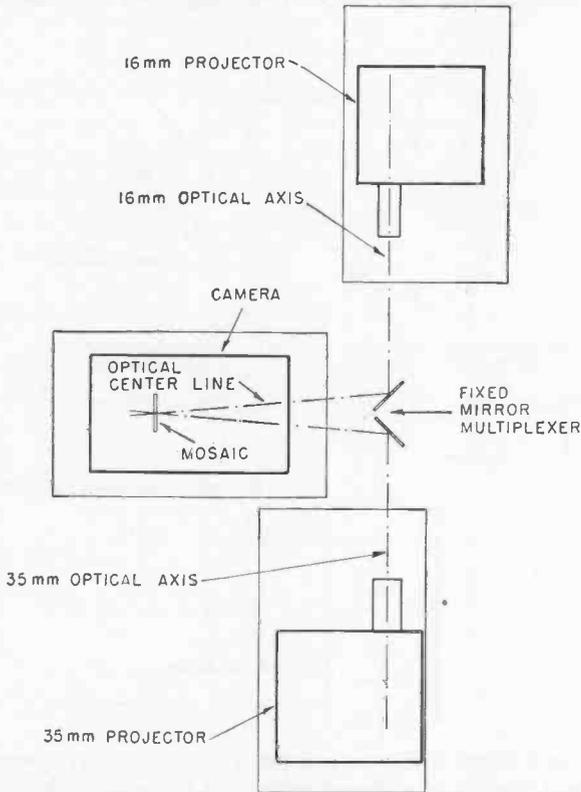


FIG. 9-16. A fixed-mirror diplexer arrangement that provides a very simple and satisfactory method for imaging two projectors upon a single camera tube.

equipped with an adjustable iris. Consequently, it may be necessary to apply an external iris that will reduce the lens opening by about one-half its diameter. This iris may be fabricated out of any suitable opaque material such as thin metal, plastic, or even cardboard.

The advantages of a fixed-mirror multiplexer include simplicity, ease of initial installation and adjustment, no precisely machined moving parts requiring maintenance, instantaneous selection of any projector, and remote operation of the machines.

**Movable-mirror Multiplexer.** A dual-faced first-surfaced mirror mounted on a turntable may also be used for multiplexing applications.

If accurate indexing means are provided, the mirror may be rotated to a number of predetermined locations and a corresponding number of projectors aligned with the television camera. For example, as shown in Fig. 9-17, four projectors are grouped around a single camera. Two 16-mm and one 35-mm motion-picture projectors are shown grouped

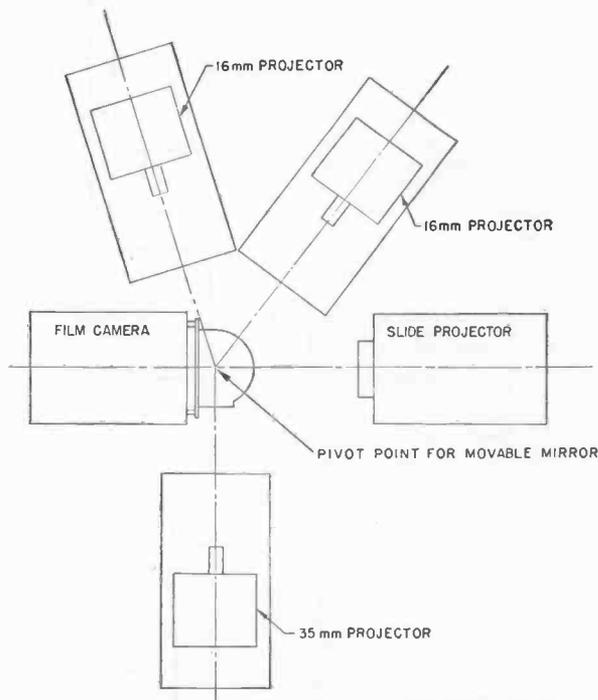


FIG. 9-17. When a mirror is pivoted in front of a camera tube, a means is provided for multiplexing a number of projectors upon a single camera. In the arrangement shown, the mirror is swung completely out of the way when the slide projector is put to use.

around the movable multiplexer mirror while a still projector is mounted for straight-through projection. This latter type of operation is made possible because the mirror is mounted upon an eccentrically pivoted plate which permits the entire assembly to be swung off center for straight-through projection.

The use of a movable-mirror multiplexer requires that each projector be precisely located with respect to the multiplexer unit since the locations of their respective optical axes are interrelated. The indexing of the mirror may be adjusted in azimuth as required but, unless an unwarranted degree of complexity is to be countenanced, the mirror cannot be

made adjustable in angle of elevation for each position. Therefore, in the initial installation, the optical axes of all elements involved (the camera, the multiplexer, and all projectors) must be located in the same plane. In addition, the optical path lengths from the mosaic or screen of the camera tube to the aperture of each projector must be of the particular value that results in the image on the camera tube being the same size for all projectors. If this is not accomplished, not only will the transmitted picture be of a different size from each projector but, in addition, when iconoscopes are employed, it will become impossible to obtain an optimum adjustment of edge lighting for all projectors.

The use of a movable multiplexer mirror may eliminate the need for doublers on the individual projectors since the mirror can be turned when it is desired to douse a particular projector. On the other hand, unless a rather elaborate mechanism is employed, it is not possible to rotate the multiplexer to a desired point from a remote operating position. Nevertheless, the movable multiplexer is potentially capable of handling more projectors on a single camera than is a fixed, two-mirror multiplexer, and its use is therefore largely a function of the operating conditions that must be satisfied.

**Track-mounted Cameras.** One of the most straightforward (but not necessarily the most convenient) methods of operating several projectors into a single camera is to line them up, as shown in Fig. 9-18. With the camera mounted on a set of rails, it can then be slid in front of any desired projector. Two or more cameras can readily be used in an installation of this type. When this is done, they are usually arranged so that they can be lifted off the rails and jumped around an adjacent camera, should the need arise to do so. An accurate indexing arrangement is

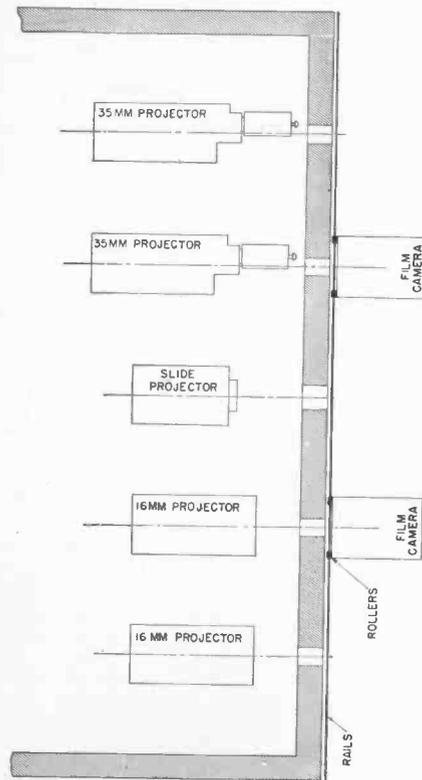


FIG. 9-18. Film cameras have been mounted on tracks as shown in order to permit their alignment with a number of projectors.

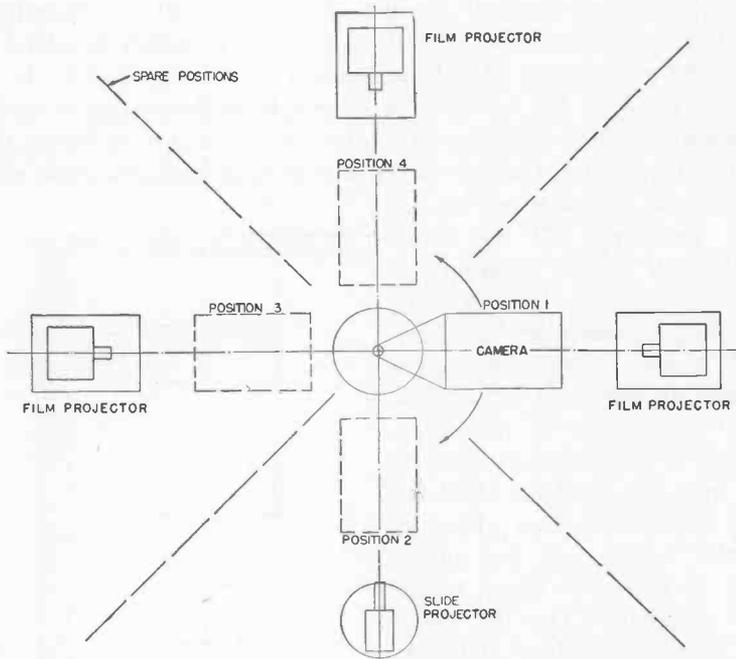


FIG. 9-19. When mounted on a turret, a film camera may be faced in a number of directions and a large number of projectors thereby multiplexed on a single unit.

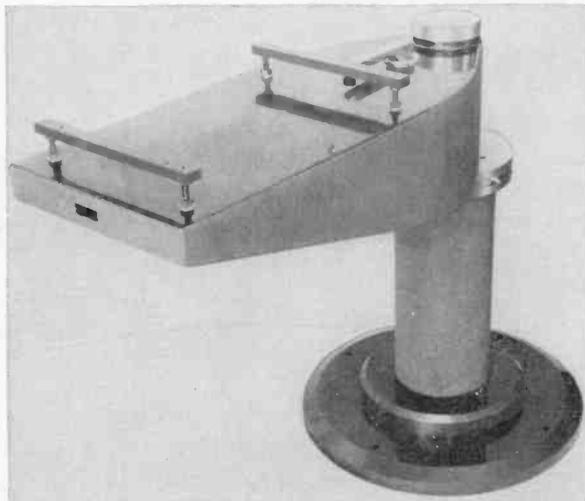


FIG. 9-20. A film camera turret incorporating precision-machined bearings and an accurate detent mechanism which ensures reproducibility of alignment with associated projectors. (Courtesy of Gray Research and Development Co.)

desirable at each projector position to facilitate the correct location of the camera with respect to the individual projectors. Unless this is done, it becomes necessary to check the focusing and centering each time a camera is placed in front of a given projector.

**Turret-mounted Cameras.** With the camera mounted on a rotatable turret, it is possible to locate the camera in the center of a group of projectors and to turn it toward any unit in the group, as shown in Fig. 9-19. Since the projectors are located on the periphery of a rather large-diameter circle, eight or so units may readily be grouped around a turret-mounted camera, should it be desirable to do so. A camera turret suitable for this type of application is shown in Fig. 9-20. The turret body, mounted on precision-machined bearings, swings at the top of a steel pedestal. A lever-operated plunger, fitting down through the turret top, engages the detent mechanism to index the turret accurately to predetermined positions. Two ball-swivel camera-support bars are provided with four jackscrews on top of the turret for support of the camera. This arrangement permits leveling the camera from front to rear or from side to side as may be required. The camera mounting arrangement is such that any type of camera may be readily accommodated.

**Sliding-mirror Quadriplexer.** A sliding-mirror quadriplexer is shown in Fig. 9-21. It consists of four front-surfaced optically flat mirrors, mounted in groups of two on separate carriages. The mirrors are adjustable with a 7-degree swing either way from a vertical plane and an equal adjustment in azimuth. Each carriage is carried on its own pair of stainless-steel rails which carry adjustable stops to limit the travel of the carriages. The carriages are held firmly against their respective stops by alnico magnets rather than by any detent or spring-loaded catch arrangement. A suitable pedestal supports the entire assembly at the correct distance above the floor.

A sliding-mirror multiplexer may be used in a variety of ways. For example, as shown in Fig. 9-22, a single carriage unit (rather than the double one illustrated) may be employed to multiplex two film projectors

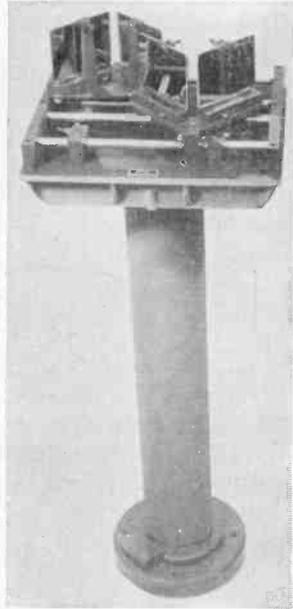


FIG. 9-21. This sliding-mirror quadriplexer employs two independent sliding carriages each carrying a pair of front-surfaced mirrors. (Courtesy of Gray Research and Development Co.)

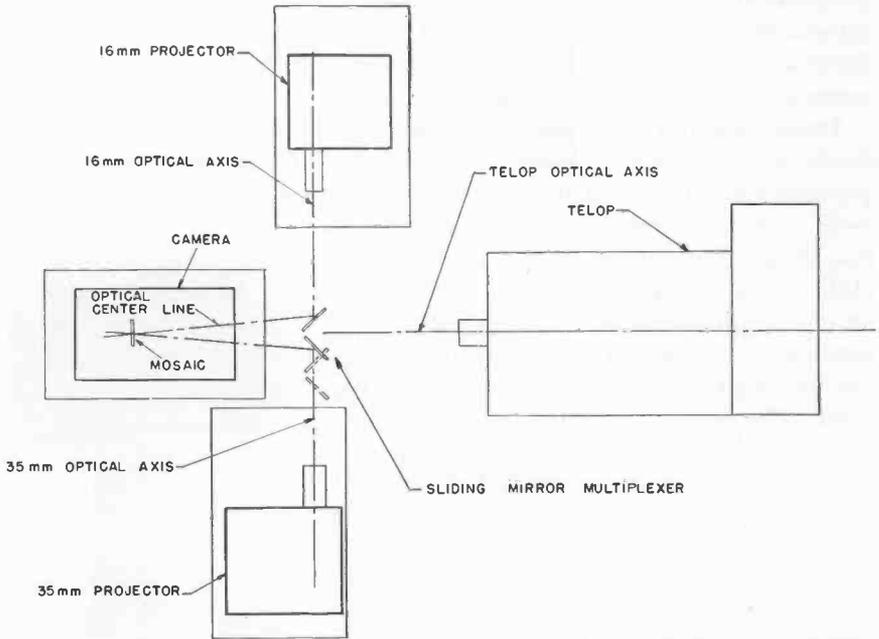


FIG. 9-22. A sliding-mirror multiplexer is basically a fixed-mirror diplexer with the added feature of being readily slid aside to provide a direct projection path for a third projector.

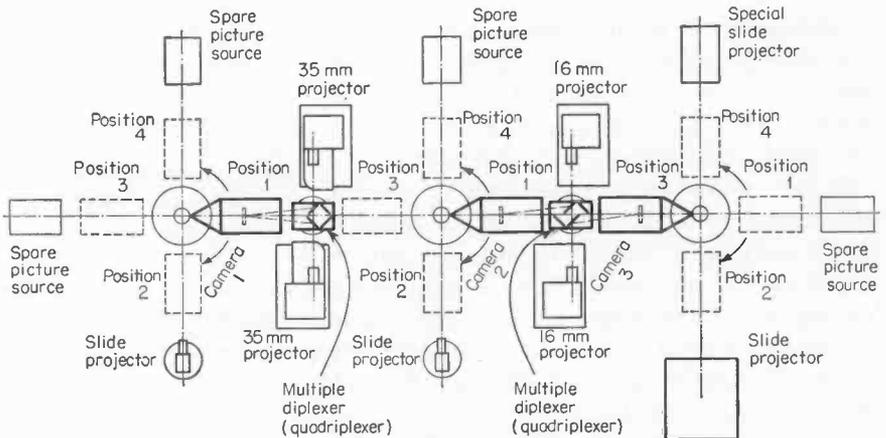


FIG. 9-23. An elaborate multiplexing arrangement employing both camera turrets and sliding-mirror quadriplexers wherein three cameras service 12 projectors in a variety of combinations. (Courtesy of KECA-TV, Los Angeles.)

into a single camera. In addition, a third projector, whose cone of light is too large to project over the top of the mirrors, may be located back of the multiplexer and the mirrors slid out of the way when the third projector is to be brought into play.

As another example, the sliding-mirror quadriplexer may be used in conjunction with the turret-mounted camera described above to form the versatile arrangement shown in Fig. 9-23. Here the combination of these two elements provides an arrangement wherein up to 12 projectors may be grouped around three cameras. Added flexibility is provided by the ability to use certain projectors on either one of two cameras. The operating requirements of different television stations are not exactly alike; therefore, the multiplexing arrangement shown may not be directly applicable to any particular station. However, one feature or another of the layout may be useful in specific applications.

## Motion-picture Film

THE REPRODUCTION OF MOTION-PICTURE FILM may not be so fascinating an operation as the production of live programs; nevertheless, the television broadcaster is destined to make extensive use of film just as his aural broadcasting counterpart makes extensive use of sound recordings. The use of film for television applications will be greatly enhanced, of course, when the producers thereof recognize the special requirements of film intended for television both as to the kind of scenes that reproduce best over a television system (see Chap. 7) and as to the need for sound quality that is vastly superior to that which has been considered satisfactory in the past.

Keeping in mind the importance of film to television broadcasting, this chapter presents pertinent information concerning both 16- and 35-mm sound-motion-picture film. The motion-picture expert has most of this information at the tip of his tongue but to the television broadcasting engineer, whose past experience has been largely in the field of waves and electrons, the information will serve as an introduction to some of the established characteristics and standards of film.

No attempt will be made to discuss the making of motion pictures, the details of processing film, or allied subjects which are really in the domain of the motion-picture field and about which volumes have been written.<sup>1</sup> Rather, the text covers a discussion of those factors that are of importance to the television broadcaster in his handling of film for program transmission purposes.

**10-1. Film Dimensions.** The dimensional standards covering motion-picture film are of considerable interest to the television broadcaster for several reasons. First, in spite of the well-established standards covering all dimensions essential to the successful interchange of film, non-standard film will be encountered from time to time. The divergence from

<sup>1</sup> Offenhauser, W. H., Jr., "16-mm Sound Motion Pictures," Interscience Publishers, Inc., New York, 1949. Contains an extensive bibliography pertaining to both 16- and 35-mm motion-picture practices.

the existing standards seldom concerns the physical dimensions of the film itself although, at times, sprocket-hole dimensions, location, or pitch may deviate from the standards governing these items. The principal difficulties manifest themselves in sound and picture synchronism, in sound-track location and width, in picture location and size, and in similar deviations from standards that are primarily the result of the manner in which the film is handled after its manufacture as raw stock. Next, the broadcaster has an interest in film dimensional standards because of the need for maintaining his projection equipment in proper condition to correctly reproduce film that is made in accordance with the accepted standards. If, in addition, he is engaged in doing motion-picture work of his own, either as direct photography or as television recording (see Chap. 11), he has a still further interest in film standards. Checking the dimensions of motion-picture film can often clear up operational difficulties encountered that might otherwise remain obscure. In the following paragraphs those dimensional standards that are pertinent to television applications of motion-picture film are presented.

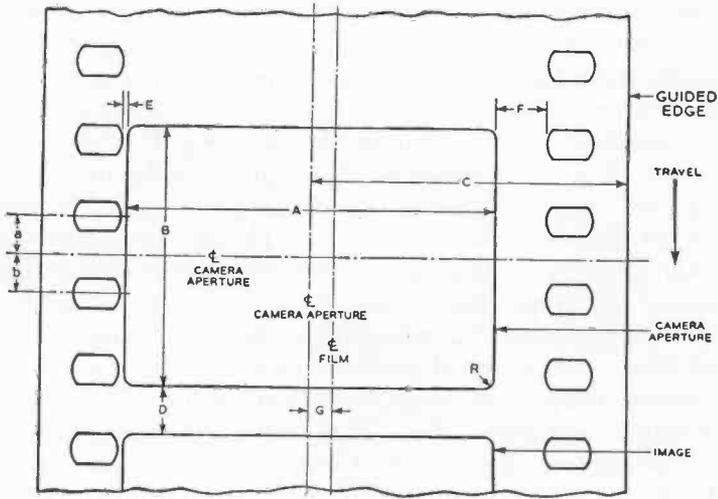
**35-mm Film.** The standard position and size of the camera aperture (and, therefore, the picture frame) for 35-mm film are shown in Fig. 10-1, together with an indication of the edge of the film that is to serve as a guide in the camera. The standard dimensional characteristics of the sound track and scanning area of 35-mm motion-picture prints are as shown in Fig. 10-2. The sound track is seen to be located between one set of sprocket holes and one edge of the picture, the total width of this space being 0.121 in. However, all of this width is not available for the actual sound track since guard areas must be provided in anticipation of the tolerances required in actual practice. The maximum permissible width of variable-area sound tracks, the nominal width of variable-density sound tracks, and the area of the sound track that is scanned are all detailed in the illustration. It will be noted that these tracks are *not* centered in the space between the sprocket holes and the picture edge. The standard linear distance between a sound and the corresponding picture is 20 frames in 35-mm sound-motion-picture film (see Fig. 10-2), the sound preceding the picture as it passes through the projector by this amount of film.

**16-mm Film.** Both silent and sound types of 16-mm film are in extensive use. The so-called 16-mm silent-motion-picture film, with its double row of sprocket holes, is used both for silent negatives and prints and for sound-picture negatives where a double-film system is employed (see Sec. 10-7, *Double-film System*). The 16-mm sound-motion-picture film, which has sprocket holes on only one side (Fig. 10-3), is used for composite sound and picture prints. It is also used for composite sound and picture

American Standard  
 Photographing Aperture of 35-Millimeter  
 Sound Motion Picture Cameras

ASA  
 Inc. U. S. Pat. Off.  
 Z22.59-1947

\*UDC 778.53



Dimension	Inches	Millimeters
A	0.868 ± 0.002	22.05 ± 0.05
B	0.631 ± 0.002	16.03 ± 0.05
C	0.744 ± 0.002	18.90 ± 0.05
D	0.117	2.97
E	0.010	0.25
F	0.121	3.07
G	0.055	1.40
R	0.03 approx	0.8 approx

$a = b = \frac{1}{2}$  longitudinal perforation pitch.

These dimensions and locations are shown relative to unshrunk raw stock.

Note: The aperture dimensions given in combination with an 0.600 × 0.825 in. (15.25 × 20.95 mm) projector aperture result in a screen picture having a height-to-width ratio of 3 to 4 when the projection angle is 14 degrees.

Approved September 26, 1947, by the American Standards Association.

Sponsor: Society of Motion Picture Engineers.

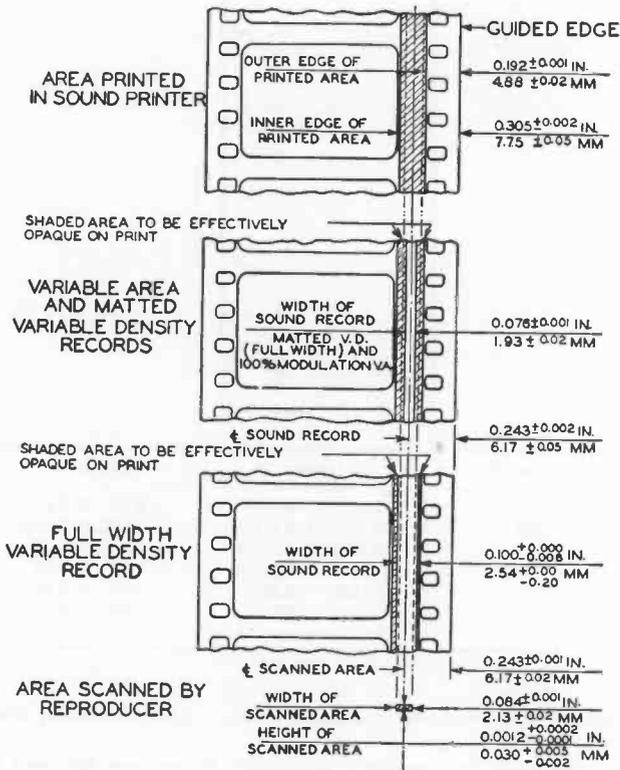
\*Universal Decimal Classification

FIG. 10-1. (Copyright, 1947, American Standards Association.)

American Standard  
**Dimensions and Locations for  
 Sound Records and Scanning Area  
 of 35-Millimeter Sound Motion Picture Prints**

**ASA**  
 Reg. U. S. Pat. Off.  
**Z22.40-1950**

Revision of  
**Z22.40-1946**  
 IUDC 778.534.4



Distance Between Sound and Corresponding Picture — The sound shall precede the center of the corresponding picture by a distance of  $20 \pm \frac{1}{2}$  frames.

These Dimensions and Locations Are Shown Relative to Unshrunk Raw Stock.

\*The only change in this standard over the 1946 edition is the correct positioning of the arrows on the dimensions marked \*.

Approved October 6, 1950, by the American Standards Association, Incorporated

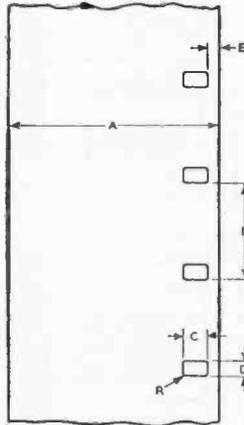
Sponsor: Society of Motion Picture and Television Engineers

Universal Decimal Classification

FIG. 10-2. (Copyright, 1950, American Standards Association.)

American Standard  
Cutting and Perforating Dimensions for  
**16-Millimeter Sound Motion Picture**  
Negative and Positive Raw Stock

  
 Ref. U. S. Pat. Off.  
**Z22.12-1947**  
 Revision of  
**Z22.12-1941**



Dimensions	Inches	Millimeters
A	0.629 ± 0.001	15.98 ± 0.03
†B*	0.3000 ± 0.0005	7.620 ± 0.013
C	0.0720 ± 0.0004	1.83 ± 0.01
D	0.0500 ± 0.0004	1.27 ± 0.01
‡E	0.036 ± 0.002	0.91 ± 0.05
L‡	30.00 ± 0.03	762.00 ± 0.76
R	0.010	0.25

These dimensions and tolerances apply to the material immediately after cutting and perforating.

\*In any group of four consecutive perforations, the maximum difference of pitch shall not exceed 0.001 inch and should be as much smaller as possible. (This requirement has been added to the previous standard Z22.12-1941.)

†This dimension and tolerance was given in respect to the center line of the perforations in the previous standard Z22.12-1941.

‡This dimension represents the length of any 100 consecutive perforation intervals.

Approved July 16, 1947, by the American Standards Association.  
Sponsor: Society of Motion Picture Engineers.

FIG. 10-3. (Copyright, 1947, American Standards Association.)

negatives where a single-film system is employed (see Sec. 10-7, *Single-film System*).

The dimensions of both sound and silent 16-mm films are identical except for the omission of one set of sprocket holes in the sound-motion-picture film. Under these circumstances, it is possible to thread silent film in either a sound projector or a single-system camera (assuming no sound recording is to be undertaken) without danger of damaging the film. On the other hand, sound film cannot be used in older style projectors that have double pulldown claws or sprockets, nor in silent or double-system cameras if they are similarly equipped.

The standard size and position of the camera aperture for 16-mm sound film are shown in Fig. 10-4. The proper edge of the film to be employed for edge guiding is also indicated.

The size and location of 16-mm sound tracks are shown in Fig. 10-5. The sound track is seen to occupy the area formerly used for one row of sprocket holes. Guard areas are provided on both sides of the sound track, between the edge of the film and the track in one instance and between the picture and the track in the other. The maximum permissible width of a variable-area sound track, the nominal width of a variable-density track, and the width of the scanned area are all detailed in the illustration. The standard distance between a picture frame and the corresponding sound is 26 frames in 16-mm sound-motion-picture film with the sound preceding the picture; *i.e.*, the sound is nearer the head of the film than the corresponding picture.

**10-2. Projector Aperture Sizes.** In televising film, the picture area may suffer successive trimmings of its edges, as detailed in Sec. 7-6. Individually, the losses of picture area are small, but in the aggregate they add up to an amount that may result in the partial cutting off of performers' heads or feet.

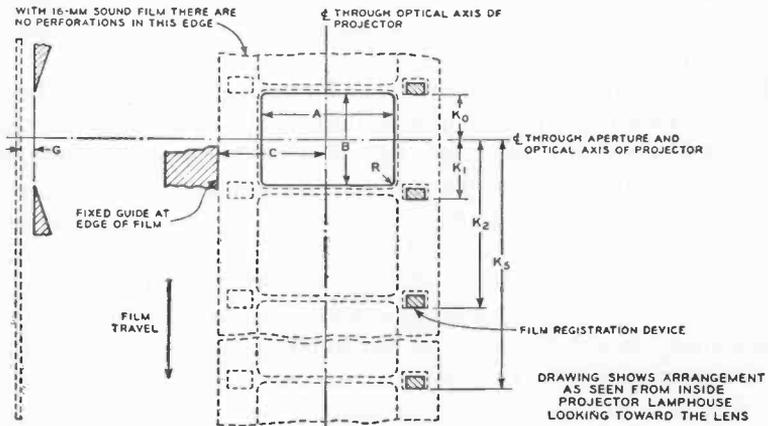
For example, the relation between the standard camera aperture and the projector aperture for 35-mm film is illustrated by Fig. 10-6. From this illustration it is seen that both the height and the width of the original picture are reduced approximately 5 per cent by the projector aperture. For 16-mm film (see Fig. 10-7) the reduction of original picture width and height amounts to about 5 and 3 per cent, respectively. Theoretically, an equal amount of the height is lost from both the top and the bottom; in practice, the allocation of the loss is a function of the accuracy of framing of the projector. As far as the width is concerned, roughly one-third of the loss is on one side of the film and the remainder on the other.

When the image is projected upon the screen of a television camera tube, there is a further loss of area because of the common (and desirable) practice of having the scanning raster, rather than the edges of the

American Standard  
**Location and Size of Picture Aperture of  
 16-Millimeter Motion Picture Projectors**

  
 Reg. U. S. Pat. Off.  
**Z22.8-1950**  
 Revision of  
**Z22.8-1941**  
 and  
**Z22.14-1941**  
 \*UDC 778.55

This standard applies to both silent and sound 16-mm. motion picture projectors. It covers the size and shape of the picture aperture and the relative positions of the aperture, the optical axis, the edge guide, and the film registration device.



Dimension	Inches	Millimeters	Note
A (measured perpendicular to edge of film)	$0.380 \pm 0.002$	$9.65 \pm 0.05$	1
B (measured parallel to edge of film)	$0.284 \pm 0.002$	$7.21 \pm 0.05$	1
C	$0.314 \pm 0.002$	$7.98 \pm 0.05$	3
K <sub>0</sub>	$0.124 \pm 0.005$	$3.15 \pm 0.13$	4
K <sub>1</sub>	$0.174 \pm 0.005$	$4.42 \pm 0.13$	4
K <sub>2</sub>	$0.473 \pm 0.005$	$12.01 \pm 0.13$	4
K <sub>3</sub>	$0.771 \pm 0.005$	$19.58 \pm 0.13$	4
K <sub>4</sub>	$1.070 \pm 0.005$	$27.18 \pm 0.13$	4
K <sub>5</sub>	$1.368 \pm 0.005$	$34.75 \pm 0.13$	4
R	0.020 maximum	0.51 maximum	1

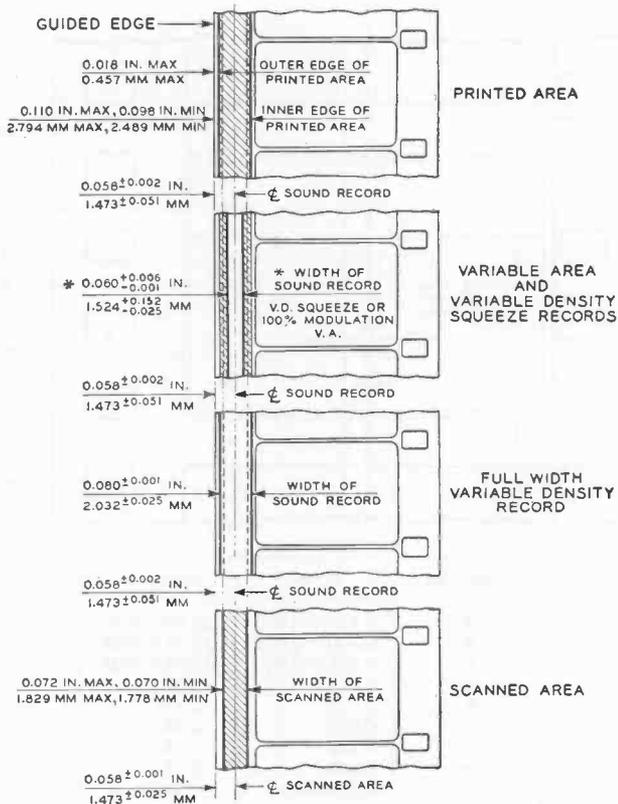
Approved March 14, 1950 by the American Standards Association Incorporated  
 Sponsor: Society of Motion Picture and Television Engineers Incorporated

\*Universal Decimal Classification

FIG. 10-4. (Copyright, 1950, American Standards Association.)

American Standard  
**Sound Records and Scanning Area**  
of 16-Millimeter Sound Motion Picture Prints

ASA  
Reg. U. S. Pat. Off.  
**Z22.41-1946**



These Dimensions and Locations Are Shown Relative to Unshrunk Raw Stock

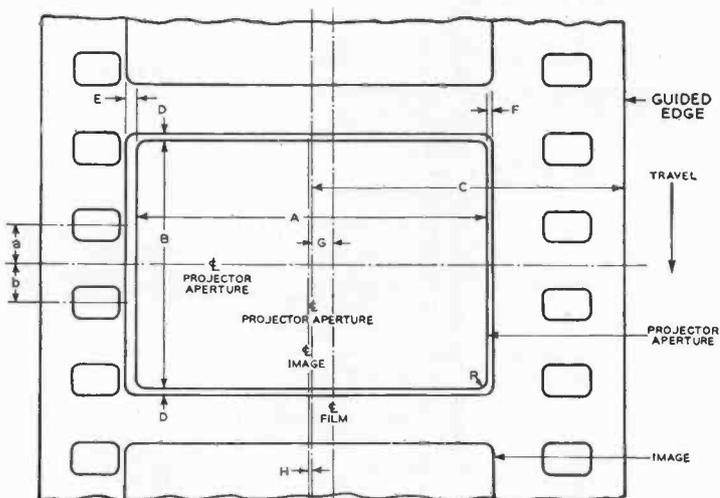
\*This dimension for the width of the sound record of variable density squeeze tracks and of variable area tracks at 100 percent modulation is based on present day equipment design. It is recommended that all future equipment be designed for a record width of  $0.060 \pm 0.001$  inch. It is also recommended that existing equipment be modified to produce prints having variable density squeeze and 100 percent modulation variable area records with a width as close as practicable to  $0.060 \pm 0.001$  inch.

Approved March 19, 1946, by the American Standards Association

FIG. 10-5. (Copyright, 1946, American Standards Association.)

American Standard  
**Picture Projection Aperture of 35-Millimeter  
 Sound Motion Picture Projectors**

  
 R-2, U. S. Pat. Off.  
**Z22.58-1947**



Dimension	Inches	Millimeters
A	0.825 ± 0.002	20.95 ± 0.05
B	0.600 ± 0.002	15.25 ± 0.05
C	0.738 ± 0.002	18.74 ± 0.05
D	0.0155	0.394
E	0.028	0.71
F	0.015	0.38
G	0.049	1.24
H	0.006	0.15
R	0.05 approx	1.3 approx

$a = b = \frac{1}{2}$  longitudinal perforation pitch.

These dimensions and locations are shown relative to unshrunk raw stock.

*Note:* The aperture dimensions given result in a screen picture having a height-to-width ratio of 3 to 4 when the projection angle is 14 degrees.

Approved September 26, 1947, by the American Standards Association.

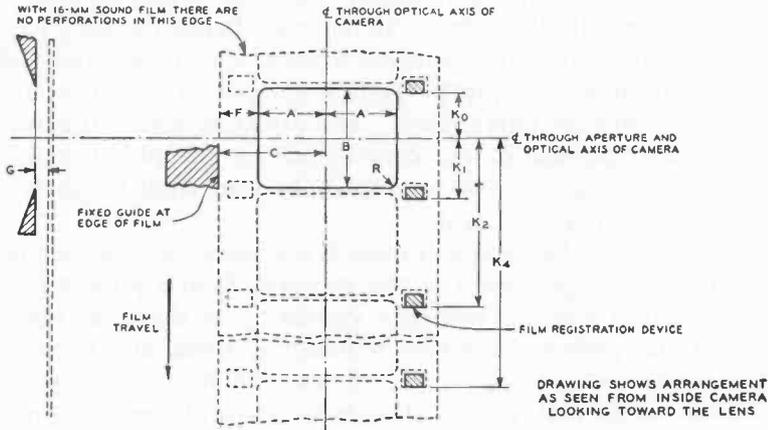
Sponsor: Society of Motion Picture Engineers.

FIG. 10-6. (Copyright, 1947, American Standards Association.)

American Standard  
**Location and Size of Picture Aperture of  
 16-Millimeter Motion Picture Cameras**

  
 Rev. U. S. Pat. 08.  
**Z22.7-1950**  
 Revision of  
**Z22.7-1941**  
 and  
**Z22.13-1941**  
 \*UDC 778.53

This standard applies to both silent and sound 16-mm. motion picture cameras. It covers the size and shape of the picture aperture and the relative positions of the aperture, the optical axis, the edge guide, and the film registration device.



Dimension	Inches	Millimeters	Note
A (measured perpendicular to edge of film)	0.201 minimum	5.11 minimum	1
B (measured parallel to edge of film)	0.292 $\pm$ 0.006	7.42 $\pm$ 0.18	1
C	0.314 $\pm$ 0.002	7.98 $\pm$ 0.05	2
F	0.110 minimum	2.79 minimum	3
K <sub>0</sub>	0.125 $\pm$ 0.002	3.18 $\pm$ 0.05	4
K <sub>1</sub>	0.175 $\pm$ 0.002	4.44 $\pm$ 0.05	4
K <sub>2</sub>	0.474 $\pm$ 0.002	12.04 $\pm$ 0.05	4
K <sub>3</sub>	0.773 $\pm$ 0.002	19.63 $\pm$ 0.05	4
K <sub>4</sub>	1.072 $\pm$ 0.001	27.23 $\pm$ 0.03	4
R	0.020 maximum	0.51 maximum	1

Approved March 14, 1950 by the American Standards Association Incorporated  
 Sponsor: Society of Motion Picture and Television Engineers Incorporated

\*Universal Decimal Classification

FIG. 10-7. (Copyright, 1950, American Standards Association.)

projector aperture determine the boundaries of the transmitted picture (see Sec. 8-6, *Image Size and Centering*). This loss amounts to approximately 2 per cent additional to both height and width (see Fig. 8-5, as typical).

Depending upon how the receiver or the picture monitor is adjusted, there may be further loss of border areas in the final reproduction of the transmitted film. As pointed out in Sec. 1-9, *Horizontal Synchronizing Pulses*, any variation in the size of the front porch of synchronizing pulses from different sources will cause the reproduced picture to shift its position laterally. In addition, as many receivers warm up, the picture drifts either laterally or vertically and, until it settles down, may be improperly framed in one or both dimensions. In order to obviate the need for service calls resulting from television-set owners who notice these shifts, servicemen are prone to adjust the picture size so that the edges are well hidden by the picture tube's mask. The extent to which this practice farther reduces the size of the over-all picture cannot, of course, be accurately estimated. In some cases it will be zero, while in others it can readily be as much as 5 per cent.

In the projection of 35-mm film there is one more loss, this one in picture width. The aspect ratio of the standard 35-mm projector size is not in accordance with the television standard. As shown in Fig. 10-6, the size of the projector aperture is 0.600 by 0.825 in. Because the standard television aspect ratio is 3 by 4, it is possible to make use of only 0.6 by 0.8 in. of the film frame. This amounts to additional loss in width of some 3 per cent. A similar problem does not exist in 16-mm film since the aspect ratio of the standard projector aperture is almost exactly 3 by 4.

As already noted, the individual losses in film area are small in themselves, but when added together, they can amount to a sizable figure, ranging from perhaps 7 to 15 per cent of either the height or the width, or both. The recommended picture areas in which essential information should be maintained (see Sec. 7-6) in television pickup work were determined with the factors enumerated above in mind. In making film for television by direct photography, similar precautions should be observed.

**10-3. Linear Speed.** The linear speed with which motion-picture film passes through the camera and the projector is commonly expressed both in terms of feet per minute (or inches per second) and of frames per second. The standard linear speed of 35-mm film is 90 ft per minute (18 in. per second) and that of 16-mm film is 36 ft per minute (7.2 in. per second). Both types of film in sound-motion-picture applications are projected at a rate of 24 frames per second. During the silent-motion-picture days, a rate of 16 frames per second was standard; consequently, when

these old films are projected on present-day machines, the action is speeded up by the ratio of 24 to 16 or 1.5 to 1.

In the motion-picture industry it is customary to discuss film in terms of its linear length in feet. With the split-second scheduling that is characteristic of both aural and television broadcasting in this country, the length of the film in terms of time is of greater significance to the broadcaster. With these facts in mind, Table 10-1 is presented for reference purposes.

TABLE 10-1. FILM LENGTH VS. PLAYING TIME

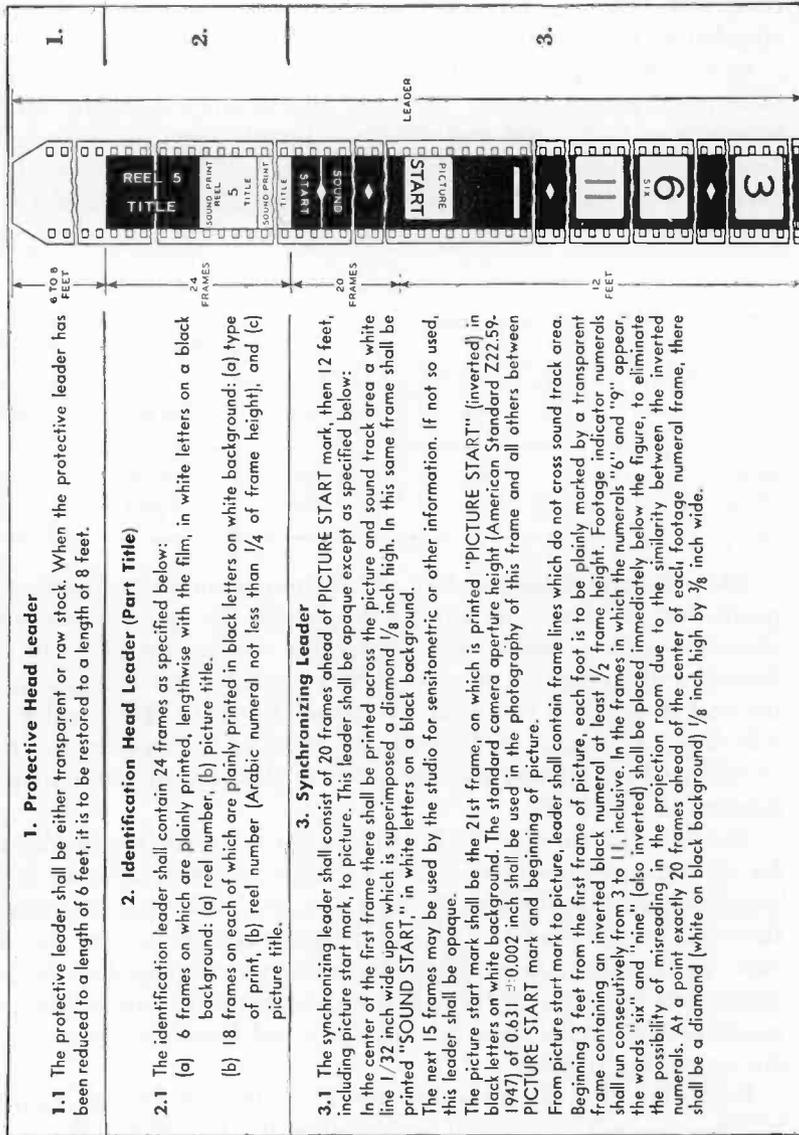
Film	Length (ft)			
	1 min	15 min	30 min	60 min
35 mm .....	90	1,350	2,700	5,400
16 mm .....	36	540	1,080	2,160

**10-4. Synchronizing Leader.** All 35-mm sound-motion-picture release prints that are assembled in accordance with the applicable standard are provided with a leader, which contains various markings to assist in threading the projector so as to obtain a synchronized change-over from the end of one reel to the beginning of the next. This leader (usually called an "Academy" leader with reference to its sponsor, the Academy of Motion Picture Arts and Sciences) is alike on all standard prints, as detailed in Fig. 10-8.

The first 24 frames or  $1\frac{1}{2}$  ft of film after the protective leader are used for identification purposes. The next 12 ft and 20 frames are devoted to synchronizing information. In the center of the first frame of this section, there is a "sound start" cue. Twenty frames later there is a "picture start" cue. In threading the projector, these frames are placed in line with the sound optics and the picture aperture, respectively, thus assuring that the machine is threaded with the standard lead between the sound and its corresponding picture.

Beginning 11 ft from the first frame of the picture and continuing to within 3 ft, each foot of film is marked with a transparent frame containing an inverted black numeral showing the footage to the start of the picture. Although the numeral is inverted from the sense that the picture is upright, the footage mark actually appears right side up to a person threading a projector. The starting time of each projector is determined by trial, and with this interval in mind the machine may be hand-operated until the properly marked footage frame is in the aperture. The

**American Standard**  
**Specification for 35-Millimeter**  
**Sound Motion Picture Release Prints in Standard 2000-Foot Lengths**



**1. Protective Head Leader**

1.1 The protective leader shall be either transparent or raw stock. When the protective leader has been reduced to a length of 6 feet, it is to be restored to a length of 8 feet.

**2. Identification Head Leader (Part Title)**

2.1 The identification leader shall contain 24 frames as specified below:

- (a) 6 frames on which are plainly printed, lengthwise with the film, in white letters on a black background: (a) reel number, (b) picture title.
- (b) 18 frames on each of which are plainly printed in black letters on white background: (a) type of print, (b) reel number (Arabic numeral not less than 1/4 of frame height), and (c) picture title.

**3. Synchronizing Leader**

3.1 The synchronizing leader shall consist of 20 frames ahead of PICTURE START mark, then 12 feet, including picture start mark, to picture. This leader shall be opaque except as specified below:

In the center of the first frame there shall be printed across the picture and sound track area a white line 1/32 inch wide upon which is superimposed a diamond 1/8 inch high. In this same frame shall be printed "SOUND START," in white letters on a black background.

The next 15 frames may be used by the studio for sensitometric or other information. If not so used, this leader shall be opaque.

The picture start mark shall be the 21st frame, on which is printed "PICTURE START" (inverted) in black letters on white background. The standard camera aperture height (American Standard Z22.59-1947) of 0.631 ± 0.002 inch shall be used in the photography of this frame and all others between PICTURE START mark and beginning of picture.

From picture start mark to picture, leader shall contain frame lines which do not cross sound track area. Beginning 3 feet from the first frame of picture, each foot is to be plainly marked by a transparent frame containing an inverted black numeral at least 1/2 frame height. Footage indicator numerals shall run consecutively from 3 to 11, inclusive. In the frames in which the numerals "6," and "9," appear, the words "six" and "nine" (also inverted) shall be placed immediately below the figure, to eliminate the possibility of misreading in the projection room due to the similarity between the inverted numerals. At a point exactly 20 frames ahead of the center of each footage numeral frame, there shall be a diamond (white on black background) 1/8 inch high by 3/8 inch wide.

FIG. 10-8. ASA Standard Z22.55-1947.

#### 4. Picture Section

**4.1 Picture.** It is recommended that picture action start and finish on fades wherever possible, otherwise significant sound should be kept at least 5 feet from the start and finish of the picture. The length of a standard reel shall be between 1750 feet minimum (except when absolutely unavoidable) and 2000 feet maximum.

**4.2 Motor Cue.** The motor cue shall be circular opaque marks with transparent outline\* printed from the negative which has had 4 consecutive frames punched with a die 0.094 inch in diameter. The center of these holes is to be halfway between the top and second sprocket holes 0.281 inch from the right-hand edge of the film with heads up and emulsion toward the observer. Following the 4 frames containing the circular opaque marks there shall be 10 feet and 12 frames to the beginning of the changeover cue.

**4.3 Changeover Cue.** The changeover cue shall consist of 4 frames containing circular opaque marks punched similarly to and of the same dimensions and position on the frame as the motor cue. Following the changeover cue marks there shall be 18 frames to the beginning of the runout trailer.

#### 5. Runout Leader

**5.1** The runout leader shall be opaque and 3 feet in length.

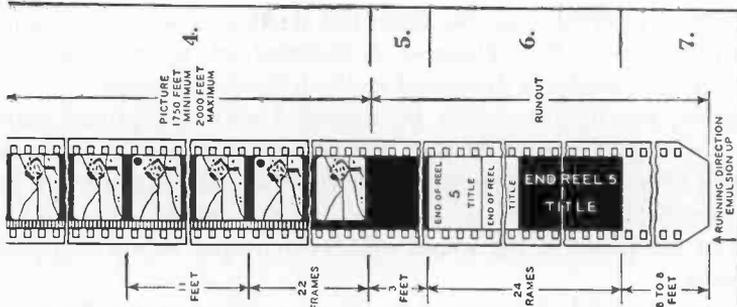
#### 6. Identification Tail Leader (End-of-Part Title)

**6.1** The identification tail leader shall contain 24 frames as specified below:

- (a) 18 frames on each of which are plainly printed in black letters on white background: (a) end of reel, (b) reel number (Arabic numeral not less than  $\frac{1}{4}$  of frame height), and (c) picture title.
- (b) 6 frames on which are plainly printed, lengthwise with the film, in white letters on black background: (a) end of reel, and (b) picture title.

#### 7. Protective Tail Leader

**7.1** The protective tail leader shall be the same as the protective head leader.



\*NOTE: To obtain the transparent outline, the use of a serrated die has been recommended. However, the following alternate method may be used: insert in the base side of the cue mark hole in the negative a skewer of hard rubber or hard wood which has been dipped in coding ink, and rotate the skewer slightly in the film in order that the ink will form a thin ring around the edge of the hole. Only a very small amount of ink is necessary.

(Copyright, 1947, American Standards Association.)

maximum time interval available from the starting of a machine and its undoubling (see Sec. 9-9, *Douser*) is determined by the motor and change-over cue standards described in the following section.

Alternately, the projector may be threaded with the proper starting numeral in the gate instead of running it up to this point. To assist in this method of operation, there is a small white diamond on a black background, exactly 20 frames ahead of each footage numeral. This diamond must fall in the plane of the sound optics for proper sound and picture synchronism.

Heretofore, probably because of its largely amateur status, 16-mm film has never enjoyed the distinction of having a standard type of leader. With the advent of television and its enormous appetite for both 16- and 35-mm subjects (which are usually put "on the air" on a split-second timing basis), the need for a 16-mm leader with timing and other markings became evident. The obvious and most simple solution was to make reduction prints of the 35-mm standard leader and to employ these for 16-mm applications. Up to 1951, this was the general practice in spite of the fact that the "footage" numerals that appear on the 16-mm leaders are actually 4.8 in. apart (although the elapsed times during projection between the footage numerals of both 35- and 16-mm film are alike, *i.e.*,  $\frac{2}{3}$  second).

In order to rectify this situation, an all-purpose film leader has been proposed.<sup>2</sup> The new leader (generally known as the "Society" leader in reference to its sponsor, the Society of Motion Picture and Television Engineers) is designed to meet the needs of both motion-picture and television projectionists and a single design is proposed for both 35- and 16-mm film. Until such time as the new leader is given the status of an American Standard, it may be expected that both the existing standard leader (Fig. 10-8) and the proposed standard (Fig. 10-9) will be found on new releases. The old one will persevere, of course, on old film subjects for years to come.

Although the appearance of the new leader is entirely different from the existing standard leader, the former is actually a modification of the basic design of the latter. In effect, only additions have been made and no features of the existing standard are omitted. The new leader retains all the specifications set forth in the prevailing standard (Fig. 10-8) except for paragraph 3 in which the frame content is detailed. Here a new schedule is proposed in order to meet simultaneously both 35- and 16-mm motion-picture and television needs. The major changes are described in the following paragraphs.

<sup>2</sup> Townsend, C. L., New All-purpose Film Leader, *J. SMPTE*, Vol. 56, No. 5, p. 562 (May, 1951).

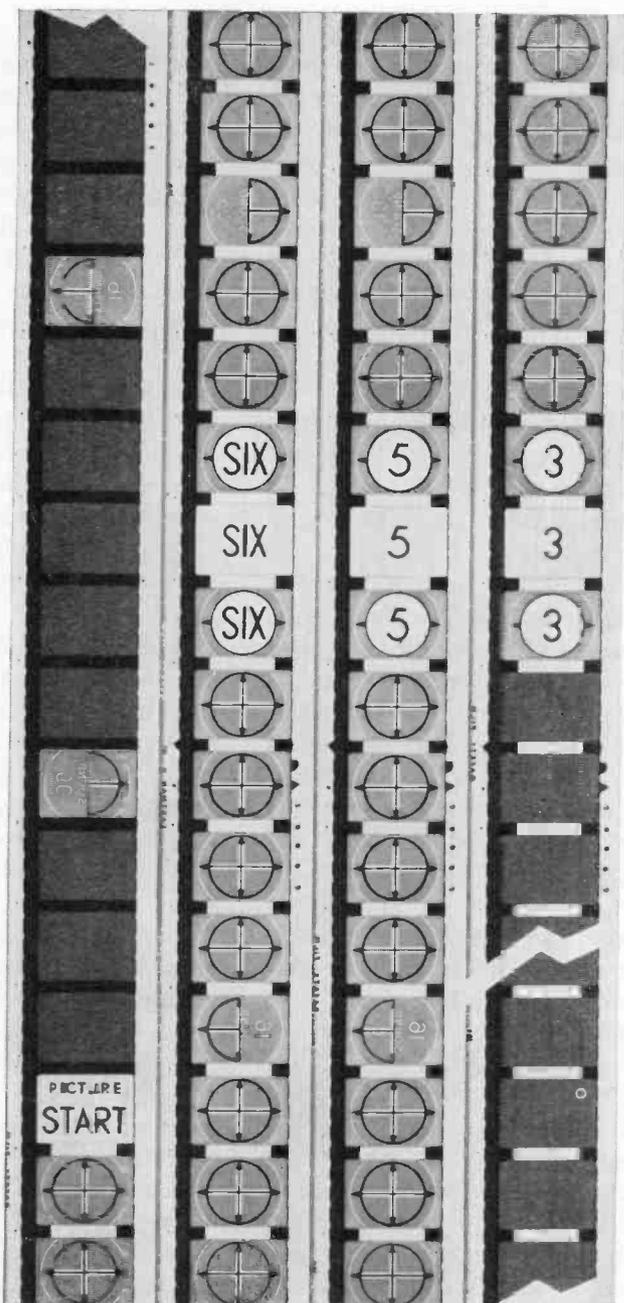


FIG. 10-9. Sample footage from a proposed film leader which incorporates features to meet both motion-picture and television requirements and which utilizes a single design for both 16- and 35-mm films. (Courtesy of Society of Motion Picture and Television Engineers.)

In place of a leader that is opaque except where cue marks are specified, a simple pattern has been substituted in order to permit checking the operation of television systems before the first picture frame reaches the projector aperture. The design used is a simplified television test pattern, as shown in Fig. 10-9, and consists of concentric black-and-white circles (to define the standard 4-to-3 aspect ratio and as an aid in judging geometric distortion) and crossed arrows (to define the normal scanning limits). In addition, approximately equal black-and-white areas on a gray background are provided to facilitate adjustment of the black-and-white video transmissions levels.

Where projection facilities permit holding a single frame in the gate of the projector, the pattern is useful for checking the adjustment of the beam current, edge lights, back lights, and other controls on an iconoscope film camera chain. Finally, the use of the pattern shown (rather than an opaque frame) avoids the possibility of creating spurious transients in the video system as are sometimes experienced when an abrupt change from an opaque frame to one containing cueing numbers or normal picture information is encountered.

Other features of the new leader include the printing of cueing numbers in three successive frames (instead of in only one) and in a direction that results in their being projected right side up (both features to aid in the visibility of the numbers during projection), the inclusion of self-identifying picture and sound threading marks for both 35- and 16-mm film, and a small video switching cue in the eighth frame ( $\frac{1}{3}$  second) before the start of the picture. The motor and change-over cues described in the following section are a part of both the existing and the proposed standards.

**10-5. Motor and Change-over Cues.** To make it possible to effect a smooth transition between the reels, 35-mm sound-motion-picture release prints are provided with two sets of cue marks: one to advise the projectionist to start his second machine and the other to indicate when to change over to the second projector. The first of these markings is called the "motor cue" and the second the "change-over cue."

The standard 35-mm motor cue consists of circular opaque marks with a transparent outline printed from a negative which has had four consecutive frames punched with a round die as specified in Fig. 10-8. The duration of the four cue marks is, of course,  $4 \times \frac{1}{24}$  or  $\frac{1}{6}$  second. Next,  $7\frac{1}{6}$  seconds from the last of the four motor-cue marks (10 ft plus 12 frames), there is the start of a second identical group of four marks which constitute the change-over cue. These also require a  $\frac{1}{6}$ -second interval. Finally, there is  $\frac{3}{4}$  second (18 frames) to the beginning of the runout trailer or opaque tail. Adding all these intervals together, there are  $8\frac{1}{4}$

seconds of picture from the first of the motor-cue marks to the beginning of the blank leader. During this interval, the second machine must get up to speed and settle down so that the sound reproduction is free from wow or flutter. It is standard practice, whenever possible, for the picture action to start and finish on fades in the sound channel. When this is not possible, it is desirable to keep significant sound at least 5 ft (3.3 seconds) from the start and the finish of the picture.

Sixteen-millimeter prints made from 16-mm negatives do not have synchronizing cue marks specified by a current American standard, although the proposed new standard rectifies this situation. Pending the establishment of a standard to cover 16-mm film, it is the practice in 16-mm work to follow the standards detailed above for 35-mm film.

**10-6. Standard Emulsion Position.** The standard emulsion position for 35-mm film is such that, when threaded in a projector, the emulsion side of the film faces the light source and, as viewed from the projector light source, the sound track always appears on the right of the picture. In the camera used for taking pictures, the emulsion side of the film always faces the lens in order that the image being photographed need not be transmitted through the base material of the film in order to reach the emulsion.

The standard emulsion position for 16-mm prints is the reverse of that for 35-mm film. For 16-mm film the emulsion position, when the film is in the projector, is toward the projector lens and as seen from the light source in a projector, the sound track is on the left of the picture.

Although film with a nonstandard emulsion position is seldom if ever encountered in 35-mm sound film (except through error), the same is far from the case with 16-mm film. Most 16-mm composite sound and picture prints in black and white do have a standard emulsion position. However, most composite 16-mm color duplicate prints have the nonstandard emulsion position. The resolution of a picture, as measured on the screen, may be reduced to as much as one-half of its potential value when the emulsion is on one surface and the projection lens is focused on the opposite one. The result, on a sound recording that may be of marginal quality in the first place, is often regrettable (see also Sec. 9-8).

**10-7. Single- and Double-film Systems.** The photographic processes leading up to the finished composite picture and sound print that is received by the television station are not of prime concern to the broadcaster. Sooner or later, however, everyone associated with the handling of sound film encounters the terms "single system" and "double system." The significance of these two terms is therefore explained in the following paragraphs.

**Single-film System.** The single-film system of recording sound in synchronism with the picture on one piece of film is used (see Fig. 11-10)

where economy of equipment or of cost overshadows the advantage of recording the sound and the picture originally on separate film negatives. Single-system recording is used mostly for newsreel work where equipment portability is of importance. It is never used for feature or other important picture work. It is sometimes employed for television recording where the cost of operation is of greater consequence than the quality of the sound recording.

The quality of single-system sound suffers for a number of reasons. First, it is difficult to filter out the intermittent motion of the film (imparted to it by the pulldown mechanism in the camera) by the time it passes over the sound-recording drum. Any residual nonuniform motion of the film manifests itself in the final sound track as flutter. Second, the single negative cannot be developed in an optimum manner for both the picture and the sound. One or the other or both must accept some compromise in the processing of the negative. Third, a single-system sound and picture negative cannot be edited as such, since the sound recording at a given point pertains to the picture content some frames later. Where editing of a single-system sound track is imperative, it is customary to proceed by first re-recording the sound from a print of the original single-system negative. Next this sound negative is edited, and then a composite print is produced from the single-system picture negative and the edited re-recorded sound-track negative. Needless to say this devious method is resorted to only in emergencies.

**Double-film System.** The double system of making sound pictures employs one film negative for the picture and another for the sound, as shown in Fig. 11-11. The double system is used for feature pictures and other major work, occasionally for newsreel production. It is always used where the best possible quality of picture and sound is desired. With the picture and the sound on separate negatives, the individual negatives may then be separately processed in the most suitable manner, and each can be edited without affecting the other. Furthermore, with double-system recording, the optimum types of film can be used for the picture and for the sound. It is necessary, of course, in making double-system film to employ some method of synchronizing the picture and the sound cameras. This is usually done through the simple expedient of employing synchronous motor drives on both units. Synchronizing marks on both the picture and the sound negative greatly facilitate the final assembly of a composite sound-and-picture release print. Various methods have been developed to cope with this process.<sup>3</sup>

<sup>3</sup> Offenhauser, W. H., Jr., "16-mm Sound Motion Pictures," Interscience Publishers, Inc., New York, 1949.

**10-8. Projector Light Filters.** The use of other than infrared light filters has not been found to enhance the monochrome television reproduction of either black-and-white or color motion-picture film (or slides) when used with arc, incandescent, or flash tube sources of illumination. On the other hand, a major improvement is obtained when the infrared radiation from these sources is removed by means of suitable filters. Measurements<sup>4</sup> and experience have proved that the elimination of infrared rays from the projected image materially improves the contrast range and the image sharpness, reduces shading requirements, and increases the signal-to-noise ratio in iconoscope chains.

In projectors utilizing pulsed light sources of illumination, there is still another reason for employing infrared filters. In this instance the filters are necessary to cut off the red and infrared components of light from the continuously incandescent electrodes of the flash tube. The heat generated by the recurring flashes of the tube is sufficient to cause these electrodes to reach a cherry-red incandescence when in operation, and if the resulting light (weak as it is relative to the intense flash) were permitted to reach the film, it would project an image onto the mosaic of the camera tube at all times. Since pulse light projectors do not employ shutters, this image would also be projected during the pulldown period of the projector thereby creating a travel ghost, *i.e.*, an image of the frame as it is pulled down by operation of the intermittent mechanism. The use of suitable filters, however, eliminates the possibility of any difficulties from this source.

Great as the improvement is when infrared filters are used for black-and-white film and slides, it is even more marked in the case of Kodachrome and Technicolor film. In this instance, in addition to the improvements noted above, the elimination of the infrared rays prevents the loss of contrast caused by the relatively great transparency of color films (and slides) to radiation in this part of the spectrum.

A particularly effective form of infrared filter is the dichroic filter which not only has low absorption in the transmission band but, in addition, eliminates the undesirable radiation by reflection rather than by absorption. This characteristic makes it possible to coat a dichroic filter directly on the surface of the condenser lens nearest the light source, as shown in Fig. 10-10, without causing the lens to absorb so much heat as to become damaged. However, since dichroic filters inherently have band-elimination characteristics, it is necessary to supplement them with other units that are effective in that portion of the infrared region where the dichroic

<sup>4</sup> Grimwood, W. K., and T. G. Veal, Use of Color Filters in a Television Film Chain, *J. SMPTE*, Vol. 57, No. 3, p. 259 (September, 1951).

filter no longer functions. An effective arrangement is to supplement the dichroic filter with a Pittsburgh No. 2043 heat-absorbing glass filter of 4-mm thickness as indicated in the figure.

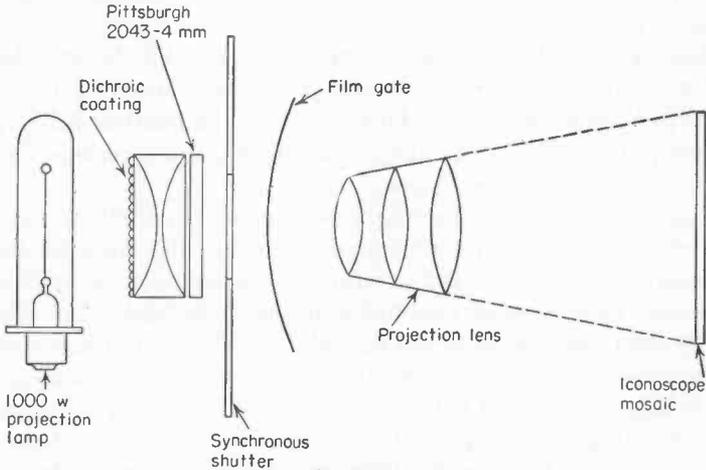


FIG. 10-10. An efficient combination of dichroic and conventional infrared filters installed in the optical system of a film projector in order to prevent infrared radiation from reaching the mosaic of an iconoscope. (After Grimwood and Veal.)

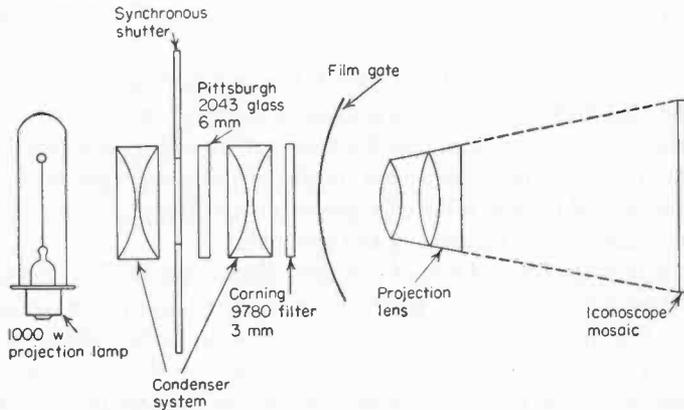


FIG. 10-11. A combination of glass filters useful for eliminating infrared radiation from television film projectors that have optical systems efficient enough to make up for the loss of light in the pass band that is introduced by filters of this type. (After Grimwood and Veal.)

Where dichroic filters are not available and where the greater absorption in the pass band may be tolerated, use may be made of more conventional types of filters, as shown in Fig. 10-11. Here a 3-mm-thick

Corning No. 9780 filter is employed in conjunction with a 6-mm-thick Pittsburgh No. 2043 filter. This combination results in a 35 per cent absorption of energy in the pass band which, in the case of iconscope film chains, usually can be tolerated only in projectors having high-efficiency light-projection systems.

Although filters may be mounted anywhere in the optical path of the projector, whenever possible it is preferable that they be placed in the light beam prior to its passage through the film, as indicated in the foregoing examples. When located in the optical path before the film, there is no possibility of the filter contributing distortion to the projected image. Every air-to-glass surface in the optical path after the film is a potential source of light reflection or lens flare, which in projection and camera lenses is usually held to a minimum by coating the surfaces of lenses. If filters are indiscriminately placed in the beam of the projected image, they may tend to degrade an otherwise excellent projected image.

The use of infrared filters in the light beam between an incandescent light source and the film results in another advantage. An effective filter in this location materially reduces the heat reaching the film. Together with an efficient cooling system for the film, the combination can reduce heating of the film in the gate to an extent that the film may be held stationary in an incandescent projector without damage. This is a decided advantage since it endows an incandescent projector with the same flexibility that a flash-tube light source enjoys in this regard.

**10-9. Resolving Power of Film.** The figures given for the resolving power of photographic films are not directly comparable with measurements of the resolution of a television system for several important reasons. First, the resolution of film is usually stated in terms of the number of distinguishable lines per unit length (*e.g.*, lines per millimeter), whereas the unit of "length" in television is the picture height. Second, in photographic measurements, the lines on the test chart are separated by spaces of the same width as the lines. If, therefore, a particular film is able to resolve a test chart having 75 black lines and 75 white spaces within the length of 1 mm, it is said to have a resolution of 75 lines per millimeter. In television, on the other hand, in effect *both* the black and the white lines are counted. Consequently, if a particular system is capable of resolving 75 black lines and 75 white lines in the height of the picture (assuming, for the moment, that the resolution is equally good throughout the height), then the television system is said to have a resolving power of 150 lines. Third, the resolving power of photographic film is usually determined for a contrast range of 30 to 1 between the black and the white lines. In television, although the picture image may have contrast ranges of even more than this in large areas, it is often materially less in

fine detail. Therefore, a film having a given resolution rating as measured by the photographic method will not necessarily be capable of the same resolution in television applications.

It is informative to review the film resolution necessary to fully exploit the resolution capabilities of the television system. In the United States television system there are approximately 490 active lines in a vertical direction (see Sec. 1-6). However, since fine details in a scene have a random distribution with respect to the scanning lines, the effective resolution is usually taken as about 75 per cent of the number of the active scanning lines, *i.e.*,  $490 \times 0.75$  or about 370 lines.

The smallest motion-picture film normally used for television service is the 16-mm size which has a picture height of 7.2 mm. Hence, 16-mm film would have to be capable of resolving  $370 \div 7.2$  or 51 television lines per millimeter to make full use of the system's capabilities. In photographic terms this is equivalent to  $51 \div 2$  or about 26 lines per millimeter resolution for the film. However, object contrast, processing methods, printing and projection machines, and similar factors all tend to reduce the over-all resolution in any film process. It is necessary, therefore, to multiply the resolution figure just derived by a correction factor in order that it may be directly comparable with film resolution figures measured under laboratory conditions. In other words, for 16-mm television applications the over-all resolving power from original subject matter to final print should be several times 26 lines per millimeter if the full capabilities of the system are to be employed.

It has been shown<sup>5</sup> that the *potentialities* of the present television system are such as to be capable of producing image sharpness approaching, in effect, the sharpness of commercial 35-mm motion-picture film. As commercially available television transmitting and receiving equipment improves in its performance, the quality of the 16-mm motion-picture film made for television purposes and its reproduction for television transmission will also have to be materially improved if it is to successfully meet the demands that will be made upon it.

**10-10. Film Lubrication.** One of the chief ingredients of the light-sensitive emulsion of photographic film is gelatin. This is a substance which is hygroscopic and readily absorbs or gives up moisture to reach equilibrium with the prevailing atmosphere. The gelatin in freshly developed film contains a considerably higher percentage of moisture than that in seasoned film. When it is in this condition, it is easily affected by heat, which tends to make it soft and tacky, particularly in a moist atmosphere. These considerations are of much importance in television recording film

<sup>5</sup> Schade, O. H., *Electro-optical Characteristics of Television Systems*, RCA Rev., Vol. 9, No. 4, p. 653 (December, 1948).

because most of it is projected within a matter of days, at the most, after it is processed; consequently, it contains much more moisture than does seasoned film.

Except when flying-spot or pulsed-light film scanners are used, freshly processed television recording film is likely to come in contact with high temperatures at the aperture of the projector. Here the light is concentrated and produces heat to a degree which may soften the gelatin and cause it to collect on the film shoe or aperture plate where it rapidly dries and forms a flintlike deposit. As the newly processed film is projected, the hardened deposit of gelatin continues to accumulate and may ultimately cause scratches on the film. Further, the resistance to the passage of the film increases, and there is the added danger that the teeth of the intermittent sprocket may tear or damage the perforations in the film to the extent that the print is irreparable.

Proper lubrication of the film tends to produce a smooth and polished surface on the gelatin. It also provides against undue friction during the projection of freshly processed prints. A very slight lubrication is all that is necessary, and it is best accomplished by a machine in the processing laboratory which deposits a thin layer of lubricant (usually a wax or a mixture of waxes)<sup>6</sup> either along the perforations or over the entire film surface (see also Sec. 10-13). Television recordings treated in this way require no further lubrication.

**10-11. Film Handling and Wear.** It can be safely said that every time a piece of film is removed from a reel for any purpose whatsoever, it is damaged to some degree. As already indicated (see Sec. 9-6, *Film Gate*), the greatest damage is likely to take place in the film gate because of emulsion pile-up on the film shoe or on the aperture plate, depending upon the emulsion position. Although there are no absolutely certain methods of preventing emulsion pile-up in motion-picture projectors, the following procedures are recommended for assuring the minimum of film wear:

- a. The film should be cleaned *after* each use and stored in an approved manner (see Sec. 10-13).
- b. If there is any doubt as to the condition of the film upon receipt, it should be cleaned *before* use.
- c. The film gate should be brushed out with a moderately stiff bristle brush *before* projection of each reel.
- d. Silk velvet, moistened with chemically pure (CP) carbon tetrachloride should be used at intervals to dissolve and remove accumulations of emulsion on the aperture plate and the pressure shoe.

<sup>6</sup> Talbot, R. H., Lubrication of 16mm Films, *J. SMPE*, Vol. 53, No. 3, p. 285 (September, 1949).

- e. If necessary, stubborn cakes of emulsion may be removed with an orange stick or similar piece of relatively splinterless *wood* and with the aid of CP carbon tetrachloride.
- f. The film shoe and aperture plate should be inspected frequently with reflected light, for signs of abrasions, scratches, or pitted areas. Worn parts should be replaced.

CAUTION: Never use a metallic tool or an abrasive, other than possibly a water solution of levigated alumina, to remove dirt from the film shoe or aperture plate.

A second potential cause of film wear is found in worn, improperly shaped, or incorrectly positioned pulldown sprockets or claws. Pulldowns in good condition will handle any film manufactured to existing standards, whether seasoned or freshly processed. However, if the pulldown is outside of standard tolerances, it may handle one type of film and not the other because of the slight difference in sprocket-hole spacing between fresh and seasoned film. Equipment in this condition should be repaired, of course.

A third cause of wear occurs in the simple process of rewinding the film. Although hand rewinding is a relatively slow process, it is less damaging to the film than machine rewinding, if properly done. Considerable damage to film is caused by rewinding onto bent reels, by overloading reels, by "cinching" the film, or by using improperly aligned rewinders which permit the film to rub upon the sides of the reels.

The useful life of films<sup>7</sup> can be prolonged and their quality improved by proper inspection and repair. Torn perforations should be removed, good splices made, and proper moisture content maintained. The films should be cleaned to remove dust, grit, and oil splotches picked up from projectors (see Sec. 10-13, *Cleaning and Lubricating*, for recommended procedures). New release prints, especially sound prints, should be lubricated before projection, preferably by the processing laboratory (see Sec. 10-10).

**10-12. Film Splicing.** Splicing has such a direct bearing upon the welfare of film that no discussion of the film characteristics important to the television broadcaster can be considered complete without a review of the correct methods of making a splice. So much film is ruined by poor splices that this operation requires (and deserves) special and constant attention.

Precision splicing equipment is essential in any professional establishment because it is difficult to make a good splice unless the emulsion

<sup>7</sup> Talbot, R. H., *The Projection Life of Film*, *J. SMPE*, Vol. 45, No. 2, p. 78 (August, 1945).

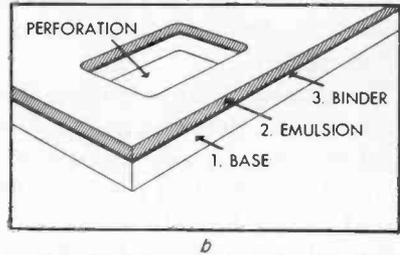
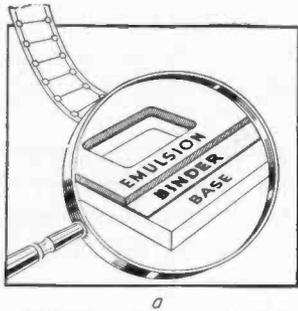
scraper is accurately guided. It is also important that the splicer, regardless of type, be kept in the best possible condition. Fresh cement, proper scraping, and sufficient pressure are absolutely essential for making satisfactory splices.

The splicing of films is often thought of as the cementing together of two surfaces. Actually, a good film splice is a weld, the film *bases* being fused together. To do this, the film must be prepared by removing the layers of material that cover the film *base* so that the two film bases involved may be brought into direct contact. The steps necessary to make a film splice are outlined in Fig. 10-12. Additional information on the process is given in the following paragraphs.<sup>8</sup>

**Preparing the Base Side.** Any dirt or oil which has accumulated on the *base* side of the film must be removed before a satisfactory splice can be made (see Fig. 10-12*d*). Rubbing with a cloth moistened with alcohol is generally effective in removing coatings of undesirable materials. However, if this simple measure fails or where an anti-abrasive backing is involved, other steps must be taken. Roughening the back of the film with a fine abrasive, such as extremely fine finishing paper or extremely fine emery cloth, will prepare the surface for cementing. All abrasive particles must be removed after this operation lest they lodge on the film surface and cause scratches during later use. Alternately, the back may be scraped, provided the skill and equipment to do so properly are available. Touching the back of the film with a brush barely moistened with film cement and then allowing this area to dry before splicing in the usual manner is also effective in preparing the base of the film. However, if too much cement is used, the splice probably will buckle and may break after a few projections. Because of the dangers that attend the use of abrasives or cement on the back of film, their use is not recommended unless necessary.

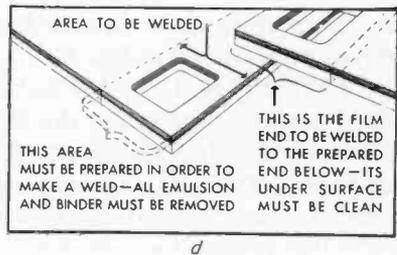
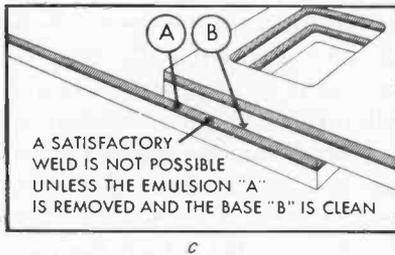
**Removing Emulsion.** Most film splicers are equipped with scrapers which, when moved across the film on a suitable guide, remove the proper width of emulsion and binder layer. The depth depends upon the pressure applied, the number of scrapes, and the knife setting (when adjustable). In scraping the film, care should be exercised to see that too much pressure is not applied too fast. The scraping should be done with light, even strokes first, then with gradually increasing pressure until the emulsion and binder layers are completely removed. If pressure is applied too rapidly, the perforations may become torn or the film base gouged, as shown in Fig. 10-12*h*. However, if the emulsion is softened by wetting, little difficulty should be encountered.

<sup>8</sup> "The Handling, Repair and Storage of 16mm Films," Eastman Kodak Company, Rochester, N. Y.



If a small section of motion-picture film were to be magnified to great size, we should see that the film is made up of more than one layer. In the above illustration the thickness of the various layers is exaggerated.

1. The flexible film base provides a durable support.
2. The emulsion coating consists chiefly of gelatin, in which is suspended the silver or dye forming the photographic image.
3. A thin layer or binder in between the base and emulsion coating binds the base and emulsion tightly together.

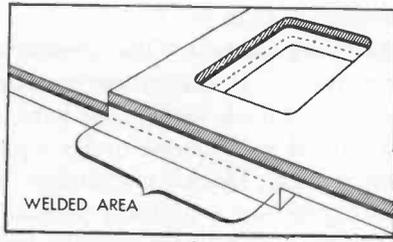
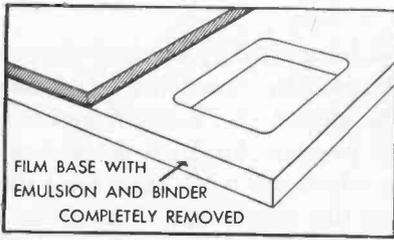


It is impossible to cement the base side of one piece of film to the emulsion side of another. The emulsion and binder must first be completely removed so that the two film base surfaces can come in direct contact with each other.

The emulsion and binder coatings should be moistened with water. This softens the emulsion slightly so that it can be removed easily. The moistened surface should be dry before the film cement is applied.

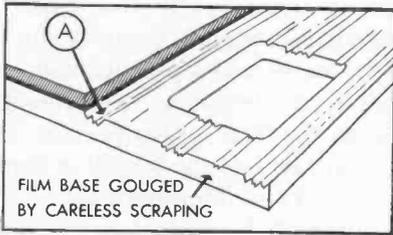
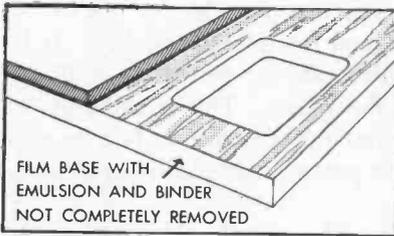
FIG. 10-12. Details of motion-picture film splicing procedures. (Copyright, 1944, Eastman Kodak Co.)

**Film Cement.** Film cement is a chemical solution capable of dissolving the film base. In addition to a solvent it contains other chemicals that stabilize its action. The working bottle of cement should be kept tightly stoppered, therefore, when not in use. The bulk of the cement should be kept in a stock bottle and a quantity sufficient for immediate use poured into a working bottle as required. When the cement is exposed to the air,



To make a *welded splice*, all of the top two layers—emulsion and binder—should be completely removed. The base side of the other film may have dirt or oil on it, picked up from projection and handling. These must be removed before a good weld can be made.

A good motion-picture film splice is actually a weld. When a perfect splice is made, one side of the film base is dissolved into the base of the other film. With most splicing apparatus this requires from 10 to 20 seconds.



If any emulsion or binder remains on the base in the area where the splice is to be made, a good weld will not result and the splice may not hold. Small specks of emulsion or binder can be removed by a fine abrasive.

Scratching or gouging the prepared film base near the emulsion edge should be avoided. Such scratches (A) weaken the weld and may cause the film to break at this point. Fine abrasive scratches are not serious.

FIG. 10-12. (Continued.)

the solvent evaporates and the cement becomes thick and gummy and may not make a satisfactory weld.

If film is old and dried out, it may be necessary to pretreat with film cement both the prepared surface and the back surface of the film to be spliced to it. The first application of cement to both surfaces is left on for only 3 or 4 seconds. It is then wiped off with a soft clean cloth, and a second, final application of cement is made to the prepared surface only. Such an operation, which causes the film to absorb added cement, may also cause splices to buckle and should be used only when all other measures fail. It may also be necessary to apply pressure for a slightly

longer period (20 to 30 seconds) than is required for film with proper moisture content.

**Applying Cement.** The cement should be applied by brush to the prepared surface in the proper amount (learned by experience) and then the cleaned back surface, or base, of the second film brought into contact with it and placed under equalized pressure for 10 to 20 seconds. Some splicing blocks, particularly those which are worn from long use, do not produce a uniform pressure over the entire area to be spliced. After completion of the splicing operation, rubbing the spliced area with a soft cloth held over the finger may give added assurance of a good splice. In any event, the back of the spliced area should be wiped with a soft cloth before the film is wound on a reel. If any excessive cement squeezed out of the weld is not wiped off, it may adhere to and leave a smear on the preceding or following convolution on the winding reel.

**Checking the Splice.** After the spliced film is removed from the splicing block, it should not be subjected to unnecessary strain, such as test pulls or "snaps," until after it has had sufficient time to dry out or "set" properly. It should, however, be examined for general quality. It is a good idea to make practice splices, which may be tested by pulling or snapping to determine the strength of the splice. This is the only way to learn the "feel" of the process. The amount of pressure, how to apply it uniformly, and the length of time that pressure should be applied can be learned only by experience.

**Causes of Unsatisfactory Splices.** The film may buckle at the splice after a short time if too much cement is applied. This may cause difficulty when the film goes through the projector gate. If too little cement is used, the weld will be completed only in spots where sufficient cement was applied. A splice such as this may not last long and will break or pull apart under the slightest strain. Additional causes of unsatisfactory splices are detailed in Figs. 10-12*g* and 10-12*h*.

**10-13. Film Storage.** Just as an aural broadcasting station must make provisions for a record library, the television broadcasting station must have facilities to accommodate a library of film.<sup>9</sup> Safety codes usually require the storage of all nitrate-base films in fireproof vaults constructed in accordance with applicable building codes. Since all regular 16-mm film is on safety-base material, the need for storage in fireproof vaults is confined to 35-mm film.<sup>10</sup>

<sup>9</sup> Weber, C. G., and J. R. Hill, *Care of Slide-films and Motion Picture Films in Libraries*, *J. SMPE*, Vol. 27, No. 6, p. 691 (December, 1936).

<sup>10</sup> Standards of the National Board of Fire Underwriters for Nitrocellulose Motion Picture Film as Recommended by the National Fire Protection Association, NBFU Pamphlet No. 40, July, 1939 (reprinted 1949).

**Storage Facilities.** The problem of storing any appreciable quantity of 35-mm nitrate film is a serious one in so far as the television broadcaster is concerned. In a few cities, *e.g.*, New York, Chicago, and Los Angeles, suitable warehouse facilities are available; in other cities, satisfactory storage space may be difficult to find. In some instances it may be possible to arrange for storage space through a motion-picture film exchange; in others it will probably be necessary to build a storage vault meeting existing safety regulations in order to acquire suitable space.

Although almost all 35-mm film is now being released on safety-base film, it will be some time before nitrate-base film is eliminated entirely. It will be an even longer time until building codes are changed in the major cities in recognition of the difference between safety-base and nitrate-base film. A few cities already make a distinction between the two kinds of film, but many treat all 35-mm film (and associated film equipment) as if nitrate base was the only kind in existence.

The preparation of 35-mm film for storage is undertaken in essentially the same manner as that described below for 16-mm with one very important exception. Cans of nitrate film should never be sealed with tape or any other means because the by-products of nitrate film deterioration are both toxic and explosive.<sup>11</sup>

In practically all cases, the storage of 16-mm film can be undertaken on the broadcaster's premises. In addition to a systematic method of cataloging the film on hand, suitable racks or cabinets must be provided for its storage. Before film is placed in storage, it should be carefully cleaned (except for film received directly from a processing laboratory) and examined for torn sprocket holes or other damage.

**Cleaning and Lubricating.** The dual purpose of lubricating and cleaning the film may be served by a relatively simple process. It may be treated by slowly drawing it through a cotton pad which is moistened with a solution of a wax in a solvent. The entire operation should be carried out slowly so that the solvent adhering to the film will have an opportunity to evaporate before the film is rewound. Fans have sometimes been employed to expedite the drying process but their use cannot be recommended except in a dust-free room (which, of course, any film-handling room really should be) because of the danger of stirring up dust and dirt.

Several types of waxes and several solvents are used for the purpose. Carbon tetrachloride has long been used as the main constituent of many film-treating and film-cleaning formulas. It evaporates rapidly, is non-inflammable, and relatively inexpensive. A 0.03 per cent solution of

<sup>11</sup> Report of the Committee on Preservation of Film, *J. SMPE*, Vol. 35, No. 6, p. 584 (December, 1940).

carnauba wax in carbon tetrachloride has proved very effective in practice. This saturated solution is readily prepared by the simple process of placing a marble-size lump of carnauba wax in one pint of carbon tetrachloride.

Carbon tetrachloride has, however, one shortcoming: its vapors may prove toxic if inhaled. Consequently, any work of this kind should be undertaken in a well-ventilated room and every effort made to prevent the escape of the vapors into the workroom air.

A solvent that does not have the drawback of carbon tetrachloride is trichlorotrifluoroethane, available commercially as Freon 113. This solvent has an evaporating rate faster than that of carbon tetrachloride, is noninflammable, and has a very low order of toxicity. It will dissolve beeswax in concentrations sufficient to provide good lubrication, a 0.1 per cent concentration being very effective. However, Freon 113 is perhaps five times as expensive as carbon tetrachloride, but in the quantities used in the average television station, this is not considered a serious factor.

A good over-all application of wax to film will leave an invisible coating that will not pick up dust nor show fingerprints and will provide steady projection even when the film has been subjected to conditions of high relative humidity.

When the above method of film cleaning cannot be employed because of some controlling circumstance, loose dust and dirt may be removed simply by running the film through a piece of dry silk velvet held in the fingers. The velvet, in turn, must be frequently cleaned by vacuuming it or brushing it with a stiff bristle brush. During cleaning operations, cotton, preferably nainsook, gloves may be worn to prevent the hands from touching the film.

Although machines are available for the cleaning of film, their use sometimes causes tiny scratches and abrasions. Hence, their use is not recommended if the more laborious hand method can be countenanced.

**Storage Conditions.** After cleaning, the film should be wound firmly, but without cinching, on a core. It should then be replaced in a lighttight film container and sealed (except nitrate-base film) with adhesive tape that is available for this purpose. Metal reels are not recommended for long-term film storage use because of the rust or corrosion that often results when they are used. Needless to say, the work should be done in a dust-free air-conditioned room, preferably maintained at a temperature between 65 and 70° F and at a relative humidity of 40 to 50 per cent. The cans should then be stored in a constant-temperature place, preferably at as low a temperature as possible down to perhaps 40° F and at a relative humidity of 40 to 50 per cent. Since this is usually not practical for a large film library, every effort should be made, at least, to maintain

the temperature of the storage place *constant, day and night*, throughout the year and no higher than 70° F at any time. In addition, the relative humidity should be held within the limits mentioned. This is important because molds, mildew, and similar growths may form on films that are stored for long periods of time in an atmosphere having too high a relative humidity. These growths are particularly harmful to color films. Excessive moisture may also cause rust and corrosion on metal reels and cans.

**10-14. Test Films.** The Society of Motion Picture and Television Engineers and the Motion Picture Research Council, Inc., have developed a series of sound and picture test films some of which were originally intended for use in motion-picture work but which have found application in television broadcasting as well. These films serve as a uniform source of picture, test patterns and sound on film for determining the performance of projectors and for assisting in the alignment of the sound optical systems and of the mechanical portions of the projector. The test films are made in both 16- and 35-mm sizes, but identical material is not necessarily available in both sizes. A catalogue describing each test film in detail is obtainable from either of the sponsoring organizations.

The test films available include a visual test film that provides means for checking picture quality as to focus and alignment on the screen, travel ghost (caused by improper synchronizing of the shutter), picture jump and weave, and lens aberration. The sound test films include means for determining response vs. frequency characteristics, accuracy of scanning-beam position, uniformity of scanning-beam illumination, and accuracy of scanning-beam focus. Test films designed specifically for television applications are also available.<sup>12</sup> These include aids for checking the low-frequency phase and amplitude response of the video channel associated with the film camera chain, the storage ability of camera tubes, the transfer characteristics of the film chain, and picture resolution. With the aid of these films, the television broadcaster is in a position periodically to measure the performance of his projectors and to make such adjustments as are necessary to maintain them in proper operating condition.

<sup>12</sup> Anonymous, Television Test Films, *J. SMPTE*, Vol. 54, No. 2, p. 209 (February, 1950).

# Television Recording

TELEVISION RECORDING is a process whereby the electrical waves corresponding to both the picture and the sound portion of a television program may be stored, in one form or another, for future reconversion to television picture and sound signals. Recording of the sound portion of the program material may be undertaken in any one of several well-known ways, *e.g.*, on photographic film, on magnetic tape, or on disk. Thus far, recording of the picture portion of the television program, with the fidelity required, has been successfully undertaken commercially only by photographic means. Other methods of storing the picture information, which is originally in the form of video-frequency electrical waves, will undoubtedly be perfected as time goes on.

**11-1. Television Recording Applications.** The first application for which television recordings were made was for use as reference recordings. Recordings of this type are employed for documentary, legal, critical review, and audition purposes. However, unlike the practice in aural broadcasting, there has not been any wide use of television recordings for this purpose. This results, primarily, from the relatively expensive apparatus required for making them and the cost of its operation. However, television recording has found and will continue to enjoy wide application for an entirely different purpose.

Pending the extension of television network circuits to all parts of the country, television recordings are the only means whereby stations that are not on a network circuit can be in a position to broadcast television programs originating in other cities. Since it will be many years before television network circuits reach all the cities where television stations are (or will be) established, it is to be expected that recordings, in one form or another, will be used for the distribution of television programs for some time to come.

Television recordings are also used for delayed broadcasts, *i.e.*, for the recording of program material that is to be stored for a short time and then broadcast. The need for this type of operation arises when it is

desired (a) to delay or to repeat the broadcasting of an event that takes place at an inopportune time from the audience viewpoint, (b) to delay the broadcasting of one of two conflicting events until time for its presentation is available, or (c) to prepare a program in advance, in order to preserve the continuity of a series of programs when the performers cannot be available for a scheduled appearance.

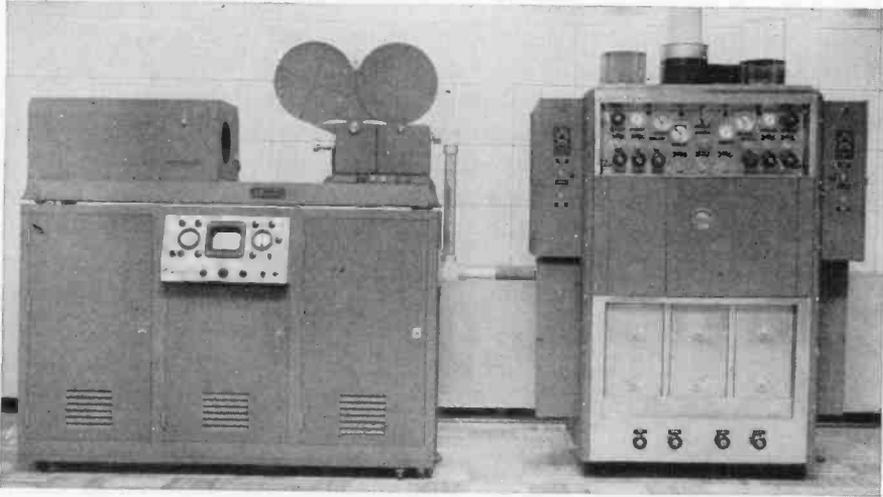


FIG. 11-1. A 16-mm television recording unit complete with a rapid film processor (right) which delivers developed, fixed, washed, and dried film to an associated projector (not shown) within less than 60 seconds after the television picture and associated sound are received and recorded by the equipment at the left. (Courtesy of General Precision Laboratory, Inc.)

Television recordings, in the form of both 16- and 35-mm film and a rapid processing techniques, are also one means for presenting large-screen television pictures to theater audiences.<sup>1,2</sup> Systems of this type have been developed (see Fig. 11-1) that are capable of photographing the television picture from the face of a picture tube, recording the sound on film in a conventional manner, processing and drying the film, and projecting it through a theater-type projector, all within 45 to 90 seconds of the time the original television program was broadcast.

Finally, television recording systems capable of, say, 1,000-line definition will inevitably come into use for the production of many films which are now made (or which cost prohibits from being made) by the relatively slow and expensive conventional photographic methods.

<sup>1</sup> Garman, R. L., and Blair Foulds, Some Commercial Aspects of a New 16mm Intermediate Film Television System, *J. SMPTE*, Vol. 56, No. 2, p. 219 (February, 1951).

<sup>2</sup> Hodgson, R., Theatre Television System, *J. SMPE*, Vol. 52, No. 5, p. 540 (May, 1949).

**11-2. Television Recording Systems.** The process of making a television recording involves recording both the video and the audio signals that constitute the original television production. Several methods of making the sound recordings are available, most of them having been developed prior to the needs of television recording. The recording of video signals for television applications had to be developed in its entirety, however. A general description of television recording systems is given in the following paragraphs and detailed information in subsequent sections of this chapter.

**Picture Recording.** From a theoretical viewpoint, the manner in which the recording of a television picture is undertaken depends upon the use which is to be made of it. For example, if the recording is required primarily for documentary or legal reference or program review purposes, the most convenient medium is undoubtedly sound-motion-picture film.

On the other hand, if it is intended for reproduction over a television system, it would seem logical to record the original video frequencies as such. This procedure offers the possibility of avoiding the degradation that is likely to be encountered in the more or less complex process of making a motion-picture negative, processing it, making a print, processing this also, and then converting the finished picture back into video frequencies with the aid of a television projector and film camera chain. Furthermore, in those applications where the television recording is used only once, it is highly desirable to employ a system that will permit reuse of the stock upon which the recording is made. All these considerations suggest a system of *video-frequency* recording that employs a magnetic or similar medium that could be erased and reused a number of times. It remains to be seen whether a commercially satisfactory method of doing this can be developed.

Where a television recording is to be used only for reproduction over a television system, consideration may also be given to methods which, although photographic in nature, do not result in a final product that is tailored to meet existing motion-picture dimensional standards. For example, motion-picture film is designed to be projected on an intermittent basis; *i.e.*, an entire frame is projected upon the screen at once. In television, on the other hand, the process of transmitting a picture is a continuous one (neglecting, for the moment, the horizontal and vertical flyback periods) since a beam of electrons continuously scans the picture area in a systematic way and thus creates the picture. In the light of these fundamental factors, consideration may well be given to the use of a photographic television recording process that involves continuous motion of the film and, in effect, line-by-line, intensity-modulated recording of the

picture signal. When viewed directly, a recording of this type would not have the appearance of a standard motion-picture film. Furthermore, the probabilities are that it would not be capable of being reproduced on a standard projector. Rather, some form of continuous-motion projector would undoubtedly be required for the conversion of the photographic image back into video frequencies.

Still another possibility is a recording in accordance with existing film dimensional standards but at a rate of 30 frames per second. This alternative is discussed in detail in Sec. 11-3.

Unless a very great improvement is obtained in the quality of television recordings by resort to nonstandard photographic methods, there is a reasonable doubt as to the desirability of adopting a method having limited versatility. The system of television recording in widespread use, therefore, turns out a product that is in accordance with the dimensional standards of conventional sound-motion-picture film (see Chap. 10). In this form the material may be used for any of the afore-mentioned applications and may be reproduced on the equipment that every television station has for handling regulation film. Television recordings are made on both 16- and 35-mm film, although the former predominates by a large margin.

**Sound Recording.** The prime requisites for the sound recording system (an inseparable part of a complete television recording system) are (a) fidelity commensurable with the original sound pickup, (b) synchronism with the associated picture, and (c) ability to make multiple copies of the sound recording when required. For the most part, conventional sound-on-film recording methods<sup>3, 4</sup> are employed for television recording applications. However, in order to obtain sound recording quality that is more in keeping with television standards, there is some use of magnetic recording of the sound that accompanies the television picture.

Both variable-area and variable-density sound-on-film recordings are employed in television recording work. As a rule, variable-area recording is employed where a double-film system (see Sec. 10-7) is utilized; variable-density, where a single-film system is in use. The reason for the distinction is detailed in Sec. 11-8, *Picture Recording Film*.

Sound-on-film recording is capable of quite acceptable performance, even from the viewpoint of the high television standards, *provided* the entire process is carefully controlled and properly executed. However, putting good sound on film does not guarantee that equally good sound

<sup>3</sup> Kellogg, E. W., *The ABC of Photographic Sound Recording*, J. SMPE, Vol. 44, No. 3, p. 151 (March, 1945). This paper contains an extensive bibliography.

<sup>4</sup> Frayne, J. G., and H. Wolfe, "Elements of Sound Recording," 1st ed., John Wiley & Sons, Inc., New York, 1949.

will result upon projection of the film. An equal amount of care and equally good equipment are required for the reproduction of the film as are used during its manufacture.

Because the recording, processing, and reproduction of sound on film leave little leeway for departure from prescribed limits, the use of magnetic sound recording methods offers certain attractions. With conventional magnetic-tape recording methods, better sound quality is possible with less precise control. For example, at the same linear speeds (*a*) equal or wider bandwidths may be recorded, (*b*) the nonlinear distortion can be less and, more important, maintained at a lower value with less effort, and (*c*) the signal-to-noise ratio can be increased some 15 to 20 db. However, these advantages are not gained without some penalty. The process of making multiple copies of the magnetic sound track is likely to be slower than the methods employed for reproducing a photographic sound track. Furthermore, the magnetic material represents an additional cost of manufacture.

More important, on the release print, the magnetic sound track must be accurately synchronized with the picture. The ideal way of doing this is to employ a stripe of magnetic material down the side of the film in place of the usual photographic sound track. This method is preferred over one involving the picture on one reel and the sound on another for the same reason that the sound-motion-picture industry abandoned separate picture film and sound recordings as soon as an integrated system became available. Although entirely practical, the separate system does require more care in handling. For example, the correct sound track must be associated with each picture reel, the sound and picture must be carefully synchronized, and this relation must be maintained throughout the length of the film or television recording. Separate magnetic sound tracks employing both sprocket-hole-driven magnetic tape and  $\frac{1}{4}$ -in-wide, non-perforated tape are successfully used for the sound recordings accompanying television picture recordings. The synchronizing methods employed to accomplish this are described in Sec. 11-10.

In television recording work there is generally only one opportunity (during the broadcasting of the program) to make the recording; accordingly it is usually the practice to record the sound (and the picture) in duplicate. By making the duplicate sound recording on magnetic tape, a considerable saving in film can be effected. Under these circumstances, when the regular sound recording is found to be unacceptable, a new sound-on-film recording can be readily made by rerecording onto film from the magnetic-tape recording. In any event, when no longer needed, the safety recording on the magnetic tape may be erased and the tape reused. A corner of a television recording room showing a synchronous

magnetic-tape recorder and a sound-on-film recorder, employed as suggested, is shown in Fig. 11-2.

Magnetic tape also lends itself to those applications where only one copy of the sound track is required and multiple release prints are not needed. Under these circumstances, assuming that facilities are available for reproducing the magnetic-tape recording synchronously with the picture, there is a considerable saving in film, processing costs, and time as compared to the use of regular sound-on-film recordings. Furthermore the sound quality can be indistinguishable from the original.



FIG. 11-2. A sound recording corner of a television recording room showing a synchronous,  $\frac{1}{4}$ -in.-wide magnetic-tape recorder at the left and a 16-mm sound-on-film recorder at the right.

**Basic Recording System.** The elements of a complete photographic type of television recording system is shown in Fig. 11-3. The picture recording portion consists of the video amplifiers necessary for increasing the amplitude of the incoming video signal to a point where it is capable of driving the control element of the picture tube that is photographed. Associated with the video amplifier are those controls required for adjusting the gain of the unit. Supplementing the video amplifier proper, there may be circuits for shaping the transfer characteristic of the channel in accordance with requirements and for creating electronic step-wedge exposure tests for processing control.

A waveform monitor is connected to the circuit at an appropriate point for measurement of the video voltage and the transfer characteristic of the complete electronic system. The usual deflection circuits and medium- and high-voltage supplies are part of the complete picture recording system. Provisions for inserted blanking and other special features (including positive or negative pictures and reversed scanning) are also included. A motion-picture camera faces the high-intensity short-persistence picture tube and photographs the images traced upon the face of this tube by the electron scanning beam. A typical television picture recording unit is shown on the left in Fig. 11-1.

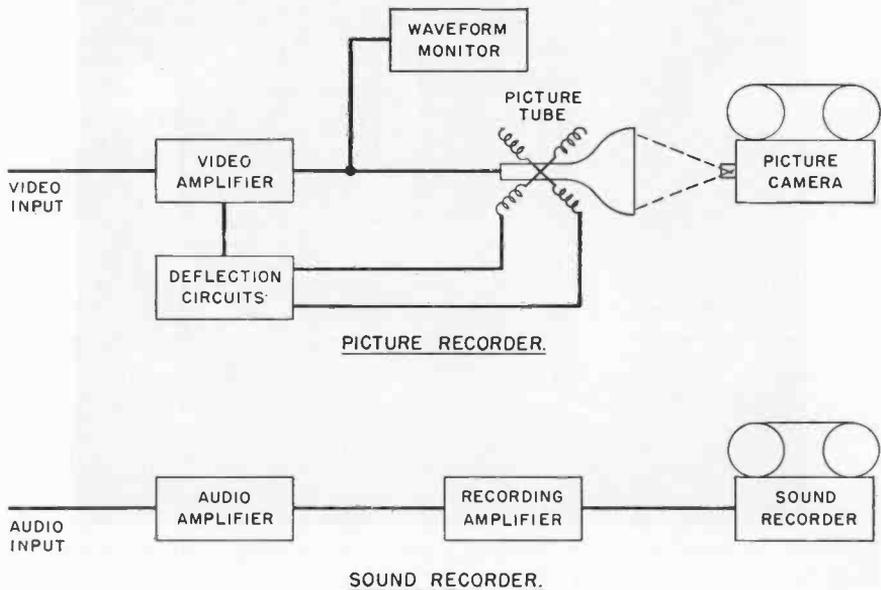


FIG. 11-3. A television recording system consists of both picture and sound recording channels employing separate cameras and film for each operation as shown or, in less critical applications, combining both operations in one camera.

Shown in Fig. 11-3 are the elements of the sound recording system which are part of a complete television recording system. These consist of a suitable audio amplifier, a recording amplifier (which also contains the circuits necessary for operation of the usual noise-reduction circuits), and the sound recorder itself. A double-film system of recording is illustrated which employs a sound recorder that is independent of the picture camera. If a single-film system is employed, the separate sound recorder may be omitted and a recording galvanometer incorporated in the picture

camera. In this case the audio output of the recording amplifier is fed to the picture camera, rather than to a separate sound recorder as shown in the illustration.

**11-3. Television vs. Motion-picture Frame Rates.** Television recordings made in accordance with motion-picture dimensional standards require that provision be made for converting 30 television frames to 24 motion-picture frames. In a sense this is the reverse of the problem encountered in adapting standard motion-picture film to television requirements wherein a conversion from 24 motion-picture frames to 30 television frames is necessary (see Sec. 9-6).

At first glance, the television recording problem might be thought to be the easier of the two, since all that is required is to throw away 6 out of every 30 television frames. In practice this usually turns out to be more difficult to do perfectly than making 30 frames per second in the television projection process out of the 24 frames per second that are on the film.

Rather than throw away any television frames it might be thought desirable to abandon standard motion-picture practice altogether and to record television pictures at a 30-frame rate. This proposal offers several attractions but it also has its drawbacks. Several aspects of the problem will be covered in detail in following sections.

**Recordings at 30-frame Rate.** Aside from the need for projection equipment that is not commonly available (e.g., 30-frame-per-second machines), there are certain practical problems that must be taken into consideration in making 30-frame-per-second television recordings. In the recording process, it may be assumed that the film will be held stationary in the camera aperture while one complete television frame (two fields) is being photographed. However, unlike regular motion-picture or still photography, the subject being photographed never exists in its entirety at any given instant. Therefore, it cannot be photographed by the simple process of opening the shutter for a period of time determined by the brightness of the subject and the speed of the lens and of the film. Rather, the film must be held stationary during the entire time that the scanning spot is tracing out the two television fields making up a complete frame. Accordingly, at the end of every other field the film must be pulled down to the next frame and be in place in time for the beginning of the next field. The time available to do this is that corresponding to the vertical blanking or retrace interval which is specified as being between 5 and 8 per cent of the time of one field (see Sec. 1-8, *Vertical Blanking Pulses*). In absolute units, this amounts to 5 to 8 per cent of  $\frac{1}{60}$  second or 0.8 to 1.3 milliseconds. This creates a film camera design problem analogous to that of an intermittent projector for flying-spot-

scanner applications (see Sec. 8-12) or for operation of a camera tube on a nonstorage basis (see Sec. 9-6, *Pull-down and Projection Cycles*).

The use of 30-frame-per-second motion-picture film for television applications would result in a 25 per cent increase in the amount of film required for a given length of program. This, in turn, would result in a corresponding increase in the cost of the film, in the charges involved in shipping it from place to place, and in the space required to store it. These are not inconsiderable items and can be justified only on the basis of a tremendous improvement in the end result, which, in this case, is the quality of the picture received in the viewer's home.

**Recordings at 24-frame Rate.** Television recordings made at a rate of 24 frames per second offer several attractions. For example, they may be screened for review purposes by standard projectors. Also, they may be televised by means of the regular television projectors available in essentially every television station. Furthermore, when they are made at a 24-frame-per-second rate, it is necessary to dispose of 6 television frames out of the 30 that occur every second. This is indeed fortunate because the time interval represented by these 6 television frames may be used to provide the badly needed pull-down time in the television recording camera.

Each television field has a duration of  $\frac{1}{60}$  second, and each frame has a duration of  $\frac{1}{30}$  second. A motion-picture frame, on the other hand has a duration of  $\frac{1}{24}$  second. By photographing one television frame onto each film frame,  $\frac{1}{24} - \frac{1}{30} = \frac{1}{120}$  second is left for film pull-down. Actually there is slightly more time than this because the simple calculation given neglects the vertical blanking time; the difference is unimportant, however, for the present discussion. Television recording at 24 frames per second may, therefore, be undertaken in the manner described below.<sup>5</sup>

A motion-picture camera capable of pulling the film down within the available time interval is focused upon the television image on the face of a high-intensity short-persistence tube. With film in the camera aperture, the shutter is permitted to open just as the picture-tube beam begins to trace one field of the television picture, e.g., the A field shown in Fig. 11-4. The shutter is permitted to remain open during the scanning of one A and one B field and then closes before the next A field is displayed upon the face of the picture tube. During the next  $\frac{1}{120}$  second, while the shutter remains closed, the film is pulled down to the next frame. During this interval, the picture-tube scanning beam has continued on its way and has scanned down to the middle of the next A field. The shutter now

<sup>5</sup> Athey, S. W., *The Mechanics of TV Recording*, *Audio Eng.*, Vol. 34, No. 5, p. V4 (May, 1950).

opens, and the camera photographs the remaining or lower half of this *A* field, the whole of the next *B* field, and the top half of the following *A* field. The shutter remains open for  $\frac{1}{30}$  second, or for just two television fields, and then closes. Again the film is pulled down, taking  $\frac{1}{120}$  second, during which time the picture-tube beam scans the remainder of the *A* field. Consequently, when the shutter opens again, the beam is just beginning to scan the next *B* field, and the process is back to where it started except that a *B* field is now photographed first and then an *A* field.

During two cycles of the camera ( $2 \times \frac{1}{24} = \frac{1}{12}$  second), five television fields have been scanned by the picture tube, three *A*'s and two *B*'s. The process is then repeated. However, this time three *B* and two *A* fields are scanned (every two film frames, the first field scanned changes from *A* to *B* and then back again). While 10 television fields are scanned, 4 motion-picture frames are recorded and the process is back to where it started.

Actually the process need not start precisely at the top of a field as was assumed for the example given. Just where the recording starts is a function of the phasing between the television scanning system and the camera motor driving system. It may start anywhere in the television field and, as long as synchronous motors are used on the recording camera and the television synchronizing waveform generator is locked to the a-c power supply, two complete fields will be recorded on each motion-picture film frame. The phasing assumed for

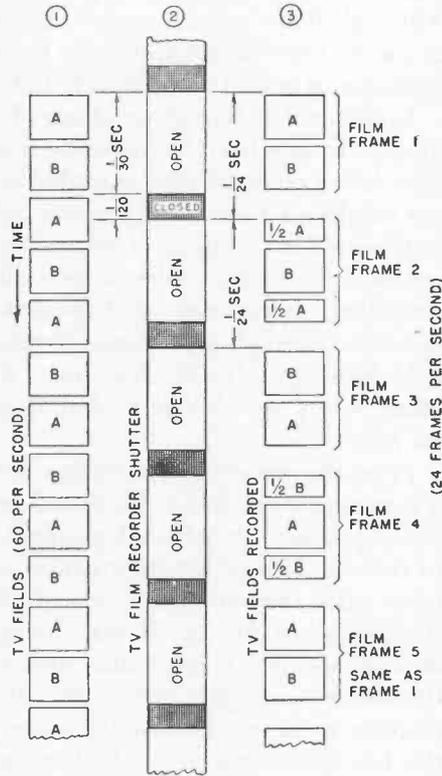


FIG. 11-4. In this diagram of a photographic television recording process for converting 60 television fields per second to 24 film frames per second, column (1) represents a series of successive television fields, column (2) indicates when the shutter of a television recording camera is open or closed, and column (3) shows the fields or parts thereof that are permitted to reach the photographic film by the shutter action. The composition of the resulting film, in terms of *A* and *B* fields, is indicated at the right.

the example given is a desirable one, however, because there is only one place in the picture where the first half of one field is spliced to a second half. For any other phasing, there will be two splices in the picture. Although these splices are invisible when the entire process is operating properly, nevertheless they may become visible upon occasion<sup>6</sup> and one irregular or partial discontinuity in the picture is usually better than two.

In the explanation given above of the method for producing 24 photographic frames from 30 television frames, it was assumed that the picture tube being photographed operated in a normal manner and that the camera employed a shutter to prevent light from reaching the film during the pulldown time. Since, in television, it is feasible to turn the scanning beam of the picture tube on and off instantaneously, the shutter in the recording camera may be dispensed with entirely. When this mode of operation is employed, special blanking signals are applied to the picture tube turning off the electron beam during the film pulldown period. In other words, an electronic shutter is employed in place of a mechanical one.<sup>7</sup>

From the preceding description of the basic television recording process it is seen that two half fields out of every five that are scanned by the television process are not photographed. It is difficult to say what happens to this one-fifth of the information and how its loss affects the final pictures when they are again viewed. The persistence of vision enters into the consideration, and it may be argued that as long as no flicker or stroboscopic effects are visible there is nothing to be gained by projecting the image at a higher frame rate. It is possible that the loss results in an increase in picture noise and a corresponding reduction in resolution, but this has never been established in a quantitative manner.

**11-4. Television Recording Camera.** The basic requirements for a television recording camera may be determined from the preceding description of the process of making 24-frame-per-second television recordings. The camera must be so designed as to permit the film to remain stationary in the aperture long enough for an exposure of  $\frac{1}{30}$  second, the shutter must then close for  $\frac{1}{120}$  second during which time (8.3 milliseconds) the film must be pulled down to the next frame. In motion-picture camera parlance this amounts to an open shutter interval of 288 degrees and a closed shutter interval of 72 degrees. During this latter interval, the film must be pulled down. This is accomplished in various television recording cameras in intervals from between 30 to 60 degrees (3.5 to 7.0

<sup>6</sup> Gillette, F. N., The Picture Splice as a Problem of Video Recording, *J. SMPE*, Vol. 53, No. 3, p. 242 (September, 1949).

<sup>7</sup> Gillette, F. N., G. W. King, and R. A. White, Video Program Recording, *Electronics*, Vol. 22, No. 10, p. 90 (October, 1949).

milliseconds). This leaves some leeway and also some time for the film to come to rest before the shutter again opens. Where electronic shutters are used, much the same pulldown requirements apply, the difference primarily being that the mechanical shutter is omitted from the camera.

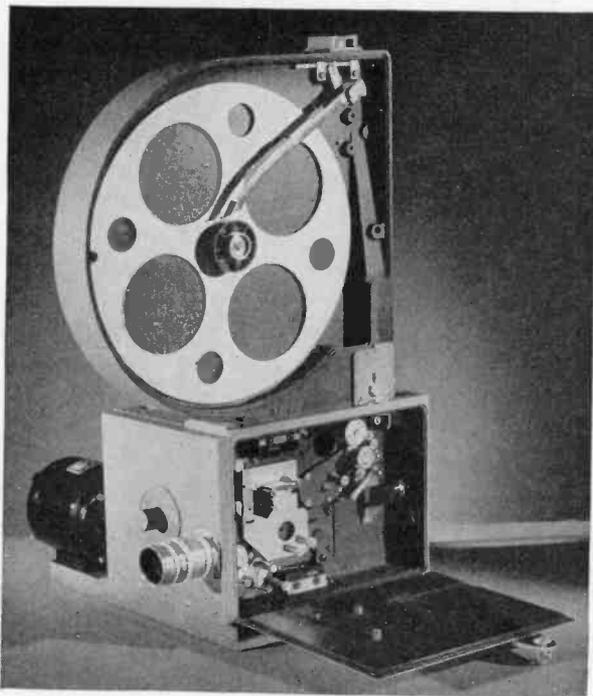


FIG. 11-5. A 16-mm television recording camera with a 1,200-ft supply and take-up magazine mounted in place on the camera. The film magazine cover has been removed and the camera door opened to show the internal construction of the units. (Courtesy of Eastman Kodak Co.)

**Typical Camera.** A photograph of a 16-mm television recording camera<sup>8</sup> is shown in Fig. 11-5. The film transport mechanism in this camera employs a slot-and-spline accelerated 8-point-star Geneva pulldown mechanism with an 8-tooth intermittent sprocket. Normally the Geneva mechanism described would produce a 15.6-millisecond (135-degree) pulldown period, but a special mechanical arrangement is employed that accelerates the motion so that pulldown occurs in approximately 6.6 milliseconds (57 degrees).

<sup>8</sup> Boon, J. L., W. Feldman, and J. Stoiber, Television Recording Camera, *J. SMPE*, Vol. 51, No. 2, p. 117 (August, 1948).

Three single-phase motors are employed to drive the camera in order to avoid the effects of intermittent loading or mechanical shocks occurring in one part of the system from interacting upon another via a common drive motor. Thus, one synchronous motor drives the intermittent mechanism, another is used for the precision timing required for the shutter operation, and both are loosely locked together mechanically by means of a floating mechanical coupling for the same reason and in the same manner as for the projector described in Sec. 9-9.

A third motor is employed for the film take-up function. To wind the film up at a constant linear rate, the roll must evidently rotate much more rapidly at the beginning of the recording than at the end and yet, in doing so, it is desirable to maintain as even a tension on the film as practical. Motors having the desired torque vs. speed relationship can be designed for this purpose. Therefore, by employing a separate motor for the film take-up function, not only are the remaining driving systems isolated from the varying needs of the take-up load but, in addition, a motor with optimum characteristics can be used for the take-up operation.

**Camera Alignment.** Preliminary focusing and framing of the television picture on the camera film may be achieved by several methods. For example, in some cameras a right-angle view finder, equipped with a magnifying lens, may be slipped under the pad springs in place of the pressure pad and the camera visually aligned with the aid of this device. On the other hand, a piece of test film may be inserted in the film gate, with the camera *not* running and the film gate illuminated with the camera shutter open. The image on the film will then be projected upon the face of the picture tube and the camera aligned until the desired image size is obtained. In any event, in order to ensure location of the optical axis of the camera at right angles to the face of the picture tube, the camera should be aligned as accurately as possible by both physical and optical measurements.

After the preliminary alignment of the camera, the final settings are determined by exposing film while using several focusing settings around the visual optimum. The film is then processed and examined by projection on a screen or under a microscope. This method of determining the actual focus point takes into account the exact position assumed by the film during its passage through the film gate and, in addition, the enlarged image permits more precise determination of the optimum adjustment than can be done with an optical view finder. The television scanning lines themselves present a convenient pattern for ascertaining the correct focus adjustment. Unless the raster lines are clearly distinguishable, the system cannot be considered in good adjustment. It is to be noted, however, that the poorer the interlace of the raster, the easier it

may be to distinguish the raster lines. Actually, of course, this apparent increase in resolution occurs because only one-half of the correct number of lines are being seen. It is advisable, of course, to obtain the best interlace and spot size possible and to resolve the resulting raster clearly.

In some instances, the shape of the scanning spot is elongated in the vertical direction in order to make the raster lines less prominent. Vertical modulation of the spot at a high frequency or astigmatism introduced into the electron gun may be employed to achieve the desired result. In any event, when this type of operation is employed, reliance cannot be placed upon resolving the raster for a check on the focus adjustment of the television recording camera. In this case, test patterns displayed upon the face of the picture tube are a convenient means for measuring the accuracy of the camera focus alignment.

**Camera Durability.** Of major importance in the design of a television recording camera is the fact that continuous operation for 30-minute periods is the expectation rather than the exception. This mode of operation is quite at variance with motion-picture practice where individual "takes" are seldom more than a few minutes in duration. In between times the cameraman has an opportunity to clean the film gate of any emulsion or dirt that may have accumulated and be ready to proceed without fear of film scratches or damage from this source. Furthermore, if the camera should fail because of film take-up difficulties, film pile-up, broken film sprocket holes, or any other reason, the action may be stopped, the trouble cleared (or another camera substituted for the faulty one), and the work may then proceed. Of course, interruption to the photography of a production may be costly. Nevertheless, the action can almost always be repeated if lost because of faulty camera operation.

Unfortunately, the same is not true of television recording. Almost invariably, the production that is being recorded is also being broadcast. Consequently, for the most part, the program cannot be stopped when there is an equipment failure of any type. To cope with this mode of operation it is necessary to incorporate a number of design features in a television recording camera which were not commonly employed for regular motion-picture cameras. These include new film gate designs, the use of special materials to minimize emulsion pile-up and scratches, substantial bearings, the use of hardened steel parts in places of wear, and similar refinements.

**Plug-in Cameras.** In television recording installations, just as in all other broadcasting equipment, it is essential that means be available for quickly replacing any defective unit with a spare in order that the operation in hand may continue with the minimum of interruption. As indicated above, the lining-up of a television recording camera requires actual

film tests in addition to such optical aids as may be available. As lengthy a procedure as this cannot be countenanced where an emergency replacement of a camera is required.

At CBS this situation is met by employing what amounts to a precision camera plug-in arrangement. This requires, first, that the location of the mask defining the picture area on the face of the picture tube be accurately standardized on all recording units. Second, means are required to ensure that the faces of all picture tubes are brought to the same plane regardless of manufacturing tolerances (unfortunately, however, there is no simple way to account for any differences in faceplate thicknesses). Third, the cameras are mounted on individual base plates which are built up to exactly the proper height and upon which the camera is precisely located in order to obtain the correct image size on the film. Finally a means is provided whereby the camera base plates are accurately keyed into a standardized position in front of the picture tube. With the cameras thus exactly located with respect to the picture tube, focus tests can be run and the exact setting of the lens predetermined and locked. Thus cameras can be changed in a matter of seconds with assurance that the image size, position, and focus will be correct.

**Matching Image Sizes.** The matter of accurately matching image sizes on all recording cameras is an important consideration in television that is not met in regular motion-picture photography. In motion-picture work a sufficient length of film can always be loaded into a camera to complete the photography of any particular scene without the need for changing over to a new reel in the midst of the work. In television recording, on the other hand, there may not be a scene change at the particular time that a change-over from one recording camera to another must be effected. Should this happen, an instantaneous change-over in the middle of a scene must be made, undesirable as this practice may be. In any event, to cope with this possibility, it is important that the image size on the negatives from all recording cameras in a given installation be exactly alike so that in multiroll recordings there will be no discernible change in picture size in going from reel to reel. As a corollary to correct alignment of the camera, it is equally important that the image on the face of all picture tubes being photographed be exactly the same size and that there be no perceivable geometrical distortion present. If these conditions also do not prevail, the careful location of the camera with respect to the picture tube will be of little avail.

**Single-system Cameras.** Just as in conventional motion-picture cameras, television recording cameras may be equipped for single-system film sound recording. The advantages and disadvantages of this method of operation were covered in Sec. 10-7, *Single-film System*, and will not be

repeated. Where single-system recording is practiced, the television recording camera is equipped with a sound drum and recording galvanometer as is often done in newsreel cameras.

**11-5. Television Recorder Requirements.** The basic elements which comprise the photographic type of television recording system described fall naturally into either mechanical or electronic categories. The camera constitutes the major mechanical device while the picture tube that is photographed and its supporting circuits make up the electronic equipment. For lack of a better name, the assemblage of electronic equipment is often called a television recording monitor. Its basic requirements, as contrasted to other picture monitors, include: (*a*) high picture brightness in an actinic sense, (*b*) excellent resolution, (*c*) extremely low geometric distortion, (*d*) an adjustable and stable transfer characteristic, (*e*) the ability to reverse horizontal sweep direction, and (*f*) the ability to produce pictures of either a positive or a negative polarity. These requisites are discussed in detail in the following paragraphs.

**Picture-tube Phosphors.** The brightness required of the picture tube that is photographed in a television recording system depends upon the speed of the film used for the process. Furthermore the spectral characteristics of the picture tube's phosphor must be commensurate with those of the film for the greatest actinic efficiency.<sup>9</sup>

In practice, the ability to judge picture quality on the tube being used for television recording purposes is of little consequence. The operating parameters are usually determined by sensitometric tests, rather than by visual observation of the picture tube being photographed. As a matter of fact, in order to compensate for any gray-scale nonlinearity that may result from the combination of recording film, film processing, and reproduction by a film camera chain, it may well be that some precompensation of the transfer characteristic of the picture monitor is deliberately introduced. Under these circumstances, the quality of the television picture that is photographed can best be judged at the program pickup point and a standard television signal transmitted to the television recording facilities. Accordingly, the type of picture-tube phosphor and the type of film used may be determined solely on the basis of the combination that results in the best television recording. The P11 phosphor is commonly used in practice because its high actinic efficiency makes possible the use of fine-grain high-resolution non-color-sensitive emulsions which may be handled in relatively bright safelights and which are less expensive than the panchromatic and orthochromatic emulsions whose color sensitivity is of no special value for monochrome television recordings. The P16 phosphor

<sup>9</sup> Fraser, R. M., Motion Picture Photography of Television Images, *RCA Rev.*, Vol. IX, No. 2, p. 202 (June, 1948).

has also been used for television recording applications, in which instance film that is sensitive in the ultraviolet portion of the spectrum is required.

**Resolution.** The ultimate resolution (and certain other characteristics) of the television picture signal that is broadcast is limited by the transmission standards that govern this class of broadcasting service. Furthermore, the quality of the signal received is limited by the characteristics of the particular receiver and the wave propagation conditions that exist. In television recording installations, however, some of these limitations do not prevail, and full advantage of the capabilities of the pickup equipment may be utilized. For example, most television camera equipment is capable of essentially uniform transmission of frequencies up to about 7 to 10 Mc. To the extent that these wide-band capabilities enhance the resolution and other qualities of the picture, they should be preserved from the television pickup camera to the picture tube that is being photographed by the television recording camera. In practice, resolution in the vertical direction is usually limited by the number of scanning lines, while in the horizontal direction the bandwidth of the system is the controlling factor. Horizontal resolution in excess of 600 lines is not unusual for television recording equipment.

**Geometric Distortion.** Geometric distortion in television is any aberration or deviation which causes the reproduced picture to be geometrically dissimilar to the original picture. At any given point in the picture, the geometric distortion is the displacement of the point from its correct position. The displacement is generally measured in horizontal and vertical components and expressed in terms of percentage of the picture height.

In television recording it is very important that the distortion be reduced to an absolute minimum. This objective is in keeping with good engineering practice in any recording operation whether it is concerned with audio or video frequencies. In any reproduction process, no matter how perfect the facilities, some loss in fidelity is unavoidable. Every effort should, therefore, be made to eliminate or reduce to a minimum all sources of possible degradation. In a television recording unit, it should be possible to maintain the geometric distortion to less than 1 per cent without a great deal of effort.

**Transfer Characteristic.** By transfer characteristic in a television recording monitor is meant the relationship between the input video voltage and the corresponding light intensity upon the face of the picture tube. In any determination of this transfer characteristic, consideration must be given to the spectral sensitivity of the film used in the television recording process since, depending upon the film, the bulk of the film exposure may be produced by ultraviolet rather than visible light. In a complete televi-

sion recording system, it is the over-all transfer characteristic that is of primary importance.<sup>10</sup> However, in so far as the television recording monitor is concerned, it is important that the transfer characteristic be stable and adjustable to the standards considered to be optimum. Some degree of adjustment is required if for no other reason than to compensate for the variation in transfer characteristic encountered in different picture tubes of the same type. In addition, as mentioned above under *Picture-tube Phosphors*, some precompensation of the transfer characteristic may be beneficial in correcting for undesirable characteristics elsewhere in the over-all system.

Quantitative means should be provided for checking the transfer characteristic regularly because of its importance upon the over-all quality and uniformity of the television recording product. For reasons already mentioned, the eye cannot be depended upon to judge the quality of the picture produced by the types of picture tubes commonly employed for television applications.

**Horizontal Sweep Direction.** In all photographic cameras it is the usual practice to place the emulsion side of the film toward the lens. This procedure is followed in order to avoid taking a picture through the film base with resulting degradation of the picture. As a matter of fact, many films employ an antihalation base or backing designed to absorb any light that may penetrate the emulsion. Such light may be reflected from the back of the base and, upon again striking the emulsion, cause halation around the image of bright objects. Consequently, motion-picture negative stock often employs a dye in the film base in order to absorb any light that penetrates the emulsion.

When photographic prints are made by a contact process, the emulsions of the negative and the positive are placed face to face in order to obtain the maximum resolution and to avoid the degradation that would occur if they were to be separated from each other by one or two layers of film base. Unfortunately, in 16-mm motion-picture photography, when these procedures are followed, the resulting print has a nonstandard emulsion position (see Sec. 10-6). One way to avoid this difficulty is to use projection rather than contact printing. However, in spite of the merits of this type of printing, it is not extensively used for a variety of reasons that are not pertinent to the present discussion. In any event, an easier method of obtaining 16-mm prints having a standard emulsion position is simply to reverse the direction of the horizontal scanning of the picture tube.

In 35-mm television recording a similar problem does not exist because the standard emulsion position in this instance is the reverse of the 16-mm

<sup>10</sup> Albin, F. G., *Sensitometric Aspects of Television Monitor-tube Photography*, *J. SMPE*, Vol. 51, No. 6, p. 595 (December, 1948).

case (see Sec. 10-6). Therefore, by photographing a picture tube with the scan in the normal direction, a 35-mm release print is obtained with a standard emulsion position.

**Picture Polarity.** Where a number of positive release prints are required from a television recording, the usual procedure is to make an original film negative by photographing a positive display on the face of the picture tube. However, if only one positive film is required, it is entirely feasible to reverse the polarity of the electronic picture and, upon photographing this negative display, to obtain a photographic positive without the need for making a print. If for any reason it should be desirable to produce a number of negative release prints, the same procedure could be followed and the original positive recording used for producing negative film copies. Furthermore, should there be occasion to use reversal film, the ability to change the polarity of the picture-tube display makes it possible to obtain a final film in the form of a positive or a negative as desired. To take advantage of the flexibility that is readily obtained with electronic circuits (as compared to photographic processes), television recording units usually incorporate means for reversing the polarity of the picture display.

Most television recording units are designed to handle a composite television signal, *i.e.*, picture plus blanking plus synchronizing waveforms. Consequently, reversing the polarity of the picture display involves more than simply reversing the polarity of the composite signal. When the polarity of a composite signal is inverted, the polarity of the blanking pulses is also inverted and retrace lines become visible instead of being blanked out. A television recording unit must, therefore, incorporate a means for inserting blanking signals of the correct polarity to cancel the inverted original blanking and thereby obliterate the retrace lines.

**11-6. Television Recording Unit.** The television recording unit shown in Fig. 11-6 produces pictures from standard composite television signals on a flat-faced 5-in. picture tube with an aluminum-backed phosphor. Larger diameter picture tubes are also used for this service in other types of equipment. In the unit illustrated, all chassis components are contained in a base which is actually two half-sized cabinet-type equipment racks fitted with a top plate and end bells. The picture tube, deflection yoke, and associated components are mounted inside a shield on a shockmounted top plate which also carries the recording camera (not shown).

The left-hand equipment rack contains the following chassis, from top to bottom, in the order named: (*a*) video amplifier and synchronizing signal separator, (*b*) -150-volt bias supply, and (*c*) +300-volt regulated power supply. The right-hand rack contains: (*a*) control panel and wave-

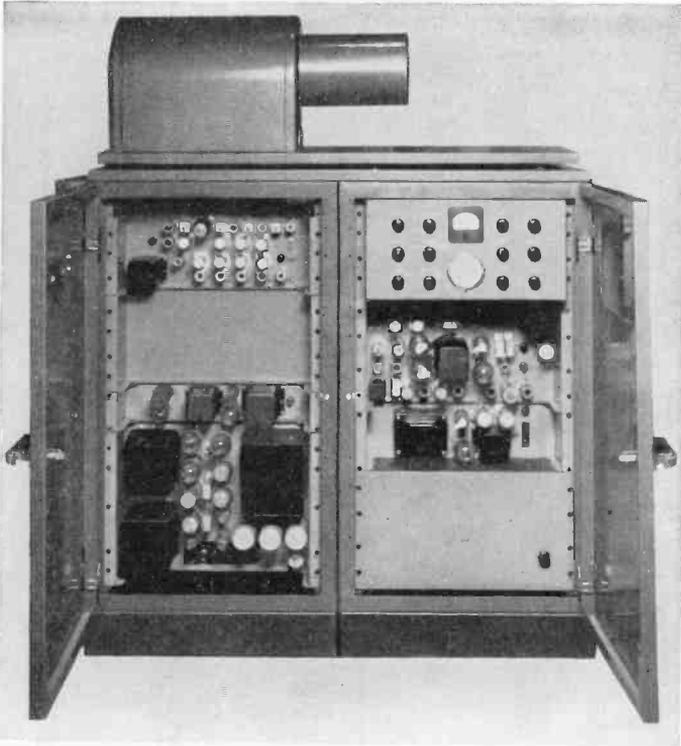


Fig. 11-6. A television picture recording unit with cabinet doors open to show the equipment contained in the pedestal. (Courtesy of Radio Corporation of America.)

form oscilloscope, (b) deflection and blanking chassis, (c) oscilloscope power supply, and (d) 25-kv high-voltage supply.

A schematic block diagram of the television recording unit illustrated is shown in Fig. 11-7. The composite television signal to be recorded is fed to the video amplifier, to the synchronizing signal separator circuits, and to the monitoring oscilloscope. The output signal from the video amplifier drives the grid of the picture tube and is also made available to the monitoring oscilloscope. The synchronizing information obtained from the separator circuits drives the deflection circuits which, in turn, energize the vertical and horizontal coils in the deflection yoke. Inserted blanking is generated by a unit provided for this purpose in order to accommodate either positive or negative picture displays. The necessary supporting power supplies are also shown in the block diagram. In the following paragraphs, a more detailed description is given, together with schematic block diagrams, of the major units of the television recording unit illustrated.

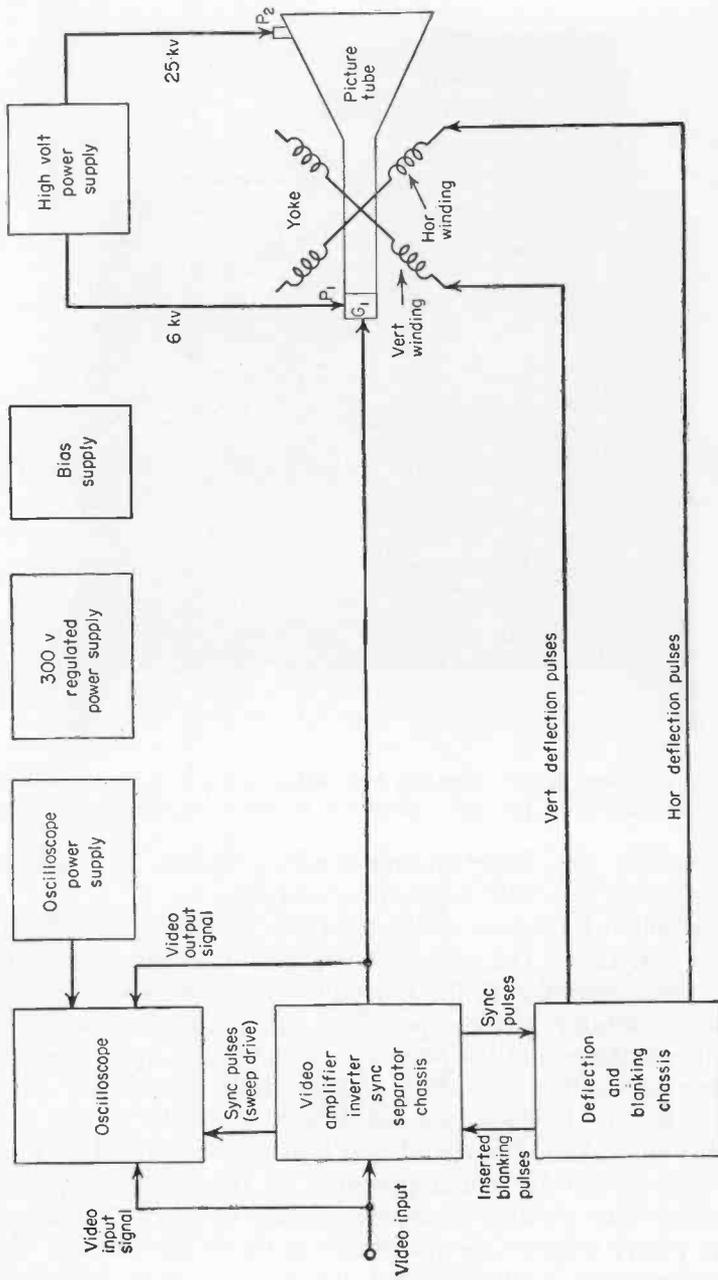


FIG. 11-7. A block diagram showing the basic elements of a television picture recording unit.

**Video Amplifier.** A block diagram of the video amplifier and synchronizing-signal separator circuits is shown in Fig. 11-8. The incoming composite television signal is applied to both a video channel gain control and to the separator circuits. The first tube V101 in the video amplifier is an inverter which is used only when a positive picture is desired. A switch determines whether the video input signal goes through the inverter stage for a positive picture or directly to the amplifier tube V102 for a negative picture. Potentiometer R102 at the input to V101 or V102 is an input level control which functions as a coarse gain adjustment.

The output of V102 is amplified by tubes V103 and V104 and is then applied to the control grid of the picture tube. The grid of V103 is connected to a fine gain (or contrast) control, located on the control panel. D-c restoration of the video signal is accomplished by a keyed, twin-triode clamper V106. The output signal is also fed through a cathode follower V105 to the oscilloscope on the control panel to permit observation of the output amplitude and waveform.

**Synchronizing Separator Circuits.** The synchronizing separator circuits extract the horizontal and the vertical synchronizing pulses from the combined video input signal. The input signal is applied to the control grid of video amplifier tube V107 which, in turn, drives tube V108. Clipper and amplifier tubes, V108 through V110, amplify and clip the signal to remove the video and blanking components. Part of the output of clipper and amplifier tube V109 is used to drive the vertical deflection circuits contained on the deflection chassis. The horizontal deflection circuits receive their drive from the output of one-half of tube V110 which is used as a clipper tube. This tube also supplies the driving signals for the oscilloscope horizontal sweep circuits. The other half of tube V110 is also used as a clipper and is connected to the clipper delay amplifier V111.

**Clamper Circuit.** The horizontal synchronizing pulses are delayed and amplified by tubes V111 and V112 to provide keying pulses for the clamping circuit utilizing twin triode V106. The purpose of the clamping circuit is to bring the blanking pulses to a constant voltage on the grid of the picture tube. This voltage is referred to as the blanking level and bears a definite relationship to the reference black level in the original scene.

The keying pulses from the output of tube V112 occur after the synchronizing pulse and during the back-porch interval. The picture-tube grid is connected to a fixed potential during the keying interval regardless of the preceding deviations caused by the picture signal or by spurious disturbances. During the transmission of the signal, however, the d-c path from the picture-tube grid to the reference potential is open so that the grid bias voltage remains unchanged, although the grid is free to follow the applied picture signal. The keying pulses occur at line rate so that clamping

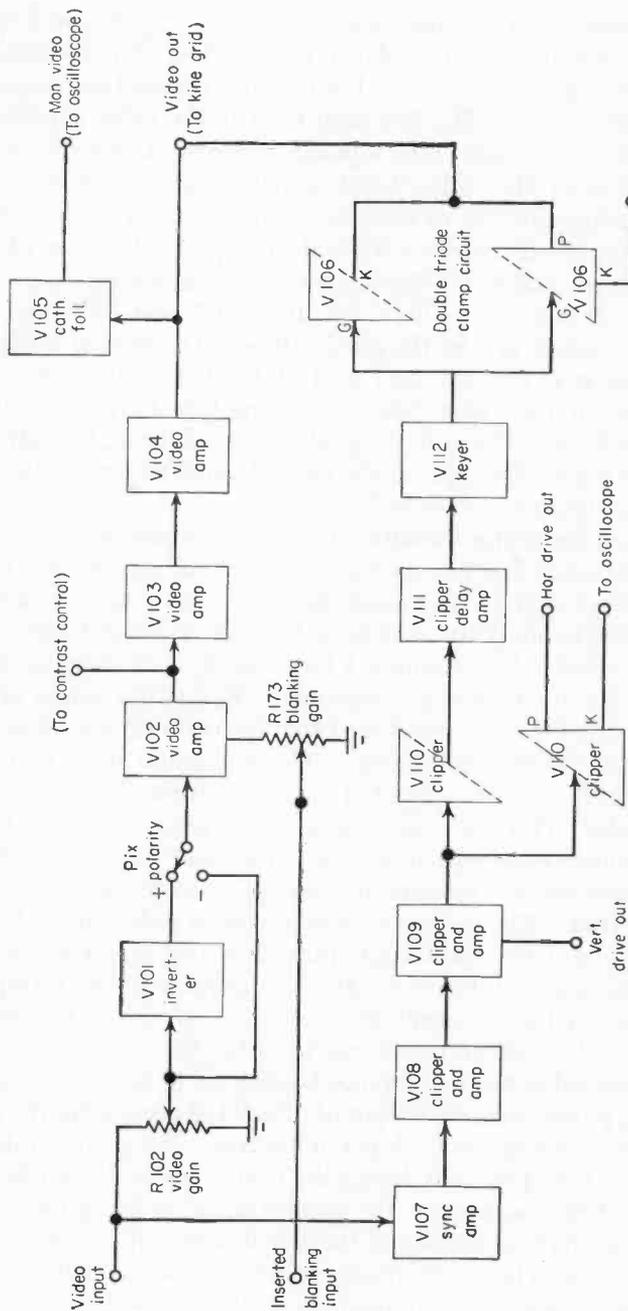


Fig. 11-8. A block diagram of the video amplifier and synchronizing-pulse separator chassis of a television recording unit.

takes place at the beginning of each horizontal line. Consequently, no spurious signal can affect the average brightness of the picture for more than one line. This results in the removal of low-frequency disturbances such as hum and power-supply surges which may have been added to the original signal.

**Deflection Circuits.** A schematic block diagram of the deflection and blanking circuits is shown in Fig. 11-9. The deflection circuits supply a saw-tooth current to each winding in the deflection yoke for horizontal and vertical scanning. The horizontal synchronizing pulse output of clipper tube V110 (Fig. 11-8) is applied to the control grid of the horizontal blocking oscillator tube V208 (Fig. 11-9). These pulses trigger the oscillator which produces pulses at the horizontal scanning frequency (15,750 cps). These are applied to the second section of V208 which serves as a horizontal saw-tooth generator. The saw-tooth output of this tube is fed to the control grids of the parallel-connected horizontal output tubes V210 and V211. The horizontal output saw tooth is then applied through the output transformer T204 and a scanning-direction switch to the horizontal winding of the deflection yoke. A damper tube V213 is connected across the deflection coils and supplies part of the deflection current and damps out oscillations in the yoke. Damper tube V212 supplies the extra damping required on the primary of the output transformer during the first part of the trace. Potentiometers R266 and R267 in the control-grid circuit of V213 change the portion of the trace over which the tube conducts and permits adjustment of horizontal linearity. An additional horizontal linearity control R246 is provided in the plate circuit of the saw-tooth generator section of V208.

Synchronizing pulses from the output of tube V109 on the video amplifier and synchronizing signal separator chassis (see Fig. 11-8) are applied to the integrating network (Fig. 11-9). The integrating network filters out the horizontal synchronizing pulses and passes only the vertical synchronizing pulses to the grid of the vertical blocking oscillator tube (one section of V206). These pulses trigger the oscillator which produces pulses at the vertical scanning frequency (60 cps). The output pulses are fed to the control grid of the other section of V206 which serves as the vertical saw-tooth generator. The vertical saw-tooth pulses are amplified in power amplifier V207 and applied to the vertical deflection windings through output transformer T202.

**Blanking Generator.** The blanking generator produces horizontal and vertical blanking pulses which are mixed with the signal in the video amplifier. When the picture polarity switch (Fig. 11-8) is set for a negative picture, the blanking component of the video signal is inverted (positive at the picture-tube grid) and makes the retrace lines visible.

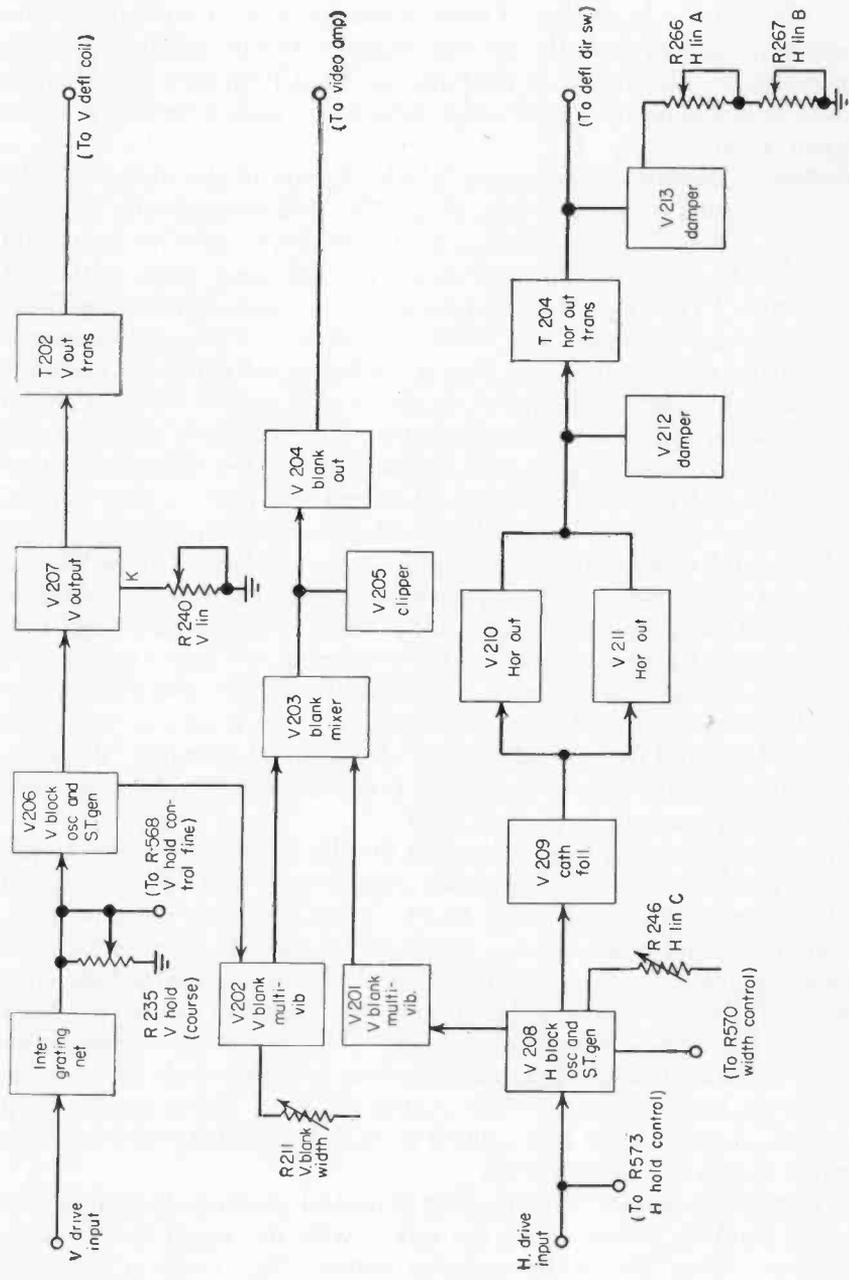


Fig. 11-9. A block diagram of the deflection and blanking generator chassis of a television recording unit.

The inserted pulses from the blanking generator, which are negative at the picture-tube grid, cancel the original blanking pulses and blank out the retrace lines.

As shown in Fig. 11-9, the blanking generator consists of (*a*) multivibrator V201 which generates horizontal blanking pulses, (*b*) multivibrator V202, which generates vertical blanking pulses, (*c*) mixer-amplifier V203, (*d*) clipper tube V205, and (*e*) output amplifier V204. The multivibrators are triggered by synchronizing pulses obtained from the deflection oscillators. The output pulses of the blanking generator are applied to the cathode of amplifier V102 (Fig. 11-8).

Potentiometer R211 (Fig. 11-9) in the control-grid circuit of multivibrator V202 controls the width of the generated vertical blanking pulses. Potentiometer R173 (Fig. 11-8) adjusts the amplitude of the combined horizontal and vertical inserted blanking pulses.

**11-7. Television Recording Procedures.** The flexibility afforded by the electronic portion of a television recording unit permits the choice of several alternative methods for producing the film desired as a final product. The procedure employed for any given application will depend upon a number of factors including (*a*) whether a positive or a negative original is desired, (*b*) the number of prints required, if any, (*c*) the facilities available for film handling and processing, (*d*) the time available for the production of the finished film, and (*e*) the purpose for which the film is to be used. Several typical procedures are outlined in the following paragraphs to illustrate those involved in making a television recording.

**Single Positive Release Print.** The steps that may be followed if only one composite positive "print" is required are charted in Fig. 11-10. A negative image is displayed upon the face of the picture tube, and this is photographed by a television recording camera; simultaneously, the sound may be recorded upon the same film. The film is then processed, and a combined sound and picture positive is obtained. Actually this is not a "print" but an original film that is exposed and processed so as to produce a positive directly.

A process of this type might be followed where there is no likelihood whatsoever of more than one positive being required and where no editing of either the picture or the sound track is to be undertaken. The procedure illustrated, when coupled with a fast processing method, may be used for obtaining a positive in a very short time. For example, this basic method has been used for theater television applications where 45 to 90 seconds after a television picture tube was photographed, the processed and dried film was passed through the regular theater projector and shown on the screen. In passing it may be noted that magnetic rather than

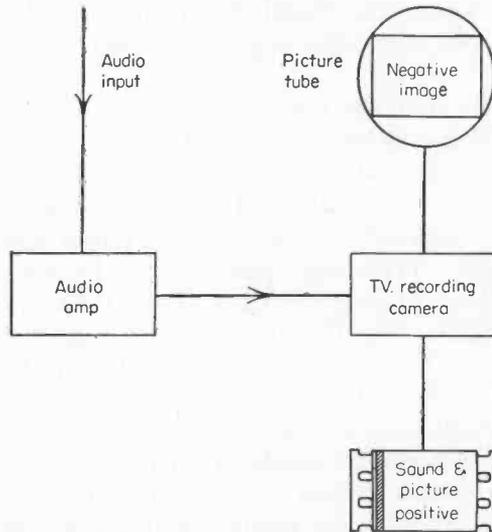


FIG. 11-10. When only one copy of a television recording film is required, the system shown may be used. Here a negative display on the picture tube is photographed, the sound recorded on the same film, and the combined picture and sound developed to form a positive print.

optical recording of the sound accompanying the television picture may be employed to advantage in an operation of the type last mentioned.

**Multiple Positive Release Prints.** Where more than one positive release print is desired, the method shown in Fig. 11-11 may be employed. Here, a positive picture image is photographed and the film processed to obtain a picture negative. If no editing of the picture or of the sound is to be undertaken and if something less than the best sound track can be countenanced, then the sound may be simultaneously recorded on the same film with the picture. On the other hand, if any editing is to take place or if the best possible sound quality is desired, then the sound should be recorded on a separate film by a sound recorder. After development, both the sound and the picture negatives are printed on a third film which, after processing, results in a composite sound and picture positive print. Normally, as many release prints as are likely to be required for television purposes may be made from the original sound and picture negatives before they become damaged to the extent that they are no longer serviceable.

**Single Negative Release Print.** There may be occasions where a television recording negative is made as described above and the need arises for reproducing it over the television system before there is time for a print to be made. For example, some important public event may be

broadcast and recorded in the afternoon and, in addition to distributing prints as soon as they are available, it may be desirable to rebroadcast the program the same evening. The negative, if available, can be used for this purpose since practically all film camera chains are capable of handling either positive or negative images (see Sec. 8-8).

If an original negative is projected, every possible precaution should be taken to avoid damaging it, particularly if it is to be used subsequently for making release positive prints. Among other things, the film gate should be spotlessly clean (see Sec. 10-11), the pressure plate should be correctly adjusted (see Sec. 9-10, *Projector Mechanism*), and the negative should be properly lubricated (see Sec. 10-10). In addition, if the facilities and the skill necessary are available, the negative may be given a lacquer protective coating before lubrication. This is an operation that requires considerable skill, however, and relatively few establishments are prepared to undertake this exacting work.

If the reproduction of a negative picture involves a time element, there may not be an opportunity to obtain a print of the sound track. Under these circumstances, use may be made of a *synchronous* magnetic-tape recording (see Sec. 11-10) or, perhaps, of a *synchronous* disk recording. With the magnetic-tape equipment there is no problem of obtaining and maintaining lip synchronism but with a disk recording there is a problem of starting both the film and the disk so as to be in exact synchronism when both are up to speed. On the other hand, the sound accompanying the original broadcast may be of only a commentary nature and only approximate synchronism required; under these circumstances, ordinary (nonsynchronous) tape or disk recorders and playback units may be used. On still other occasions, a running com-

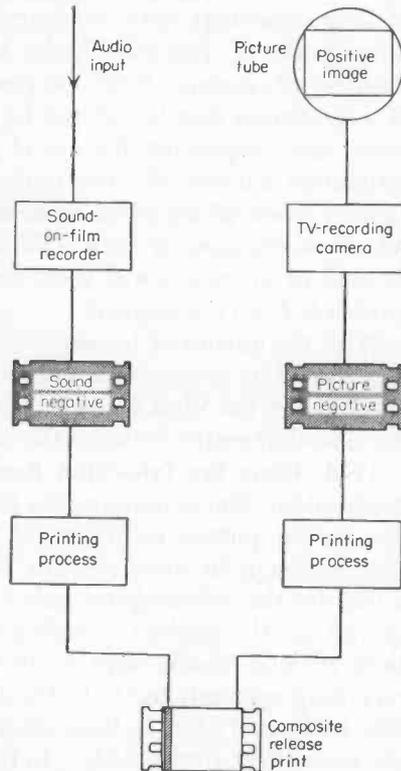


FIG. 11-11. Where multiple copies of a television recording are required, it is common practice to make separate sound and picture negatives as shown and to print as many composite release prints from these as required.

mentary may simply be made by an announcer during the broadcasting of the television recording.

Prior to the availability of transcontinental video transmission circuits, CBS made extensive use of television recordings to bring Hollywood program originations to the television network stations in the East and Middle West. Original 35-mm negatives were used for the picture portion of these recordings and 1/4-in. magnetic tape (without perforations) for the sound portion. This unorthodox method of operation was pioneered for a variety of reasons. First, the procedure avoided even the small amount of degradation that is suffered by a first generation print. Second, and much more important, the use of a picture negative made it possible to counteract successfully the undesirable transfer characteristics of film camera tubes which often manifest themselves in the form of black or white compression, or both. Third, the sound quality obtainable by this method of operation was such that the reproduced sound was indistinguishable from the original.

With the advent of transcontinental video circuits, the same system is being used in reverse in order to delay the broadcasting of East Coast programs on the West Coast by a 3-hour period in order to compensate for the time differential between the two coasts.

**11-8. Films for Television Recording.** In most television recording applications, film is required for three different operations: (a) a suitable film for the picture recording, (b) a film for the sound recording negative, although in some systems this is not used (see Sec. 11-10), (c) a film for the release print unless only one copy of the recording is required and the original recording suffices. Safety base film is available in both 16- and 35-mm sizes in all the types normally used for television recording applications.<sup>11</sup> In the 16-mm size the film comes in lengths of 800, 1,200, and 2,000 ft, these sizes being suitable for 15-, 30-, and 50-minute recordings, respectively. In the 35-mm size, however, regular lengths are 1,000 and 2,000 ft, neither one of which is particularly suitable for television work where the program unit is normally 15 minutes (1,350 ft) and practically all productions are either 15, 30, or 60 minutes in duration.

**Picture Recording Film.** Photography of a television image from the face of a picture tube is quite different, in several respects, from direct photography. For example, in a monochrome television system, the image to be photographed is made up of shades of one color. Therefore, the film need be sensitive only to the color of the particular picture tube used or, conversely, the color of the picture tube should match the film characteristics. Next, the television image that is photographed never exists in

<sup>11</sup> "Motion Picture Films for Professional Use," Eastman Kodak Company, Rochester, N. Y.

its entirety upon the face of the picture tube. Rather, it is traced by a spot of light whose intensity is proportional to the point-to-point brightness of the scene being televised. Under these circumstances, unlike direct photography, the film is exposed by a relatively high-intensity source of light (in highlight areas) for a very short period of time.

As a matter of fact, the photography of a television image is more like variable-density sound recording rather than direct picture photography. In variable-density sound recording, the film is exposed to a varying intensity monochrome light source whose full intensity is relatively high compared to that to which a regular picture film is exposed. On the other hand, the length of exposure is short since the sound recording film is moving past a narrow slit of light at a fairly fast rate of speed. In television recording, of course, the film is stationary during the exposure time, but the spot of light is constantly moving over the surface of the film in a systematic fashion. The analogy between these two different types of recording is so perfect that, in practice, variable-density sound recording film has found very wide use for television *picture* recording applications where an original negative is being produced.

Variable-density sound recording film has several other characteristics that recommend it to television picture recording applications. It has relatively high resolving power and low graininess and can handle the contrast ranges usually found in television work. Furthermore, the film is sensitive only to blue and near ultraviolet light and can, therefore, be loaded into magazines and processed with relatively bright safelights of red or yellowish-green color. Being more or less color-blind, the film is less costly to manufacture than panchromatic films and is among the least expensive film types available. Finally, where single-system recording is employed, the use of a variable-density sound recording film for the television picture recording automatically provides the best available film for the accompanying sound recording which, of course, would be a variable-density recording.

The speed of regularly available variable-density sound recording films is adequate for most television recording applications. In this connection, however, it is to be noted that the increase in speed of color-sensitive or panchromatic films is chiefly a function of the widened spectral band to which they respond. As a result, this increase in speed is not necessarily realized when the film is exposed to light of relatively narrow spectral bandwidth such as is emitted by most picture-tube phosphors used for television recording work. In addition, ordinary photographic exposure meter and film speed ratings are based upon continuous light spectra resembling daylight or tungsten lamp illumination and upon exposure times of the magnitude commonly employed in picture camera applica-

tions. Thus, it is not possible to apply such data to the problem of determining the correct exposure for film used for television recording work. This matter is covered in more detail in Sec. 11-9, below.

Where an original positive (rather than a negative) recording is to be made (by photographing a picture tube displaying a negative picture), a different kind of film stock may be used to advantage. In this instance use may be made of fine-grain, release positive film. If single-system recording is used in this case, then variable-area sound recording must be employed. This results from the fact that development of a release positive type of film in a positive type of developer yields a direct positive picture and sound track image of sufficient contrast to accommodate variable-area recording.

**Sound Recording Film.** When the recording of the sound that accompanies the television picture is done on film, either one of two methods is employed: The sound is recorded either by a variable-area or a variable-density method. Since the requirements are entirely different, separate types of film are employed for each method.

When a composite sound and picture print is made, it is the usual practice to permit the requirements of the picture to determine the characteristics and the processing of the positive film. Therefore, it is necessary that the sound recording negative have characteristics that are suitable for printing upon this predetermined type of film. The factors available for the control of the final result are (*a*) the choice of the sound negative stock, (*b*) its exposure during recording, (*c*) the processing of the sound negative, and (*d*) the exposure used when printing the sound track on the release positive stock.

The properties desirable in film for variable-area sound negatives are high resolving power, high contrast, fine-grain structure, and sufficient speed to yield dense images with the relatively small amount of light that can be transmitted through the sound recording optical system. For variable-density sound recording, a film stock of low contrast is desirable because the requirements of over-all linear reproduction are best satisfied when the contrast that results from the combined action of the negative and positive films is about the same as the contrast that was present in the original. In photographic terminology this means that the over-all gamma should not be much greater than unity.

Separate types of safety-base film suitable for variable-area and for variable-density sound-on-film recording are available in both 16- and 35-mm sizes. Both film types are sensitive only to the blue and the ultraviolet end of the spectrum and consequently can be handled under relatively strong safelights of the proper color.

The choice between variable-area and variable-density sound recording

may not be a simple one to make. As a matter of fact, the continued existence of the two types is proof of the merits of each. Under some circumstances, the choice does not present itself as a problem as, for example, when single-system recording is involved (see *Picture Recording Film*, above). To oversimplify the differences between the two methods of recording, it may be observed that where *conventional* processing techniques are in use, the variable-density system seems to result in less tendency toward cross-modulation distortion while variable-area recording usually results in a better signal-to-noise ratio. However, by special handling during processing or through the use of specialized processing equipment, variable-density sound tracks can be made about as quiet as conventional variable-area tracks, and with adequate control the latter can be made with just as low distortion as the former. The choice between the two kinds of recording will, therefore, often depend upon a careful consideration of all the factors pertaining to a given situation.

**Release-print Film.** Where one or more release prints are made from the original picture and sound recording negatives, it is customary to employ a fine-grain, release positive film. This film differs from the negative materials used for the original recordings and is designed to complement them in a way that will result in a final print suitable for the intended purpose. Since monochrome television release prints are normally made from black-and-white negatives, there is no need for color-sensitive types of emulsions to be used for the print stock. Release-print stock, like sound recording stock, is sensitive primarily to the blue and ultraviolet, and consequently the prints are normally made with either white or ultraviolet light.

**11-9. Film Exposures.** The correct film exposure in television recording work is a function of many factors including (a) the spectral response and decay characteristics of the phosphor used in the picture tube, (b) the brightness of the image, (c) the spectral sensitivity of the photographic film, (d) the nature of the subject matter, (e) the processing conditions, (f) the type of film to be used for the prints (if any), and (g) the final application of the finished product. In television recording the length of the exposure is not so much a function of the time that the shutter is open but, instead, of the decay time of the picture-tube phosphor. The phosphors commonly used for television recording applications decrease in intensity as much as 100 to 1 in 0.1 millisecond or less, whereas the shutter of the recording camera is open for approximately  $\frac{1}{30}$  second or 33 milliseconds. Over a small range of values, the sensitometric characteristic of film is largely a function of the product of the time of exposure and the intensity thereof. However, where there are wide differences in the absolute values of the exposure time and the light

intensity, this simple relation does not hold. In other words, in order to determine the characteristics of film used for television recording applications, it must be tested by exposures and light intensities comparable to those met in practice.

Determination of the exposure for any given set of conditions is largely an empirical process, but the correct operating conditions can be best determined by a systematic approach to the problem. Equally important, once determined they should be rigidly adhered to with the aid of adequate controls.

Before any picture tests are attempted, it is advisable to correlate the brightness level of the picture tube with the density obtained on the film when the latter has been processed to the specified gamma value. To do this a gray-scale step-wedge may be displayed upon the face of the tube and a series of test exposures made for different maximum values of the step-wedge and with a given lens opening. The video voltage corresponding to each step in the gray scale may be determined by observation of a waveform monitor connected to the output of the video amplifier driving the picture tube.

If a gray-scale step-wedge generator is not available, a plain raster, of adjustable brightness, may be used. It is possible to create a raster of this type simply by adjusting either the grid cutoff bias of the picture tube or the magnitude of the inserted blanking signal. However, if the transfer characteristic of the monitor is adjustable, any measurements should take into account not only the transfer characteristics of the picture tube and the film but also those of the television recording unit itself. Consequently, it is desirable to have available a blanking signal of adjustable amplitude mixed with fixed-amplitude synchronizing signals, that can be inserted at the input of the television recording unit. A series of exposure tests may then be made by varying the brightness of the raster and noting the video voltage applied for each test step. After the film has been processed to the desired gamma, the density of the various steps may be determined with the aid of a densitometer. These film density values may then be plotted against the logarithm of the corresponding input voltage in order to determine the combined transfer characteristic of the television recording unit, the picture tube, and the film involved in the test. The picture tube, the film, and the manner of its processing will all have a bearing upon the final result.

A transfer characteristic of the type described is shown in Fig. 11-12. This curve is typical of those obtained using picture tubes with P11 phosphors and fine-grain variable-density recording film processed in a negative bath to a  $\text{IIB}$  gamma of about 0.8, as is ordinarily done for regular picture negative materials. Depending upon the intended application of

the television recording negative, it may be desirable to develop the film to materially different values than the one mentioned as an example. As a matter of fact, a whole family of curves, made for different operating parameters, may be made to determine the particular set of values which results in the desired type of transfer characteristic.

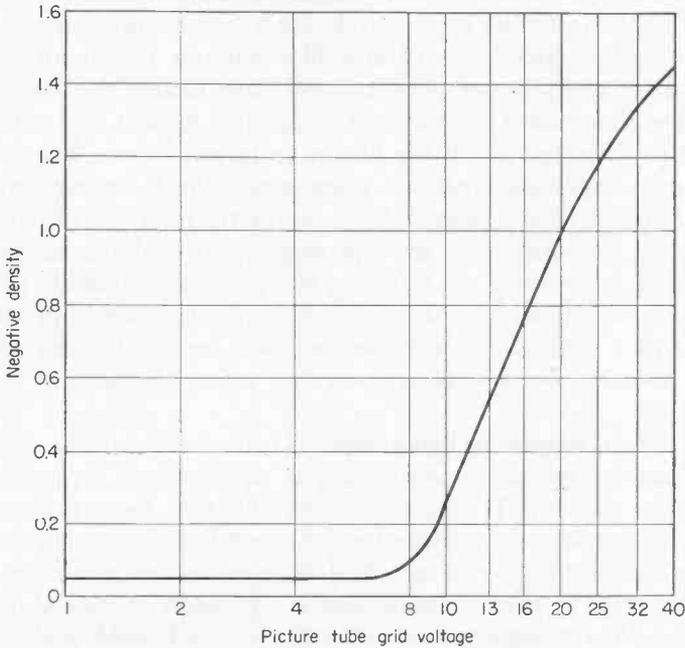


FIG. 11-12. The combined transfer characteristic of a television recording picture tube and a film negative made with the aid of an electronic step-wedge generator.

From curves of the type described, the video voltage necessary for any given negative density may be determined directly. In the example shown, it is seen that picture signals of approximately 26 volts will produce a negative density of about 1.2. Therefore, if it is desired that the highlights in the negative be of this value, it is simply necessary to adjust the amplitude of the video signal so that the highlights correspond to this voltage.

It is evident that any extensive series of exposure tests employing rasters whose brightness is varied in known steps becomes a tedious affair if the individual adjustments must be made manually. Since tests of this type should be made on a routine basis as a quality control measure, some automatic means for displaying a series of rasters of systematically varying intensity should be employed. Furthermore, when this method of testing

is employed, high-voltage power-supply regulation and accuracy of focus must be scrutinized carefully since an all-white raster of high intensity is not a condition normally encountered in regular television picture transmission. Some television recording units may not take kindly to this somewhat abnormal method of operation. A gray-scale step-wedge generator overcomes all these potential difficulties and has much to recommend it for this and other types of television testing applications.

The particular combination of film, film gammas, maximum and minimum negative and positive densities, and other factors that result in the best finished film cannot be stated categorically. A great deal will depend upon the purpose for which the film is to be used (whether for direct viewing, television transmission, or other application), the particular combination of negative and positive films employed, their individual method of processing, and even upon the type of projector and film camera chain (if any) that is involved. As a starter, it is probably advisable to aim for a finished product that simulates the best regular motion-picture film. With this as a beginning, variations one way or another may be tried in order to tailor the television recording more precisely to television requirements.

**11-10. Sound Recording Equipment.** The recording of the sound that accompanies the television picture is just as important an operation as recording the picture. Trite as this observation may seem, preoccupation with the picture recording operation has sometimes been detrimental to the sound recording operation. Well-designed sound recording equipment is available in several forms, and the problem of making excellent sound recordings is largely one of attention to detail, good quality control procedures, and proper operation and maintenance of the equipment.

**Sound-on-film Recorders.** Unlike a motion-picture camera which employs intermittent motion, one of the primary objectives of a sound-on-film recorder is to move the film at an absolutely constant rate past a sound recording head. Although this may seem to be a relatively simple task, the accuracy of motion demanded by high-fidelity requirements is so great that it is only by virtue of the most careful design and precision workmanship that the requirements can be met.

The basic film transport arrangement used in most sound-on-film recorders employs an arrangement of drive sprockets, idlers, and guide rollers that move the film past an exposure light beam while the film is on the surface of a rolling drum. An important objective of the drive system of a sound-on-film recorder is to filter out the disturbances to smooth motion that is caused by entry and withdrawal of the driving sprocket teeth from the film perforations. With 16-mm film this occurs at a rate of 24 cps and with 35-mm film at 96 cps rate. Part of the filtering action

is generally obtained by means of a conventional flywheel, but this device is usually supplemented by much more elegant mechanical filters to smooth out the motion of the film over the sound drum.

In the 16-mm sound-on-film recorder shown in Fig. 11-13, a large flywheel is attached directly to the sound drum shaft to stabilize its motion. The inertia of this flywheel is also instrumental in producing good motion of the drive sprocket. However, there is also a two-stage filtering arrange-

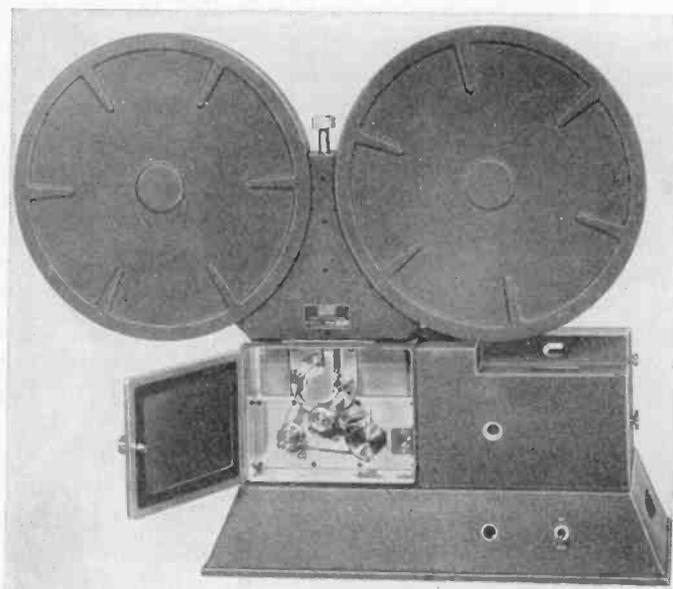


FIG. 11-13. A 16-mm sound-on-film recorder capable of producing either variable-area or variable-density sound tracks. (Courtesy of J. A. Maurer, Inc.)

ment between the drive sprocket and the flywheel. This is accomplished by coupling the drive sprocket to the flywheel hub by resilient felt bushings and the hub to the flywheel itself by a film of oil in what amounts to a fluid drive system. The resulting flutter of the drive system is less than 0.05 per cent.

For television recording applications, the recorder shown may be equipped with 1,200-ft supply and take-up reels which accommodate sufficient film for a  $\frac{1}{2}$ -hour recording with some leeway for runover and tests. The magazines must be loaded in a darkroom, but the recorder itself may be threaded and operated in normal room lighting. The magazines are lighttight as is the sound drum compartment when its door is closed. This door, incidentally, contains a large sheet of ruby glass

through which the motion of the film may be watched while the machine is in operation.

The entire mechanism is driven by one synchronous motor so that it maintains complete synchronism with other similarly equipped film cameras or sound recorders. By using a relatively large-diameter metal core in the film magazines, the problem of supplying a constant take-up torque over a range of speeds is somewhat alleviated (see Sec. 11-4, *Typical Camera*). The film core diameter is 4 in., and with 1,200 ft of film on the core the outer diameter becomes approximately  $10\frac{1}{2}$  in. This requires that the rotational speed of the take-up reel vary over a range of only 2.6 to 1. This is accomplished by driving the take-up reel through a friction clutch.

The light-modulating system employed in the recorder illustrated is capable of producing either variable-area or variable-density sound tracks as desired. Furthermore, either negative or direct-positive tracks may be recorded. The optical system produces a light image on the surface of the film that is only 0.0001 in. (0.1 mil) in height. With an image of this size, it is feasible to make sound recordings that are uniform within 1 db over the frequency range from 50 to 10,000 cps. However, to obtain sound track prints that extend to frequencies as high as this, it is necessary to make use of the very best type of film printing and processing techniques.

A 35-mm sound-on-film recorder is shown in Fig. 11-14. This unit is capable of making any of the standard 35-mm types of negative and direct-positive tracks. The film drive system of this machine consists of a sound drum, the shaft of which carries a flywheel and runs on precision ball bearings. An undamped sprocket roller assembly, a damped roller assembly, and the necessary sprocket-pad roller assemblies complete the film transport mechanism. The recording drum in this machine is film pulled and coupled through its shaft to a solid, dynamically balanced flywheel. It will be noted that, in sound-on-film recorders (both 16 and 35 mm), a tight loop of film is employed as compared to the loose loop that is necessary in projectors in order to isolate the intermittent motion imparted to the film by the pulldown mechanism from the continuous motion essential at the sound drum. In sound recorders there is no intentional intermittent motion present; consequently, there is no need for a loose "uncoupling" loop.

The mechanism is driven by a single synchronous motor which is coupled to the recorder drive shaft by precision chain sprockets, a silent chain, and helical gearing. The main shaft drives the sprocket and right-angle helical gears that are associated with the take-up mechanism. The take-up reels are driven by these gears through a built-in take-up clutch. The clutch is necessary to cope with the change in rotational speed of the take-up reel as the diameter of the film on the reel gradually increases

during a recording operation. The particular recorder illustrated is equipped with 1,000-ft reels (sufficient for approximately 11 minutes), but for television recording applications 3,000-ft reels can be accommodated by a design change, thereby providing for continuous recording of a 30-minute performance.

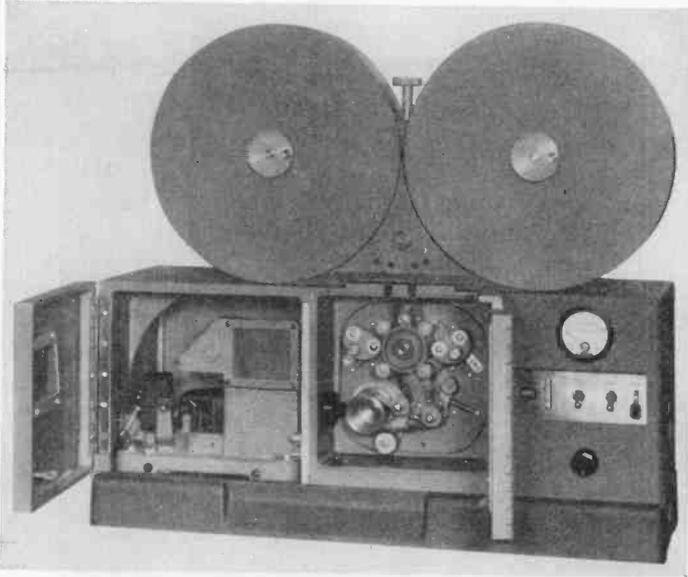


FIG. 11-14. A 35-mm sound-on-film recorder capable of producing any of the standard types of negative and direct-positive sound tracks. (Courtesy of Radio Corporation of America.)

**Magnetic-tape Recorders.** Synchronous magnetic-tape recorders are also employed for recording the sound accompanying a television recording. Recorders of this type are sometimes used in preference to sound-on-film recorders for the reasons set forth previously (see Sec. 11-2, *Sound Recording*).

Both sprocket-hole-driven magnetic film (in 35-mm, split 35- and 16-mm sizes) and  $\frac{1}{4}$ -in.-wide tape without perforations are used for synchronously recorded tracks. Although the entire surface of the tape or film is often coated with magnetic material, an area somewhat less than  $\frac{1}{4}$  in. wide is used for the magnetic recording. In the case of wide film, the only purpose in coating the entire surface is to avoid film curl and to permit the material to spool evenly. The perforations are employed to provide a means for operating the tape recorder synchronously with other recorders and with motion-picture cameras.

The sound-on-film recorder described in the preceding section and illustrated in Fig. 11-14 can also be fitted for magnetic-tape recording. A close-up view of the operating compartment that contains the film transport mechanism of a 16-mm magnetic-tape version of this recorder is shown in Fig. 11-15. Comparison of this photograph with Fig. 11-14 shows the general nature of the modifications necessary to convert from a film to a magnetic recorder.

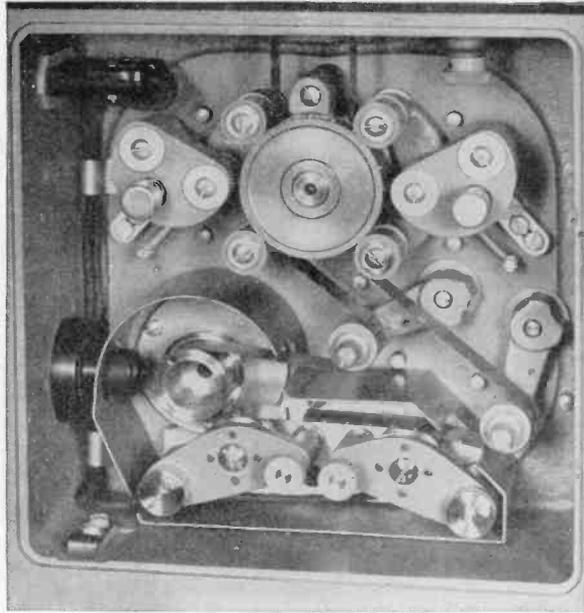


FIG. 11-15. The film transport compartment of a 16-mm sound-on-film recorder modified for magnetic recording work. The magnetically coated film first passes over a combined recording and reproducing head and then over a monitoring head, both located at the bottom of the compartment. (Courtesy of Radio Corporation of America.)

A unit that has been especially designed for the recording and reproduction of magnetically coated perforated films is shown in Fig. 11-16. This unit can be adapted to handle either 35-mm film at 90 ft per minute, 17.5-mm film at either 90 or 45 ft per minute, or 16-mm film at 36 ft per minute. The different film widths are accommodated by installing the proper rollers, sprockets, and drum, while the speed changes are obtained by the proper selection of gears for the drive motor.

As in optical sound-on-film recording machines, a tight loop of film is maintained and, in this instance, two stabilizer drums are used. As shown by the illustration, the film feeds from the supply reel onto one side of

the drive sprocket, thence through the mechanical filtering system, back to the opposite side of the sprocket, and then to the take-up reel. The correct tension on the film is maintained by two sprung rollers, one of which is critically damped by means of a fluid dashpot. A recording head is positioned as close as possible to one stabilizing drum, and a reproducing head in a corresponding position with respect to the second drum. A mu-metal shield box encloses the magnetic heads in order to reduce hum pickup from stray fields. This drive system is capable of producing film motion which produces less than 0.1 per cent (rms) flutter when reproducing a recording.

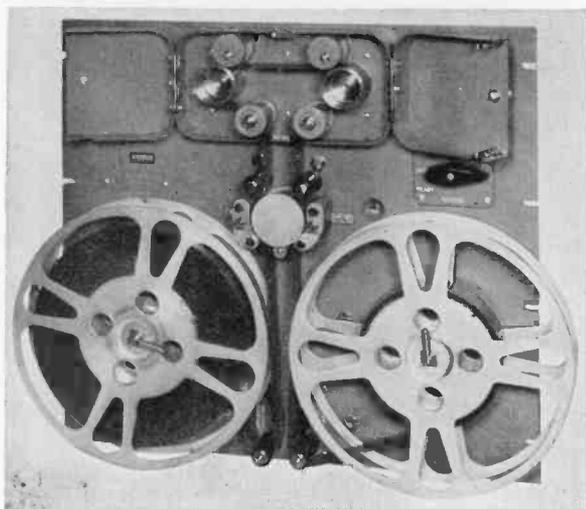


FIG. 11-16. A 35-mm magnetic film recorder specifically designed for the purpose. The recording and reproducing heads are at the very top of the assembly in a magnetically shielded compartment, the doors of which are shown open. (Courtesy of Radio Corporation of America.)

From a practical viewpoint there is little if anything to be gained by employing a magnetic track more than  $\frac{1}{4}$  in. wide; consequently, except for providing space for sprocket holes, there is no need for 16- or 35-mm-wide tape. As a matter of fact, perforated tapes of these widths must necessarily be thicker than narrower tape in order that they may be capable of being handled in the usual way and in order that the sprocket holes may have sufficient strength for their intended purpose. The stiffness of wide stock, however, makes it difficult to obtain the intimate and constant contact required between the magnetic-tape surface and the recording and reproducing heads for best results. Further, as already mentioned, sprocket-hole drive presents the problem of filtering out the flutter intro-

duced into the motion of the film. Accordingly, the use of conventional  $\frac{1}{4}$ -in.-wide nonperforated magnetic tape is attractive since no excess material is involved and the omission of sprocket holes greatly simplifies the problem of obtaining good motion. The use of a medium without perforation does, however, pose the problem of maintaining absolute synchronism between the sound recording and the picture film.



FIG. 11-17. A magnetic-tape recorder that handles  $\frac{1}{4}$ -in.-wide tape and which, with the aid of a control track, is capable of recording and reproducing sound in exact synchronism with an associated picture.

A magnetic recorder employing  $\frac{1}{4}$ -in.-wide nonperforated tape and capable of making and reproducing recordings that remain in complete synchronism with an associated film camera or projector<sup>12</sup> is shown in Fig. 11-17. To accomplish this, special methods are employed since synchronously driving the capstan that controls the motion of the tape is not enough to obtain the type of accuracy required.

<sup>12</sup> Hare, D. G. C., and W. D. Fling, Sound Track Recording on  $\frac{1}{4}$ " Magnetic Tape, *J. SMPTE*, Vol. 54, No. 5, p. 554 (May, 1950).

The desired synchronism is obtained with the aid of a control track that, in effect, prints magnetic "sprocket holes" upon the tape during the recording operation. On playback, the spacings between these magnetic markers are gauged and the speed of the tape adjusted so that they pass over the reproducing head at a constant and correct rate for synchronous playback. This is accomplished by amplitude-modulating a 14-kc carrier by the 60-cps frequency of the a-c line at the time of recording. During playback, the 14-kc carrier is demodulated, and the 60-cps reference component is applied to a phase comparator where it is compared to the new 60-cps power-line frequency. By an ingenious arrangement, corrections are made to the reproducer's drive system which result in frame-by-frame synchronism. The response of the sound channel of the reproducer is attenuated above 13 kc in order to avoid any reproduction of the control track in the sound channel. The accuracy of the control circuits is such that for recordings of one-half hour duration the sound track never deviates from exact synchronism by more than a fraction of one frame, if that much. In fact, the amount of drift is so small that it can be determined only by special measurement techniques and is not discernible by simply watching the picture and listening to the accompanying sound.

Where a magnetic recorder is used for recording the safety sound track (see Sec. 11-2, *Sound Recording*), the resulting recording need be used only when the original sound-on-film recording proves to be imperfect. Under these circumstances, a new film recording is made by re-recording the magnetic track onto film. The resulting sound film negative may then be combined with the picture negative for making the release prints. A re-recording operation of this type merely requires that, upon playing back the magnetic recording, it maintain accurate synchronism with the sound-on-film recorder. The control features already described accomplish this type of operation.

However, where the magnetic recording is to be played back synchronously with a picture, additional means must be provided to ensure that the picture projector and the magnetic sound reproducer start up and remain in step at all times. This may be accomplished with the type of equipment illustrated by comparing the projector sprocket-teeth rotation with the capstan rotation of the tape recorder. This may be done with the aid of two very small servo-type motors, one of which is fastened to any shaft of the projector whose rotation is definitely related to that of the drive sprocket, and the other to one side of a differential in the tape reproducer. The other side of the differential is connected, through a gear chain of proper ratio, to the capstan drive shaft. The output of the differential then will be a measure of the difference in rotation between the capstan and the projector drive sprocket. Any rotation of this output

shaft is an indication of a framing error and is caused to correct the speed of one machine or the other in the direction which reduces the error to zero. A suitable means is provided for storing relatively large framing errors and to correct these errors rapidly to a small fraction of a frame. The framing errors occur only during the starting time of the two machines of course, and once they are up to speed, the two are maintained in synchronism by the methods first described. If, at any time, the machines are stopped, the automatic framing mechanism will "remember" how much farther one machine coasts than the other and, upon restarting, the error will be corrected and the two machines brought back into synchronism. The basic synchronizing action described takes place in less than 4 seconds from the time the machines are started from rest.

It might be expected that editing magnetic tape of the type described would introduce irregularities in the control track that might prove troublesome. However, if splices are made completely at random, a maximum possible error of one-quarter of a frame may be introduced. On the other hand, the probability of a number of splices all introducing errors in the same direction is relatively small. Furthermore, should it be necessary, relatively simple means can be provided to avoid random splicing and, instead, an integral number of the magnetic markers removed from or added to an edited recording. In practice it has not been found necessary to resort to this refinement in editing technique. The synchronous magnetic-tape equipment described has been employed for millions of feet of sound recording and reproducing in conjunction with television recording operations and has proved completely satisfactory in performance.

Both perforated and nonperforated magnetic-tape recording systems have their individual advantages and disadvantages. Perforated tape is easier to edit but, depending upon whether 16-, 17.5-, or 35-mm tape is used, it costs from ten to twenty times as much, for a given length, as  $\frac{1}{4}$ -in. nonperforated tape. Furthermore the  $\frac{1}{4}$ -in. tape is thinner and, therefore, more pliable than the perforated tape; consequently, better contact is obtained with the erase, record, and playback heads and higher fidelity of recording and playback therefore results. Where no editing is to be undertaken, there is little question but that the  $\frac{1}{4}$ -in. tape has outstanding attractions. Furthermore, editing is by no means impractical; witness the fact that CBS has employed, for some time, a separate  $\frac{1}{4}$ -in. magnetic track to accompany television recordings that regularly are extensively edited before being released. This practice has resulted in sound reproduction that was indistinguishable from the original performance.

## Program Transmission Systems

BOTH AUDIO AND VIDEO PROGRAM CIRCUITS are required for the transmission of television program material from the origination point to the transmitters that ultimately broadcast the material. The facilities required may be divided into two general classifications: (a) local or short-haul circuits for connecting off-premise pickup points with the main studios, for connecting the main studios with the local transmitter, and for network connections, and (b) network or long-haul circuits for interconnecting television stations throughout the country. The probable extent of the television program transmission system that will be developed may be gauged from the magnitude of the facilities that are in use for aural broadcasting service. In the United States, of the 3,000-odd stations, more than 1,000 receive service over more than 150,000 miles of program circuits. A quarter of a century was required for the development of these aural broadcasting facilities, and there is every reason to believe that, given time, television transmission systems will become equally extensive.

Fortunately, the development of transmission facilities to handle the nation's communications needs has resulted in equipment and methods that are also applicable, in part, to television requirements. The tremendous growth in demand for communication facilities has encouraged the development of means for transmitting many telephone or telegraph messages over a single wide-band channel. The number of messages that can be handled at one time over a given circuit has been ever increasing so that hundreds of simultaneous telephone conversations may now be handled by a single transmission channel. Video signals, which require a bandwidth equivalent to that of hundreds of telephone messages, can be carried over similar wide-band channels, provided suitable terminal equipment is installed. Thus, the development of television transmission circuits benefits from the joint use of methods and facilities required for other communications needs and vice versa. Three general methods are employed for the transmission of video program material: (a) wire pairs,

(b) coaxial cables, and (c) microwave radio circuits. In a comprehensive television network, all three may be used.

The aural portion of the television program may be carried at audio frequencies on conventional program circuits where the length of the circuit is such that the difference in time of transmission on the audio and the video circuits may be tolerated. On very long circuits, however, the greater velocity of propagation on the video circuits, as compared to conventional audio circuits, would cause the sound to be out of synchronism with the picture. Under these circumstances, it is necessary to employ transmission circuits for the audio frequencies whose velocity of propagation is commensurate with that of the video circuits.

In the following sections, there are described the various types of short- and long-haul video circuits that are in service for the transmission of television signals, including coaxial cable and microwave radio systems. The equipment employed at repeater and terminal stations for the different systems is covered together with a description of the ingenious alarm system used for monitoring the performance of unattended repeater stations.

**12-1. Short-haul Video Circuits.** Television broadcasting stations make use of local or short-haul video (and audio) transmission circuits for carrying program material from remote pickup points (such as athletic fields, auditoriums, theaters, and other off-premise locations) to the main studios. Furthermore, circuits of this type are often used to interconnect several studios used by a given television station where these studios are not all in the same group. Finally, local circuits are employed for carrying program material from the main studio or program distribution center to the local transmitter and to or from the network connection point. Balanced wire pairs, coaxial cables, and microwave radio circuits are all used for these services.<sup>1</sup> These circuits are usually arranged for a bandwidth of about 4 Mc.

**Unshielded Balanced Pairs.** The demand for local video circuits entails connections to a large variety of places, often on short notice. To handle this requirement, use is sometimes made of ordinary paper-insulated cable pairs that are available in existing telephone cables. However, the attenuation in these pairs at video frequencies is relatively high, as evidenced by the data given in Fig. 12-1. Accordingly, when circuits of this type are employed for video transmission, it is necessary to provide amplification at intervals of from 0.5 to 1.5 miles.

In general, paper-insulated pairs of the type described are used where the loops are short or where shielded low-loss video pairs (see below) are

<sup>1</sup> Nebel, C. N., Local Wire Video Television Networks, *Elec. Eng.*, Vol. 70, No. 2, p. 130 (February, 1951).

not available. Telephone cable pairs employed for video service must be carefully selected to avoid interference with and from other services. In addition, all branch circuits or bridges and all cable stubs more than a few feet in length must be removed in order to prevent the creation of reflections from the impedance discontinuity that would otherwise exist at such points.

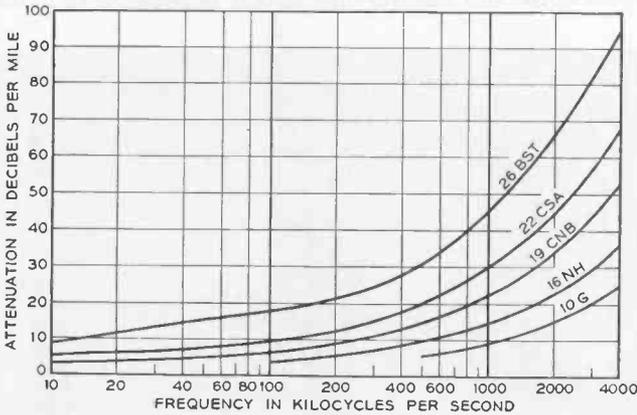


FIG. 12-1. Attenuation as a function of frequency for typical paper-insulated twisted-pair telephone cables. The numbers on the curves indicate the wire gauge. (After Nebel.)

At the higher video frequencies, the cross talk between unshielded cable pairs is likely to be quite high. This effectively limits the number of video channels that can be carried in a single cable sheath even when they are operating at comparable transmission levels and in the same direction. Where the transmission is in opposite directions, even more difficulty from cross talk may be anticipated, and it is usually necessary to employ cable pairs in separate sheaths for this type of operation.

**Shielded Balanced Pairs.** Where there is a recurring or a continuing demand for video circuits between particular points or where a lower-loss circuit is required, use may be made of polyethylene-insulated shielded pairs of the type shown in Figs. 12-2a and 12-2b. This cable consists of two No. 16-gauge copper wires insulated from each other by a unique type of construction. The wires are first individually wrapped with polyethylene strings, the pitch of the winding being quite large. Next, there is a wrap of polyethylene tape, and then two of the insulated wires are twisted together with 2-ply polyethylene strings placed in the interstices to fill the space and make a round assembly. The pair is then helically wrapped with polyethylene tape over which there is placed either two opposite-wind copper tapes or an inner, longitudinally seamed copper

tape and an outer, helically wound copper tape. The complete assembly is then placed either in its own lead sheath or in a lead-covered cable along with other pairs of the same and of other construction.

A cable of this type overcomes the cross-talk limitations of unshielded balanced pairs and thereby increases flexibility in the use of video circuits within a cable plant. In fact, the polyethylene-insulated shielded cable is so free from noise and interference that it is possible to place as many

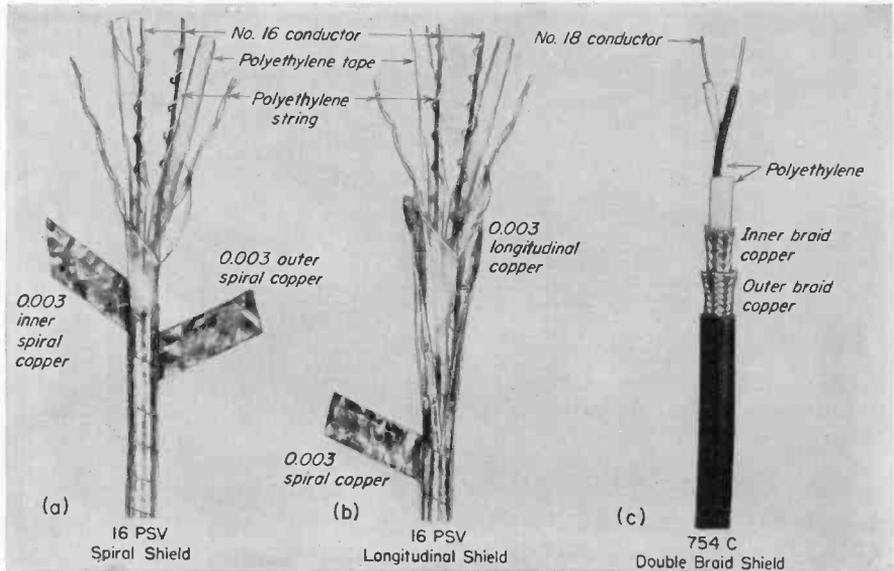


FIG. 12-2. Polyethylene-insulated shielded cable pairs of a type used for short-haul video transmission circuits. (Courtesy of Bell Telephone Laboratories, Inc.)

pairs as desired in a single cable without difficulties arising from cross talk. The attenuation between shielded pairs of the type described ranges from 120 to 145 db at 4 Mc depending, respectively, upon whether the double-spiral or the longitudinally seamed and single-spiral outer shield construction is used.

The attenuation loss of this polyethylene-insulated cable at 4 Mc is only about 18 db per mile and, as shown by Fig. 12-3, is considerably less than that of conventional paper-insulated pairs. Accordingly, repeaters may be spaced at intervals of perhaps 3 to 5 miles, a spacing which greatly reduces the probability of having to locate an amplifier at points outside the established telephone central offices.

Another type of polyethylene-insulated twisted-pair cable used for television program service is shown in Fig. 12-2c. This cable employs solid

polyethylene insulation over each wire, a covering jacket of the same material over the twisted pairs, double braided-copper shields, and an over-all outer jacket of polyvinyl chloride. As shown by Fig. 12-3, the attenuation loss of this type of cable is greater than that of the polyethylene-string insulated cables described above, being in the vicinity of 26 db per mile at 4 Mc. The cross talk between two adjacent pairs of cable of this type is approximately 150 db which, for the purpose in hand, is exceedingly low. Although cable of the type just described is moisture-resistant and may be pulled into underground cable ducts, it is intended primarily for wiring within a telephone company's plant or on the premises of a broadcasting station.

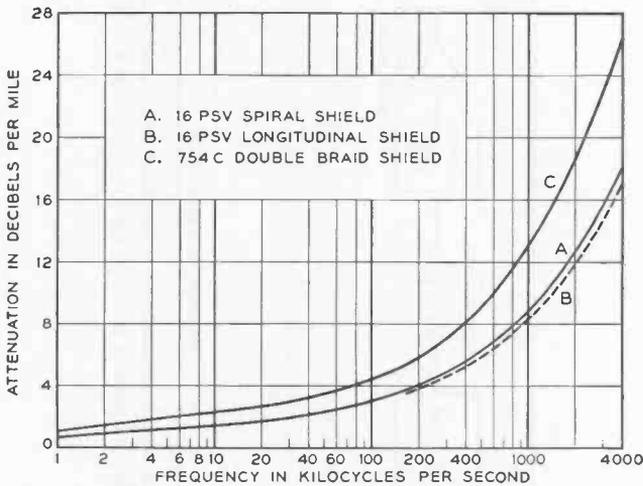


FIG. 12-3. Attenuation as a function of frequency of the shielded video pairs shown in Fig. 12-2. (After Nebel.)

The impedance of the polyethylene, shielded pair is such that it may be connected directly to unshielded, regular telephone cable (see preceding section). This makes it possible to use strategically located polyethylene-insulated cables as the basis of a city-wide video network and to supplement these cables with regular telephone pairs to reach occasional pickup points.

**Transmitting Terminals.** The video equipment used by broadcasting stations is usually designed to operate between unbalanced (one side grounded) 75-ohm source and load impedances. Video program transmission circuits, on the other hand, are usually balanced 110-ohm circuits. Consequently, at the transmitting terminals in broadcasting stations (and at field locations), provisions must be made to convert from 75-ohm one-

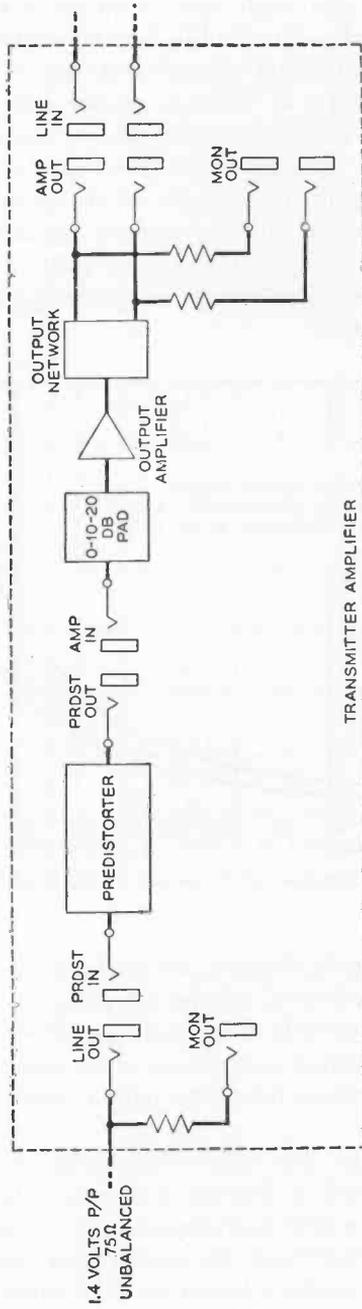


Fig. 12-4. Block diagram of the circuits employed in transmitting terminal equipment installed on the broadcaster's premises when amplification of the video signal must be undertaken before it can be applied to a video program circuit.

side-grounded to 110-ohm balanced-to-ground circuits when feeding short-haul circuits of the type in general use.

At transmitting terminals where amplification of the video signal is required before it can be applied to the video program circuit, an equipment arrangement such as shown in Fig. 12-4 is often used. The circuit illustrated accepts the signal from the broadcaster's 75-ohm unbalanced video circuit and delivers it to a balanced 110-ohm video program circuit, the conversion being accomplished by the output amplifier.

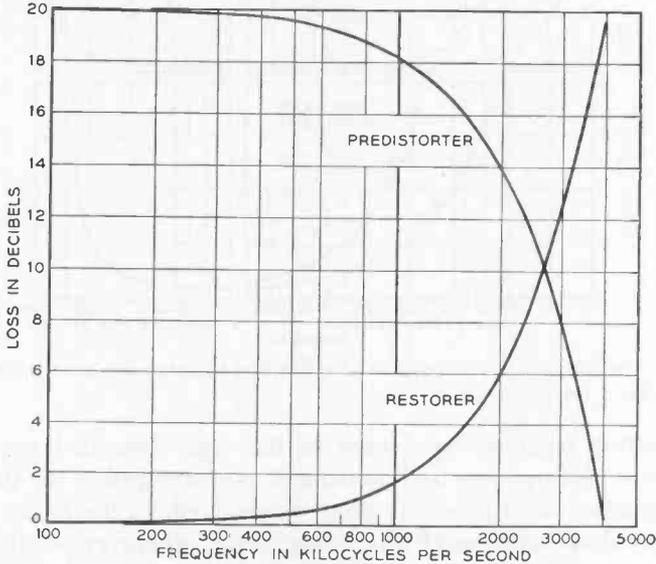


FIG. 12-5. Loss characteristics of preemphasis and deemphasis networks used in transmitting and receiving terminals to improve the signal-to-noise ratio of the transmission. (After Nebel.)

The predistorter or preemphasis network shown is used where added protection from circuit noise is required because of one or more long circuits between repeaters. The predistorter is a 75-ohm unbalanced constant-resistance equalizer that has a transmission characteristic as shown in Fig. 12-5. When used (in conjunction with an appropriate deemphasis network at the receiving terminal), the device results in an average improvement in signal-to-impulse noise of 12 db and an improvement of almost 16 db in signal-to-random noise, after taking into consideration the reduced load capacity of the associated amplifiers resulting from the 20-db lift at 4 Mc which the preemphasis network introduces.

Although the circuit arrangement of Fig. 12-4 shows the availability of means for bridging monitoring equipment across the outgoing line, it

is to be noted that monitoring at this point is useful only for signal continuity checks. This results from the fact that the load impedance presented to the output amplifier by the video line is not constant with frequency. Therefore, if an effort is made to obtain quantitative data at this point, the results are likely to be erroneous.

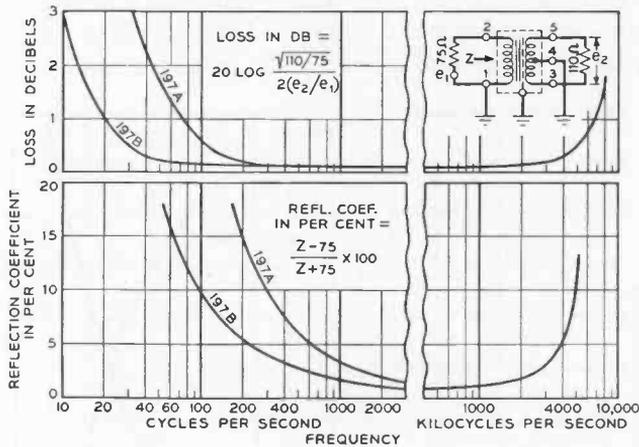


FIG. 12-6. Transmission characteristics of video line transformers over the range from 10 cps to 8 Mc. (After Nebel.)

Transmitting terminal equipment of the type described requires the maintenance of amplifiers and associated power supplies on the broadcaster's premises or, if a remote point is involved, in the field. Because of the many disadvantages of this arrangement, wherever possible the installation of amplifying equipment is avoided at such terminals. This can usually be satisfactorily effected when these terminals are not too far from a telephone central office. However, under these circumstances there is still the problem of effecting a transition from the 75-ohm one-side-grounded broadcasting equipment circuits to the 110-ohm balanced-to-ground program transmission circuits. This is accomplished in practice by means of a repeating coil or transformer capable of passing video frequencies and of isolating the unbalanced from the balanced circuit. The transmission characteristics of typical transformers of this type are shown in Fig. 12-6. Wherever circumstances permit, use is made of these video transformers or repeating coils in a circuit arrangement, such as shown in Fig. 12-7.

**Receiving Terminals.** The type of equipment required on the broadcaster's premises for the termination of incoming video program circuits depends to a large degree upon the loss of the last section of the short-haul cable employed for the service. Where polyethylene-string, shielded pairs

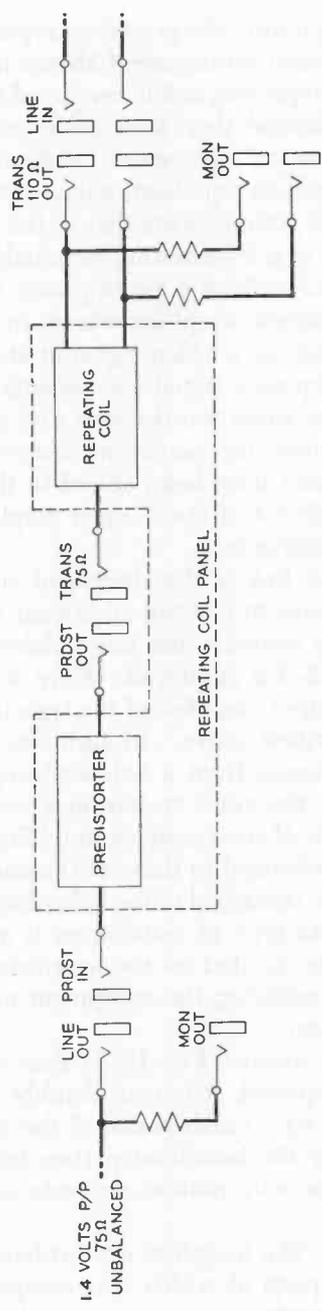


FIG. 12-7. Where it is unnecessary to undertake amplification of the video signal before application to a video program circuit, the transmitting terminal equipment on the broadcaster's premises need consist only of a preemphasis network and a video line coil.

are used and the cable length from the preceding repeater does not exceed about 1.5 miles, the equipment arrangement shown in Fig. 12-8 may be employed. Again, a video repeating coil is employed to effect transformation from the 110-ohm balanced short-haul cable circuit to the 75-ohm unbalanced circuit of the terminal equipment. Following the transformer, there is a restorer or deemphasis equalizer, whose attenuation characteristic, as shown by Fig. 12-5, complements that of the preemphasis equalizer that may be employed at a transmitting terminal. This restorer network is used, of course, only where a preemphasis equalizer is also in service. Next, there is a clamper amplifier which, in addition to supplying the gain necessary to deliver a video signal at standard transmission level, restores the lower frequency signal components that were removed by transmission through the video transformers and amplifiers along the route. The clamper amplifier also serves to remove spurious low-frequency disturbances that may have been added to the signal during its transmission. The output circuit of the clamper amplifier is designed for operation into a 75-ohm resistive load.

Where the loss in the last link of the short-haul cable exceeds a prescribed amount, it is necessary to provide additional amplification at the receiving terminal. In this instance, the more elaborate equipment arrangement shown in Fig. 12-9 is employed. Here, a receiving amplifier is used in addition to a clamper amplifier of the type used for the simpler terminal arrangement described above. In addition, since the receiving amplifier is arranged to operate from a balanced-to-ground circuit and into an unbalanced circuit, the video transformer used in other circuits can be omitted. The details of the receiving amplifier used for this type of terminal installation are identical to those of the amplifier employed at intermediate repeater points, described in the following section. Wherever possible, this more elaborate type of installation is avoided since it requires that two amplifiers be located on the broadcaster's premises with the attendant problems of servicing the equipment and providing a dependable source of a-c power.

Although the first circuit shown (Fig. 12-8) does not completely dispense with amplifying equipment, it is considerably less elaborate than the second circuit (Fig. 12-9). Furthermore, if the clamper amplifier is supplied and maintained by the broadcaster, then telephone equipment on the premises need contain only passive elements, and its maintenance becomes relatively simple.

**Intermediate Repeaters.** The length of a short-haul video circuit and the type or types of cable pairs of which it is composed determine the number of intermediate repeaters (if any) required in the circuit. The type of cable involved determines the spacing between repeaters, and the

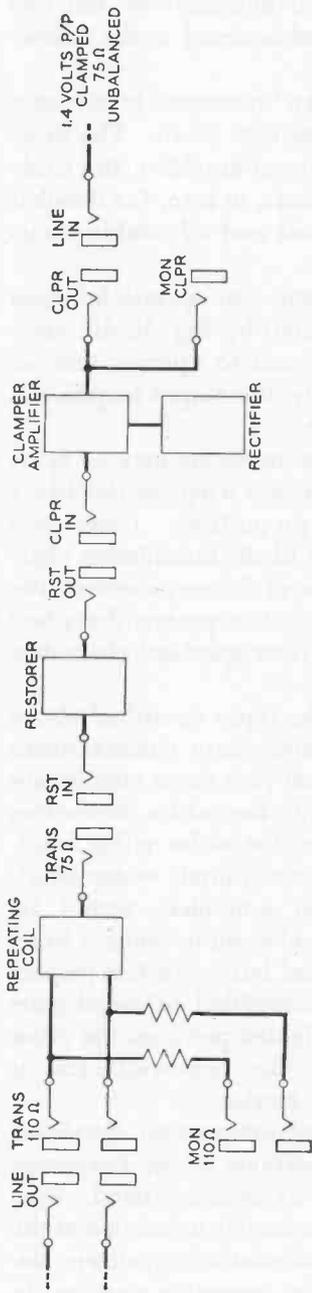


FIG. 12-8. Block diagram of a video receiving terminal of the type installed on the broadcaster's premises when the received signal level is such that only a nominal amount of amplification is required.

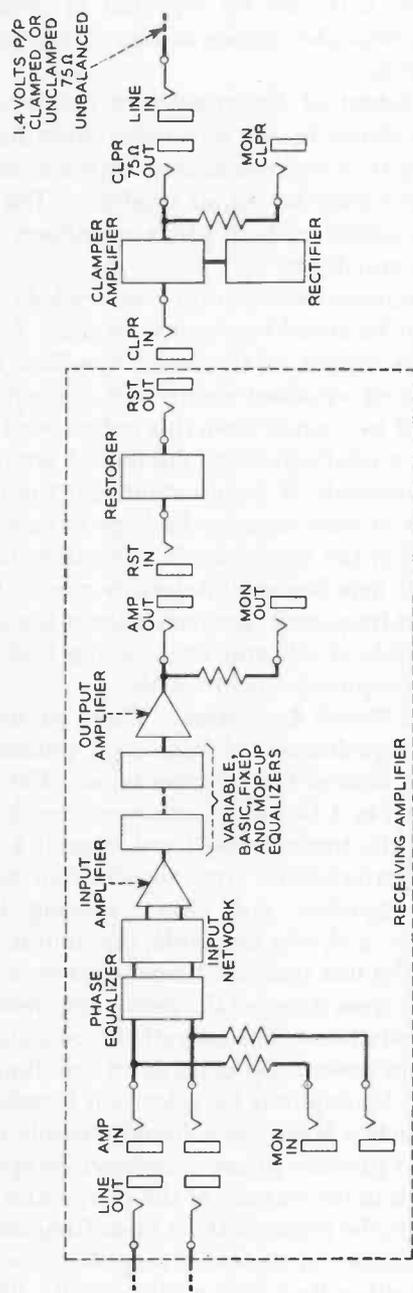


FIG. 12-9. Block diagram of the video receiving terminal equipment that is employed when the received signal intensity is below the level that can be handled by the less elaborate facilities shown in Fig. 12-8.

distances that may be expected in practice are indicated by the two specific examples, shown in Fig. 12-11 (discussed in detail in the following section).

The extent of the equipment employed at an intermediate repeater point is shown by the schematic block diagram of Fig. 12-10. The three basic parts of an intermediate repeater are the input amplifier, the cable equalizers, and the output amplifier. The equalizers, in turn, (as detailed below) consist of both phase equalizers and fixed and adjustable transmission equalizers.

The intermediate repeater, as a whole, is designed to operate between 110-ohm balanced-to-ground circuits. As indicated by Fig. 12-10, however, the output of the input amplifier is designed to operate into an unbalanced equalizer circuit and, correspondingly, the output amplifier is designed to operate from this unbalanced circuit.

Since a relatively large number of intermediate repeaters may be operated in cascade, it is important that the transmission irregularities likely to recur in each repeater be kept to very small proportions. Unless this is done, in the aggregate the deviation from an ideal transmission characteristic may become intolerably great. Because of this requirement, the response-frequency characteristics of the intermediate repeaters described are capable of adjustment to within 0.05 db of their specified characteristic at frequencies below 4 Mc.

**Video Circuit Equalizers.** Video circuits of the types described above require equalization of both their attenuation and phase characteristics over the desired transmission band. For the most part these circuits are equalized to 4 Mc, but there is nothing inherent in the cables themselves to limit the transmission band, should a demand for wider video bandwidths materialize. New equalization would be required, wider bandwidth amplifiers and closer spacing between amplifiers would be necessary, and, like any cable, the limit to the bandwidth becomes a function of the loss that can be handled on a practical basis. In this respect and also from a cross-talk viewpoint, ordinary unshielded balanced pairs have limitations. The polyethylene-insulated shielded pairs, on the other hand, are potentially capable of handling any video bandwidth that is likely to be required for television broadcasting service.

In practice it has been found possible to design attenuation equalizers that also provide phase correction except for portions of the frequency spectrum in the vicinity of the extremities of the transmission band. Furthermore, the phase shifts at these frequencies are largely a function of the characteristics of the video amplifiers and the attenuation equalizers employed rather than of the cable itself. The phase correction required is, therefore, substantially independent of the length of cable between ampli-

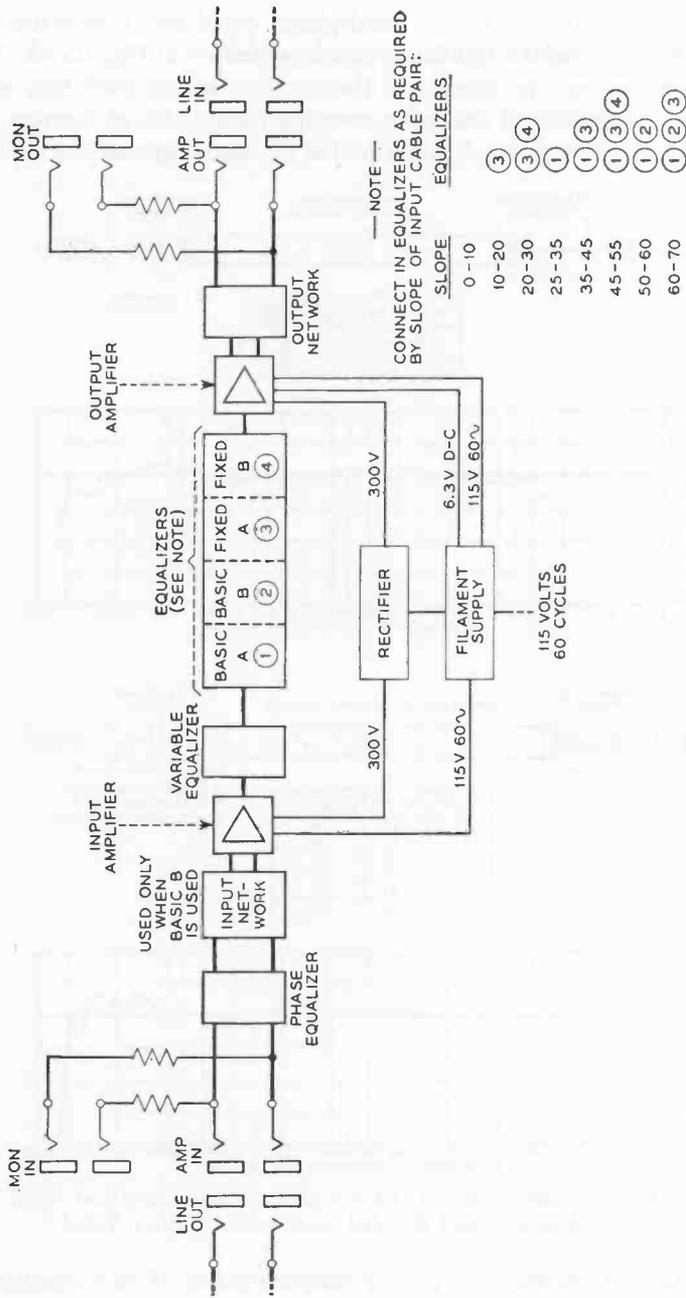


Fig. 12-10. Block diagram of an intermediate repeater of the type used on short-haul video program transmission circuits.

fiers and can be provided by a fixed-phase equalizer, connected immediately before the input amplifier network, as shown in Fig. 12-10. Under these circumstances equalization of the circuit resolves itself into correcting for the attenuation of the cable over the bandwidth of interest, phase correction being automatically obtained at the same time as just explained.

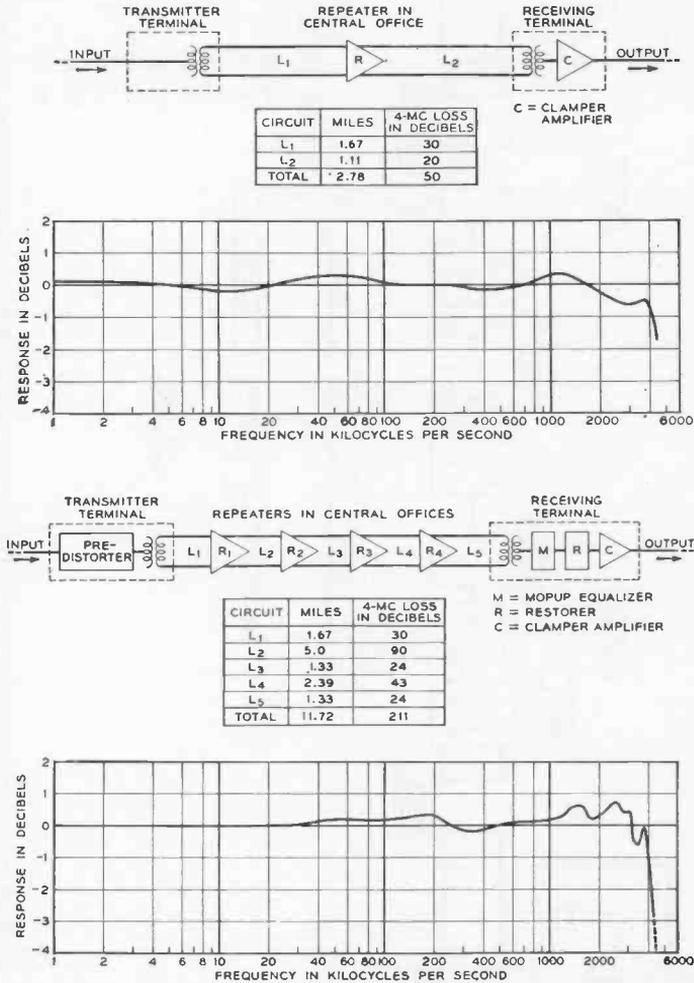


FIG. 12-11. The response-frequency characteristics of two short-haul video circuits composed of polyethylene-insulated shielded cable pairs. (After Nebel.)

The equalized response-frequency characteristics of two circuits composed of polyethylene-string-insulated shielded pairs are shown in Fig. 12-11. The first of the circuits had an over-all length of just under 2.8

miles and employed one intermediate repeater. The response of this circuit is seen to be very uniform and with a maximum deviation from uniform response of less than 0.7 db over a 4-Mc range. The second circuit illustrated was almost 11.8 miles long and employed four intermediate repeaters, all of which were located in telephone central offices (which accounts for the wide differences in repeater spacing). The response-frequency characteristic of this circuit was also quite uniform with a maximum deviation of less than 0.7 db, except at the extreme high-frequency end of the transmission band where the response is down 1 db.

**Microwave Radio Circuits.** In addition to the local video circuits that are made up of wire pairs, both broadcasting and telephone companies make use of microwave radio links to establish short-haul video channels. Microwave facilities are especially useful where the nature of the terrain is favorable and where suitable transmitting and receiving sites are available. Furthermore, they lend themselves particularly to those cases where only temporary service is required in order to cover a special news or sporting event from a point where no regular wire facilities suitable for video transmission are available. Finally, assuming that line-of-sight transmission paths exist, microwave facilities can be usually set up more quickly than wire circuits which require repeaters at frequent intervals and careful equalization of the several wire links that are often connected in tandem. Typical microwave transmitting and receiving equipments are described in Chap. 3, and a discussion of their application to short-haul video transmission given in Chap. 4. The use of equipment of this kind for establishing temporary circuits to points where wire service is not normally available is usually more economical than the installation of a special wire circuit. Radio circuits, however, are likely to be more subject to noise, interference, and transmission vagaries than are wire circuits.

**Coaxial Cables.** In some instances, coaxial cables are installed for local video transmission purposes. Circuits of this type are not balanced to ground, however, and are susceptible to low-frequency noise induction and to cross induction between other coaxial cables in the immediate vicinity. In the intercity coaxial-cable system, heterodyning methods are employed to shift the video frequencies in that portion of the spectrum where the shielding afforded by the coaxial structure is effective. However, carrier methods are not justifiable for short-haul local television circuits because of the complexity and cost of the equipment required for this type of operation. Transmission on local cable circuits, therefore, is at video frequencies extending from the very low frequencies up to about 4 Mc. To cope with the low-frequency disturbances encountered under

these circumstances, clamper or stabilizing amplifiers (see Sec. 6-7) are usually employed to mitigate the effect of such interference.

Two general types of coaxial cables are employed for short-haul video circuits. One type consists of an outer copper tube having a diameter in the vicinity of  $\frac{1}{4}$  to  $\frac{3}{8}$  in., with a central conductor insulated from the outer conductor by disks spaced at intervals of perhaps an inch or so. The second type of coaxial cable sometimes used for short-haul circuits consists of a central conductor surrounded by a continuous layer of polyethylene, teflon, or similar dielectric, over which is woven a flexible metallic shield which forms the outer conductor. The losses in this type of cable are considerably greater than in the wafer-insulated type and such cable is, therefore, applicable only on relatively short circuits. Coaxial cables of the types described are usually installed by broadcasters for their own use rather than by a local telephone company (see also Sec. 15-1).

**12-2. Long-haul Video Circuits.** Unlike a motion picture, a television program once produced and broadcast is no longer available for subsequent showings, short of producing the entire performance over again or through the medium of a television recording. Under these circumstances and in view of the relatively elaborate and costly arrangements that must usually be made for a production of any magnitude, it is only reasonable to expect that every effort is made to make the performance available to as large an audience as it is economically feasible to reach. Since the transmission range of any given television transmitter is limited to approximately line-of-sight conditions, it is evident that extensive means are required to distribute television program material on a nationwide basis. Assuming that spontaneity is not a factor, television recordings can be used for the purpose (see Chap. 11). However, where simultaneous broadcasting of the program material is required, use must be made of intercity video network facilities (Fig. 12-12).

**Coaxial Cable Systems.** A pair of coaxial cables, together with their associated equipment, are capable of handling 600 two-way telephone conversations or, alternately, a 2-way television circuit 2.8 Mc wide.<sup>2</sup> A long-haul coaxial system of this type consists of (a) the coaxial cables, (b) a series of auxiliary repeater stations spaced at relatively close intervals, (c) intervening main repeater stations at fairly wide intervals, and (d) terminal stations which translate the television video signal from its original place in the frequency spectrum to the transmission band of the cable, and vice versa. Coaxial cable systems have been in service for one purpose or another since about 1940, and the total mileage now installed

<sup>2</sup> Abraham, L. G., Progress in Coaxial Telephone and Television Systems, *Trans. AIEE*, Vol. 67, p. 1520 (1948).



amounts to well over 60,000 miles. It is to be noted, however, that by no means is all of this cable equipped for television service. Rather, the intermediate and terminal equipment associated with this coaxial cable plant is in keeping with the most urgent service needs in the particular sections of the country where the cable is installed.

**Microwave Radio Systems.** In addition to their use for short-haul applications, microwave frequencies are employed also for long-haul radio relay circuits. The equipment used for these two types of service is quite different in constructional details, however. Short-haul equipment, for the most part, is assembled so as to be readily transportable. Its installation is usually, although not always, of a temporary nature, and operating personnel are usually in attendance whenever the equipment is in use. Long-haul equipment, on the other hand, employs large, permanently installed antennas and associated equipment that is capable of operating for long periods of time unattended and is permanently installed in structures often especially constructed for the purpose. By the use of highly directional antennas, the transmitted energy may be precisely guided toward the receiving antenna which, in turn, may have a very narrow acceptance angle. The combination of high-gain transmitting and receiving antennas makes it possible to achieve accurately directed, essentially interference-free channels that, to a degree, approach the ability of wire circuits in these respects.

There are approximately equal amounts of both coaxial cable and microwave relay circuits in service in this country. Because of the importance of both types of long-haul video transmission systems to television broadcasting, both kinds are described in detail in the following sections.

**12-3. Coaxial Cable Characteristics.** The coaxial cable that is employed extensively for intercity routes has an outer tubular copper conductor, 12 mils (0.012 in.) thick, with an inner diameter of 0.375 in. (Some early coaxial cable was 0.27 in. in diameter, and the shell was 10 mils thick.) The inner conductor is a solid copper wire 0.10 in. in diameter, supported by polyethylene wafers 70 mils thick and spaced 1 in. apart (early cable employed hard-rubber wafers). The cable is provided with a protective covering consisting of a double layer of helically wound steel tapes, each  $\frac{3}{8}$  in. wide and 6 mils thick, applied so that the gaps of the inner layer are covered by the outer one.

The physical arrangement of a typical cable used in practice is shown in Fig. 12-13. The cables usually consist of eight coaxial conductors grouped around a number of paper-insulated wires that are employed for auxiliary purposes. In addition, layers of regular telephone pairs may surround the core of coaxial conductors for still other service needs.

Cables are installed by either burying them in the ground or placing them in underground raceways or ducts.

One of the reasons for placing the cables underground is to reduce the amount of temperature variation to which they are subjected. If this were not done, the problem of compensating for changes in transmission characteristics by reason of temperature variations would tend to become very difficult because of the precision that is desired. Relatively great accuracy is necessary in correcting for deviations between individual re-

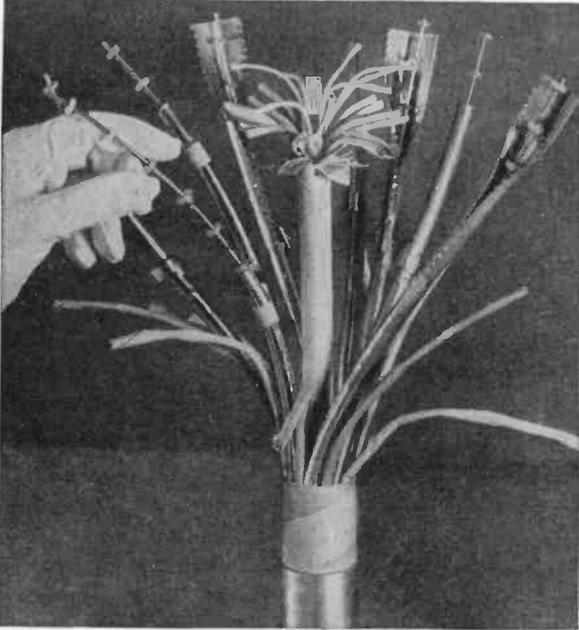


FIG. 12-13. A long-haul video cable containing eight coaxial conductors around a core of paper-insulated wires and surrounded by paper-insulated telephone pairs. The polyethylene supports for the inner conductor of the coaxial cable and other details of their construction are shown. (Courtesy of Bell Telephone Laboratories, Inc.)

peater stations because of the large number of repeaters involved in a system of any considerable length. In designing a system for use in this country, consideration has to be given to the need for being able to extend the circuit from coast to coast. The total cable loss of a circuit of this extent amounts to about 28,000 db at the upper end of the transmission band and about 4,000 db at the lower end. Thus, large amounts of gain, attenuation equalization, and phase equalization are required. In fact, a transcontinental circuit requires approximately 500 repeaters, half of

which are dynamically regulated units that provide automatic equalization of cable loss. With this number of units, any error in the correction introduced by each repeater must be minute if the over-all result is to be satisfactory for the intended service.

**12-4. Auxiliary Repeater Stations.** The repeaters in service on the coaxial cable system are spaced at about 8-mile intervals and provide a useful transmission band from 64 to 3,100 kc. The exact spacing between repeaters depends upon the average temperature of the region and upon the availability of accessible locations for their installation. The block schematic diagram of a typical auxiliary repeater is given in Fig. 12-14.

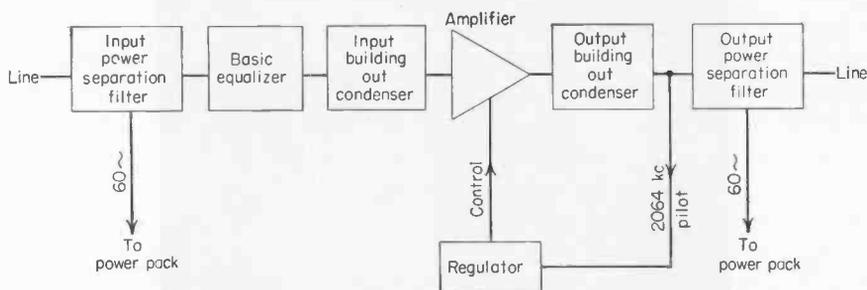


FIG. 12-14. Block diagram of an auxiliary repeater for long-haul coaxial cable applications.

At the input and at the output of each auxiliary repeater there is a power separation filter to separate 60-cps power from signal frequencies and to provide some of the attenuation equalization at the lower end of the transmission band. Following the input power separation filter, there is a basic equalizer unit which compensates for a large part of the transmission loss of the cable. Next, there is an adjustable input building-out capacitor to approximately offset the impedance variations seen from the viewpoint of the amplifier input because of connecting cable, splices, and other circuit irregularities. Finally, there are the auxiliary amplifier itself, an output building-out capacitor, and an output power separation filter.

**Primary Power Supply.** The primary power necessary for the operation of the auxiliary repeaters is obtained in the form of 60-cps alternating current over the central conductors of the coaxial cable from main repeater stations. The power transmission system consists of an arrangement wherein the primaries of the power packs at each repeater are arranged in series with the inner conductor of its associated coaxial cable to form a series feed from a power-supply station. Coaxial cables are always installed and equipped in pairs in order to provide a circuit in both directions for the accommodation of two-way telephone conversa-

tions. Consequently, the central conductor of one cable may be used for the outgoing power lead and the conductor in the second coaxial cable for the return power lead.

**Video Amplifier.** The video amplifier employed in the auxiliary repeater consists of a three-stage feedback amplifier whose feedback circuit is designed to perform two important functions: (a) provide that portion of the attenuation equalization required by the preceding cable section which is not supplied by the basic equalizer and (b) provide a means for automatically compensating for variations in loss in the preceding cable section because of temperature changes.

Each stage of the video amplifier employs two tubes in parallel as a safeguard against tube failure. Should one tube fail in any or all stages, the amplifier will continue to function with only a small impairment in performance, primarily in the form of increased waveform distortion. In addition to the main feedback circuit that encompasses all stages, the output stage is provided with a cathode-feedback circuit to improve the peak-amplitude handling capacity of this stage.

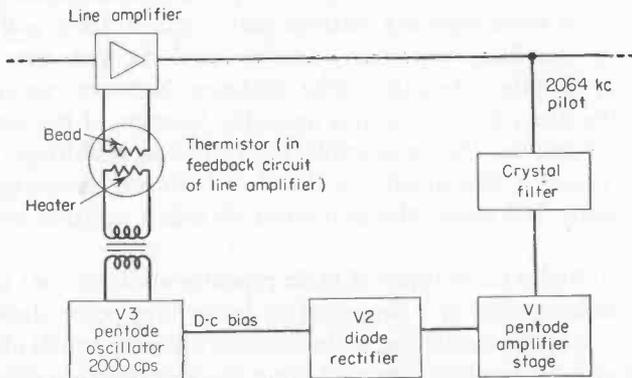


FIG. 12-15. Pilot tone regulators are associated with coaxial cable line amplifiers, as shown in this block diagram, in order to provide a means for obtaining automatic gain compensation.

**Automatic Regulators.** The automatic gain compensation is accomplished with the aid of a 2,064-kc pilot regulator tone introduced into the circuit at the sending end specifically for this purpose.<sup>3</sup> The input to the regulator circuit is bridged across the main circuit at the output of the video amplifier as shown in Fig. 12-14. Details of the regulator are shown in Fig. 12-15 from which it is seen that the pilot frequency is selected by a crystal filter, amplified, rectified, and the resulting direct

<sup>3</sup> Gould, K. E., Equalization of Coaxial Lines, *Trans. AIEE*, Vol. 68, p. 1187 (1949).

current used to control the output of a local 2,000-cps oscillator. The controlled output of the audio oscillator is used to heat a thermistor, which is located in the feedback path of the video amplifier and arranged to control its gain. The circuit is such that a drop in pilot level results in an increase in amplifier gain which restores the pilot level to essentially its original value.

Automatic regulators of the type described are used at approximately every other auxiliary repeater point. A manually adjusted gain control is employed at the intermediate points where a fixed gain is employed except as readjustment is required to cope with seasonal variations in temperature. Changes in loss of the manually regulated repeaters are taken up by the automatic regulator at the next repeater. The elimination of automatic regulators from alternate repeaters simplifies the equipment at these points, reduces the number of circuits that may require maintenance, and approximately halves the number of pilot regulators in tandem thereby improving the over-all stability of the regulator operation.

**12-5. Main Repeater Stations.** In addition to the coaxial cable and the auxiliary repeaters described above, a complete coaxial cable system requires a series of main repeater stations and a transmitting and receiving terminal. The auxiliary repeaters, as already indicated, are spaced at approximately 8-mile intervals. The distance between main repeater stations, on the other hand, depends upon the location of the cities served by the coaxial system, the availability of telephone buildings, and other factors. In practice, the maximum distance between main repeater stations is currently 165 miles, the minimum 40 miles, and the average 105 miles.

There are actually three types of main repeater stations: (a) nonswitching, (b) switching, and (c) dropping or branching point stations. The nonswitching and the switching main stations are very much alike except that the latter have facilities for switching the transmission channel from a regular to a spare line. A branching point station, on the other hand, is similar to a switching point but, in addition, provisions are made for bridging the main circuit (in order to provide program material to a local broadcasting station while maintaining the through circuit) and also for interrupting the through circuit when desired and originating local program material for the outgoing circuit. The functions of main repeater stations are to provide the means for (a) carrying out the operations just enumerated, (b) amplifying the transmission, (c) automatic and manual equalization of a more elaborate nature than that undertaken by auxiliary repeaters, and (d) providing primary power to the auxiliary repeaters.

**Basic Facilities.** The basic circuit (Fig. 12-16) of nonswitching main repeater stations is similar to but more elaborate than that of an auxiliary

repeater. First there is the power separation filter which, in this case, is used for supplying power to the central conductors of the coaxial rather than for taking power from them. Next, there is the basic equalizer and a receiving amplifier whose gain is controlled by a 2,064-kc pilot tone, both units being similar (but not identical) to those used at auxiliary repeater points. Then, there is a special automatic attenuation equalizer which is controlled by three additional pilot tones of 64, 556, and 3,096 kc. These pilot tones, like the 2,064-kc one used at all repeater stations, are originated by the transmitting terminal.

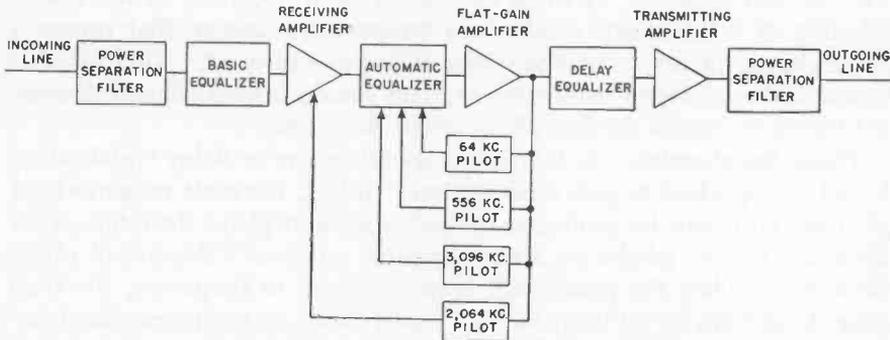


FIG. 12-16. Block diagram of the equipment at a main repeater point in a long-haul coaxial cable transmission system.

Following the pilot-controlled equalizer there is a flat-gain video amplifier across the output of which are connected the crystal filters that pick off the four pilot tones from the main circuit for operation of their associated regulators. Next, there is sometimes a second equalizer, this one manually adjustable, which is used to clean up any residual gain variations. When this second equalizer is used, it is necessary to provide a second flat-gain video amplifier to make up for the losses introduced by the clean-up equalizer. Finally, the equipment chain at a main repeater station contains a delay or phase equalizer and a transmitting amplifier for increasing the amplitude of the signals to a level suitable for transmission over the coaxial cable. Depending upon whether the main repeater station is nonswitching, switching, or a branching point, suitable auxiliary facilities are provided to perform the various supplementary functions.

**Automatic Attenuation Equalizers.** The automatic attenuation equalizer mentioned above is a complex form of adjustable network. Its functions are twofold: (a) to provide a means for manually adjusting the over-all

gain of the system as a function of frequency and (b) to provide three automatically controlled loss-frequency characteristics which serve to reduce the gain variations arising with the passage of time, thus reducing the necessity for frequent manual realignment.

The automatic control portion of the device is similar, in some respects, to the regulation facilities described for the auxiliary repeater points in Sec. 12-4, *Automatic Regulators*. In the auxiliary repeater, a 2,064-kc pilot tone is used to control the gain of the repeater via its feedback circuit. In the automatic equalizer, on the other hand, thermistors are supplied with heater current from regulators operating from pilot tones at 64, 556, and 3,096 kc. A small amount of control current in the heater winding of a thermistor results in a temperature change that causes a large change in the resistance of the thermistor element. This variable resistance is employed as an element in an equalizer network and thereby is utilized to control the loss of the network directly.

**Phase Equalization.** In television circuits, phase or delay equalization is just as important as gain equalization. In fact, the same magnitude of picture ghosts can be produced by both gain and phase deviation, 1-db deviation in gain producing about the same effect as 7 degrees of phase deviation. When the phase shift is proportional to frequency, the time delay is uniform for all frequencies. Under these circumstances the delay is not detrimental since, if all frequencies are delayed the same amount, the net effect is simply to delay the arrival of the signal by a fixed amount. The function of delay equalizers, therefore, is to provide the amount of phase correction required to obtain an over-all uniform delay at all frequencies that are of interest.

Equalizers having a delay complementary to that of the unequalized system are, therefore, employed at each main repeater station such that the sum of equalizer and system delay is constant with frequency at a value equal to or greater than the maximum delay of the unequalized system. As a rule, the bulk of the equalization required for a given length of circuit is provided at the transmitting end. This is a convenient and economical choice from the standpoint of providing the gain necessary to compensate for the loss introduced by the delay equalizer.

On the other hand, an adjustable delay equalizer is usually located at the receiving end of the circuit for ease in establishing the correct settings necessary to trim up the circuit.

**Video Amplifiers.** In the above description of a main repeater station, three types of video amplifiers were mentioned: a receiving amplifier, a transmitting amplifier, and a flat-gain amplifier. The receiving amplifier, which is connected to the receiving end of the cable, is similar to the auxiliary repeater amplifier described in Sec. 12-4, *Video Amplifier*, ex-

cept that its internal output impedance is constant at approximately 75 ohms over the useful band of frequencies. The receiving amplifier includes a variable feedback circuit, like that in the auxiliary repeater amplifier, so that compensation may be made for variations in the loss of the cable associated with the combination of a transmitting and a receiving amplifier.

The transmitting amplifier, which is connected to the transmitting end of the coaxial cable, is also similar to the auxiliary repeater amplifier, except that the input circuit presents an impedance of approximately 75 ohms over the useful band while the output circuit is similar to that of the auxiliary repeater amplifier. The output of the receiving amplifier and the input of the transmitting amplifier are arranged to present finite impedances to associated circuits in order to effect an impedance match with other equipment in the main repeater station.

The flat-gain amplifiers, which are used to offset the loss introduced by various equalizers, have a gain of approximately 40 db which, as the name implies, is constant with frequency. These amplifiers are not intended to contribute to the correction of the gain-frequency characteristic of the cable and, unfortunately, they introduce appreciable delay distortion. This is corrected, however, by the delay equalizers already described.

**Protective Devices.** A transcontinental coaxial circuit has a total of approximately 500 repeaters, about 460 of which are located in unattended huts or similar locations and the remaining 40 of which are at main repeater stations. The main repeater stations, in turn, are divided into groups, each having one attended station and from one to ten unattended stations. Thus, it is evident that well over 90 per cent of the repeaters on a coaxial cable circuit are unattended. It is the responsibility of each attended main station to maintain and service the unattended stations in its group. In one instance, the distance between the most distant stations in a maintenance group is 1,650 miles.

In order to cope with this problem, a number of service protective features have been incorporated in the coaxial transmission system. These include a spare coaxial circuit in each direction and terminal equipment arranged so that this spare circuit will be automatically switched into service if one of the regular circuits fails or if the pilot tone exceeds prescribed limits. The switching is instantaneous and causes essentially no interruption to regular service. Furthermore, an alarm is given so that the trouble may be remedied by appropriate maintenance procedures.

All auxiliary repeater stations that are equipped with automatic gain regulators also have pilot tone alarm units. These devices monitor the amplitude of the rectified current from the pilot control circuit and, should it deviate beyond prescribed limits in either direction, the alarm unit

places a short across a pilot alarm circuit. This, in turn, actuates an alarm at the nearest attended main station where steps to initiate corrective measures may be taken.

Probably the most ingenious and elaborate of the protective devices, however, is the alarm and control system that is an integral part of the coaxial transmission system.<sup>4</sup> This equipment permits remote control and supervision by an attended main station of the equipment in all unattended main stations in its area. Alarm registration devices, equipment for controlling the unattended station, and facilities for indicating conditions at any of the unattended stations are all installed in the attended main station. At the unattended stations, on the other hand, there is the equipment necessary for sending alarms, executing orders, and sending indicator signals to the control station. A schematic diagram of a typical coaxial cable maintenance and control section is shown in Fig. 12-17.

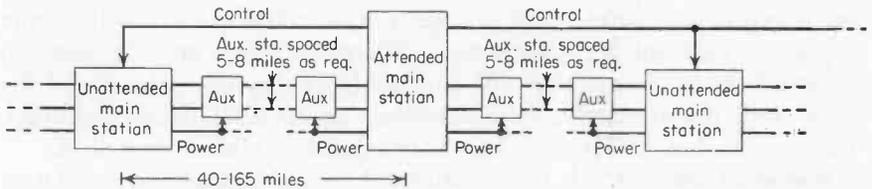


FIG. 12-17. Schematic diagram of a typical coaxial cable maintenance and control section involving unattended main and auxiliary repeater stations. (After Hearn and Weber.)

When an alarm condition occurs in any one of the remote main stations, the alarm-sending circuit associated with that station seizes the alarm channel (indicated as channel 1 in Fig. 12-18) and sends a d-c signal along the line toward the attended main station. This signal is received and retransmitted by each intermediate unattended station until it reaches the attended main station. This process serves to indicate to the alarm-sending equipment at the intermediate stations that the alarm-sending circuit is in use so that alarms originating at these intermediate stations during these periods will be stored until the alarm-sending circuit is available.

Receipt of an alarm signal at a control station causes a d-c signal to be sent in the direction of the station originating the alarm. This signal is also repeated by the intervening unattended stations, and its arrival at the remote station is an indication that the alarm-sending channel is available and that it is functioning properly. The alarm-originating station

<sup>4</sup> Hearn, R. B., and L. A. Weber, B-1 Alarm and Control System for Remote Control of Coaxial Cable Stations, *Trans. AIEE*, Vol. 69, p. 622 (1949).

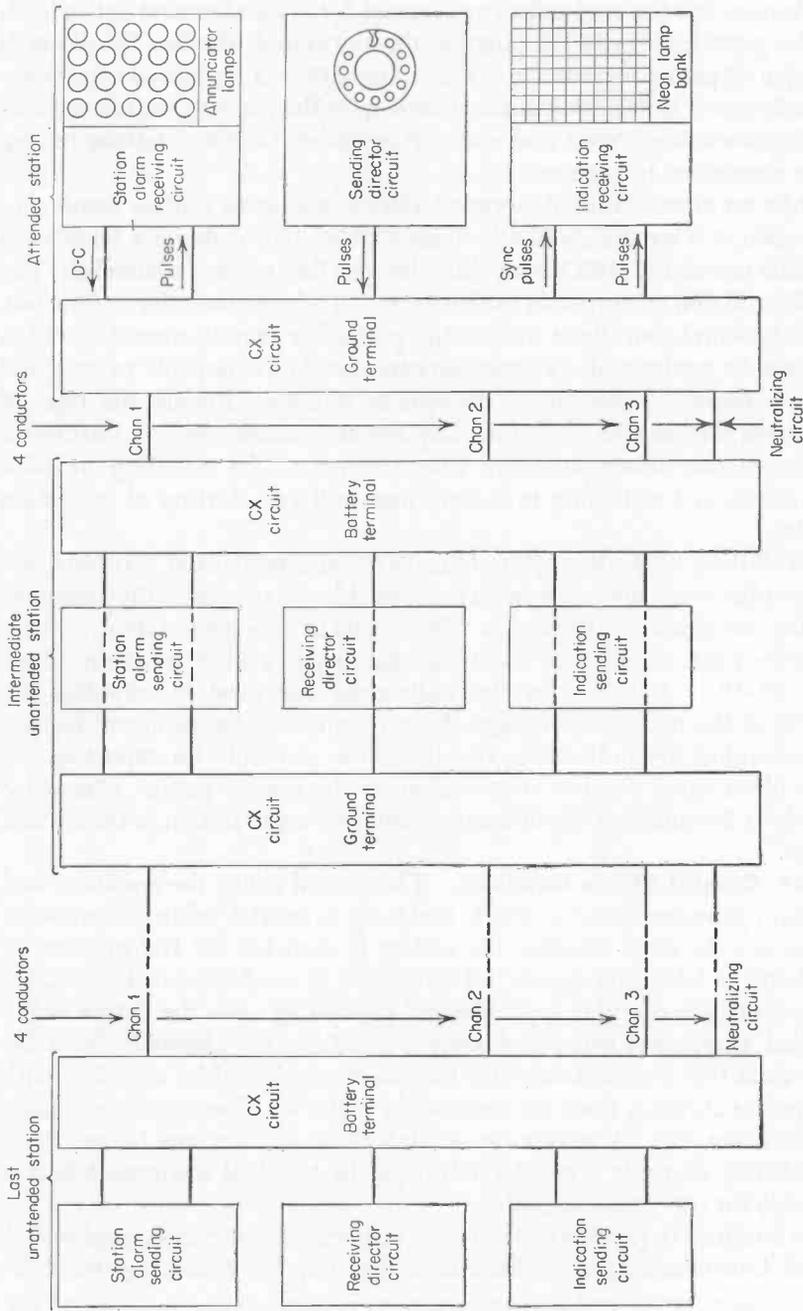


FIG. 12-18. Schematic diagram of the alarm and signal circuits employed for protective purposes on a coaxial cable circuit. (After Heam and Weber.)

then transmits a series of pulses on channel 3, the number sent out indicating the particular station originating the alarm and whether the alarm is of major or minor importance. This information is registered on annunciator lamps at the control station whereupon the sending station releases the alarm-sending circuit and makes it available to other stations having alarm conditions to register.

When an attendant at the control station wishes to initiate some control action at a remote station, he dials a three-digit code on a telephone-type dial associated with the sending director that utilizes channel 2. The first digit dialed corresponds to the station to which the order is directed, and the second two digits dictate the particular remote-control function that is to be performed. This arrangement makes it possible to send 100 separate orders to any one of 10 remote stations. Among the type of operations that can be undertaken by remote control are (a) starting of gasoline-engine-driven auxiliary power supply, (b) resetting of pilot level relays, (c) switching to a spare line, and (d) starting of indication circuits.

The starting of the indication circuits by an attendant at a control station results in an operation which is capable of automatically transmitting the condition of as many as 168 circuits at a remote station. These indications are received at the main station on a bank of neon lamps (Fig. 12-18). Fourteen of the indications are used to establish the identity of the remote station and the correctness of the received display; the remaining 154 indications are, therefore, available for reporting the status of an equal number of conditions at the remote point. Channel 3 is used for transmitting the indications from a remote station to the control station.

**12-6. Coaxial System Terminals.** The coaxial cable, the auxiliary, and the main repeater stations which make up a coaxial cable transmission system are the same whether the system is used for the transmission of telephone or television signals. The system, as a whole, can be used for the transmission of either type of signal depending upon the nature of the terminal equipment associated with a coaxial cable channel. It is for this reason that the existence of a section of coaxial cable, complete with its repeater stations, does not necessarily make it automatically available for television use. Whether or not television service can be provided immediately depends upon the nature of the terminal equipment that is available for use with the cable.

The facilities required at a television terminal station<sup>5</sup> associated with a coaxial transmission system include means (a) for translating the tele-

<sup>5</sup> Morrison, L. W., Jr., Television Terminals for Coaxial Systems, *Trans. AIEE*, Vol. 69, p. 1193 (1949).

vision video frequencies upward into the transmission band of the coaxial system and (b) for restoring the resulting carrier frequencies back to their original place in the frequency spectrum. As will become evident from the following paragraphs, this process is not simply one of heterodyning the original frequencies to a new location and then demodulating the resulting signal at the receiving point. Rather, a somewhat complicated double modulation process has to be employed in order to locate the original video signals in the available transmission band of the coaxial cable system.

**Transmission Band Considerations.** Television signals in their video-frequency form normally occupy a band of frequencies ranging from a few cycles per second to over 4 Mc. The coaxial cable system now in commercial service, on the other hand, is designed for transmission of frequencies between only 64 and 3,100 kc. Consequently, means must be provided for discarding a portion of the original video signal and then translating the remainder up into the band of frequencies that can be handled by the coaxial system.

If some portion of a television signal must be sacrificed, it is usual to limit the extent of the high frequencies. This results in loss of fine detail, the amount of degradation being a function of the reduction in bandwidth. In order to transmit as wide a band of frequencies as possible, a vestigial sideband transmission system is employed. Although this does not preserve quite so much of the bandwidth of the original signal as would a single sideband system, it does avoid the major problems attending single sideband transmission.

The extent of the delay distortion of a long coaxial system is an important consideration in television signal transmission. Furthermore, the amount of distortion increases rapidly as the lower frequency limit of the transmission system is approached. Taking into account the amount of delay distortion that is tolerable for television applications, it was decided that the lower practical limit for television signal transmission over the coaxial system is in the vicinity of 200 kc. Accordingly, the coaxial cable system, when employed for television signal transmission, utilizes a transmission band extending from approximately 310 to 3,100 kc with a vestigial sideband extending down to 200 kc. This results in the transmission of a video signal having a bandwidth of approximately 2.8 Mc.

As already indicated, extension of this bandwidth upward would require closer spacing of the repeaters and the installation of wider bandwidth amplifiers, equalizers, and associated equipment. Extension of the bandwidth of the coaxial cable system downward is not practical because of the susceptibility of this type of transmission facility to low-frequency disturbances.

The frequency range below 100 kc is not entirely lost, however, since the region from 80 to 88 kc may be employed for the accompanying sound channel using a single sideband system of transmission. This arrangement effectively copes with the difference in wave propagation velocities that would be encountered were the sound channel carried by conventional program circuits operating at audio frequencies.

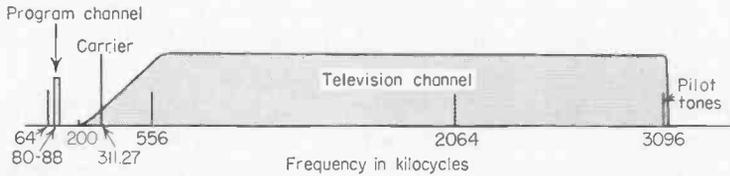


FIG. 12-19. The frequency relationship in a coaxial cable transmission system between the aural program channel, the visual signal carrier, the associated main and vestigial sidebands, and the four pilot tones. (After Morrison.)

The exact location of the television signal in the transmission band of the coaxial system is chosen so as to take advantage of certain inherent characteristics of the television signal and of the coaxial line. Theoretical and experimental studies show that, in frequency regions related to the vertical and horizontal scanning frequencies and their harmonics, there are concentrations of energy produced by the television signal.<sup>6</sup> In the remaining regions the energy content is relatively low and sometimes completely absent. Furthermore, the introduction of interfering signals in these idle regions results in less disturbance to the picture than an equal amount of energy introduced into those parts of the spectrum that are related to the scanning frequencies and their harmonics. Thus, the frequencies of the pilot tones employed for automatic equalization purposes are carefully selected so as to fall in a portion of the spectrum where they will produce a minimum of interference to the picture display.

The exact location of the television carrier signal, the associated main and vestigial sidebands, the four pilot tones, and the aural program channel (which employs single sideband transmission) are shown in Fig. 12-19. The methods employed for shifting the television video signal from its original place in the spectrum to the location shown in this illustration and then back again, prior to transmission to a local broadcasting station, are described in the following paragraphs.

**Modulation Process.** When it is desired to shift a single frequency or a band of frequencies from one part of the spectrum to another, it is the common practice to make use of heterodyne methods. However, this process is such that the shift in frequency must be large compared to the bandwidth

<sup>6</sup> Mertz, P., and F. Gray, Theory of Scanning, *Bell System Tech. J.*, Vol. 13, p. 464 (July, 1934).

of the signal being translated. Unless this is the case, the frequencies of some of the heterodyne components are likely to fall within the band occupied by the original signals. This creates problems of beats between the original signal and the heterodyned components.

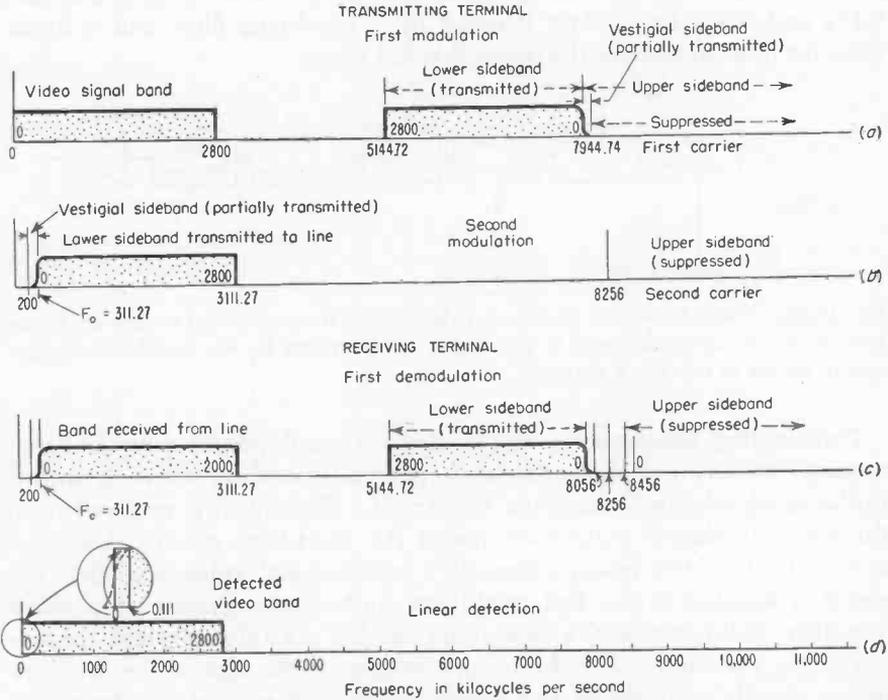


FIG. 12-20. Details of the double-heterodyne process employed at transmitting and receiving terminals on a coaxial cable system. (After Morrison.)

In adopting a television signal to the transmission band of the coaxial cable system, it is necessary to shift a band of video frequencies, extending from a few cycles per second to 2,800 kc into the region from 310 to 3,100 kc. This calls for a shift in frequency of only 300-odd kc, which is very small compared to the bandwidth of the original frequencies. A double modulation process is, therefore, required to achieve the desired result. By this means the original signals are shifted upward by an amount sufficiently large to employ conventional heterodyne processes. One sideband of the heterodyned signal is then shifted back downward to within 300-odd kc of its original place in the spectrum. By this multiple heterodyne process, the relatively small frequency shift required is obtained. Details of the double-heterodyne process described are shown in Figs. 12-20a and b.

At the receiving terminal it is necessary to restore the transmitted signal to its original place in the spectrum. This is also accomplished by a double-heterodyne method as shown by Figs. 12-20c and d. Here the incoming signal is first heterodyned by a 8,256-kc carrier. The lower sideband resulting from this process, which falls in the region between 5,144 and 8,056 kc, is then selected by a band-pass filter and a linear detector used to recover the original video signal.

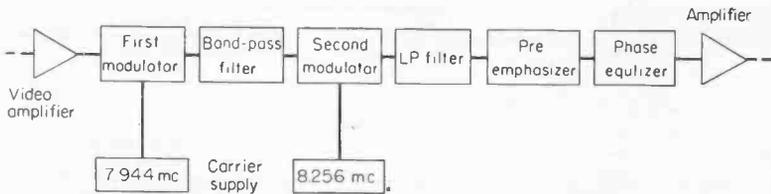


FIG. 12-21. Video-frequency picture signals received from television studios are translated to the transmission band of the coaxial cable system by the double-heterodyne system shown in this block diagram.

**Transmitting Equipment.** The equipment employed at a transmitting terminal to carry out the modulation process described above is shown in the block schematic diagram, Fig. 12-21. The signal is received from the local origination point over one of the short-haul circuits described in Sec. 12-1. After passage through a conventional video amplifier, the signal is applied to the first modulator unit which consists of a video amplifier, a d-c restorer, a modulator, and a crystal-controlled carrier-frequency oscillator. The d-c restorer clamps to the tips of the synchronizing signals and adjusts the associated circuits so that synchronizing signal tips correspond to a fixed value of carrier at all times.

Next in the circuit is the band-pass filter that selects the lower of the two sidebands for further processing. The second modulator is similar to the first except that no d-c restorer is necessary and the crystal-controlled carrier oscillator is on a different frequency. Subsequent to the second modulation step, a low-pass filter selects the lower sideband, after which preemphasis is applied. A phase equalizer is then introduced to correct for the delay distortion introduced by the various processes described and, finally, an amplifier is employed to bring the resulting signal up to a suitable transmission level.

**Receiving Equipment.** The components employed at a receiving terminal are shown in Fig. 12-22. The first element in the chain is a pilot-tone elimination filter. This unit employs three crystal filter networks for eliminating the corresponding number of pilot tones that fall within the transmission band (the fourth pilot frequency, at 64 kc, is outside the

band containing the desired television signal information). Next, there is a phase-correction network which is employed for equalization of the delay distortion introduced by various processes undertaken at the receiving terminal. Following this unit, there is a postemphasis or restorer network which complements the preemphasis network at the transmitting terminal.

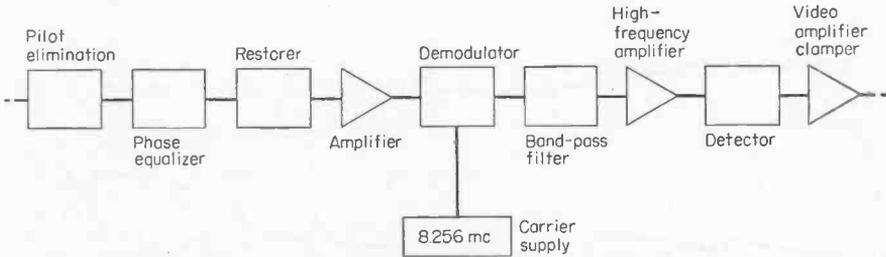


FIG. 12-22. At coaxial cable receiving terminals the incoming signals are converted back to video frequencies for transmission to local television stations by the double-demodulation system shown above.

The signal is then amplified and applied to the demodulator which undertakes the first step in restoring the incoming carrier signal to its original place in the frequency spectrum. The lower sideband of the resulting signal, which falls in the 5- to 8-Mc region, is selected by the following band-pass filter and applied to a high-frequency amplifier which provides sufficient gain in the 5- to 8-Mc region to provide adequate level for the linear detection stage that follows. Finally, the demodulated signal, which now occupies its original place in the frequency band, is applied to a stabilizing amplifier where it is amplified and clamped. This clamping action serves to remove low-frequency disturbances that may have been added to the original signal during transmission over the circuit.

**12-7. Microwave Relay System.** Long-haul microwave relay systems have been established between many major cities<sup>7</sup> as shown by Fig. 12-23. The equipment employed for these applications operates in the vicinity of 4,000 Mc and therefore requires line-of-sight transmission between relay points. The spacing of microwave repeater stations will depend, of course, upon the nature of the surrounding terrain, the elevation of the transmitting and receiving antennas, and associated factors. The first transcontinental microwave circuit for example, involves a total of 107 stations which are spaced from 9 to 50 miles apart, averaging 28 miles for the approximately 3,000-mile circuit. The heights of the supports

<sup>7</sup> Grieser, T. J., and A. C. Peterson, A Broadband Transcontinental Radio Relay System, *Elec. Eng.*, Vol. 70, No. 9, p. 810 (September, 1951).



the frequency spectrum extending from 3,700 to 4,200 Mc, as detailed in Fig. 12-24.

Examination of this frequency allocation plan shows that adjacent channels are separated by 40 Mc but the transmitting and receiving channels are interlaced so that the separation between any two adjacent transmitting channels for a given direction of transmission is 80 Mc. It follows, of course, that the receiving channels are likewise so separated. It will be noted that only two center frequencies, 40 Mc apart, are employed for

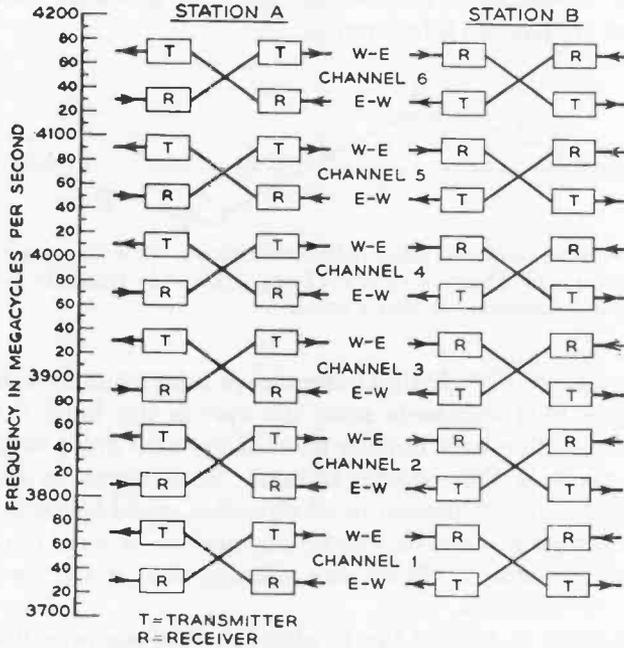


FIG. 12-24. Frequency allocations at two successive repeater stations of the 12 channels (6 in each direction) handled by microwave repeater stations. (After Clutts.)

any given circuit and the transmissions alternated back and forth between them. By this arrangement the transmitter that repeats the signal picked up by its associated receiver is always operated on a frequency 40 Mc removed from that to which the receiver is assigned. This arrangement prevents the possibility of feedback from a transmitting antenna to a receiving antenna on the same repeater building. By transposing the frequency assignments back and forth as described, all available frequency allocations are in service throughout the transmission system.

It is to be noted, however, that a given frequency assignment is repeated at the second following station. Thus the importance of the zigzag

routing mentioned above becomes evident. As shown in Fig. 12-25, if station A transmits on frequency  $f_1$  to station B, then station C will also employ the same frequency to reach station D. Thus, the routing must be arranged so that there is no possibility of transmissions from one station being directed toward the third station beyond. It is possible, of course, that high terrain may be conveniently encountered along this potential interference path, in which case the possibilities of direct transmission may not be present. Barring a fortuitous deployment of mountain ranges, a staggered transmission path is desirable to avoid the possibility of interstation interference.

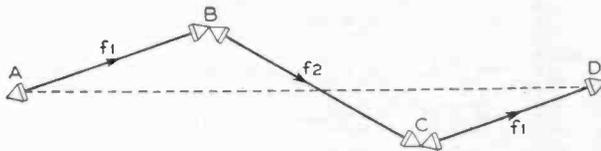


FIG. 12-25. A zigzag course is often deliberately chosen for a microwave relay route in order to avoid the possibility of station A being received by station D, both of which employ common frequencies. (After Clutts.)

The performance of individual microwave relay stations is maintained at exceedingly high standards since the system has been designed for satisfactory operation over circuits upward of 4,000 miles long involving perhaps as many as 150 repeater stations. In a circuit as long as this, a minute discrepancy, if present in all repeaters, could become intolerable in the aggregate; *e.g.*, a 0.1-db loss in transmission at some particular frequency could become 15 db for the entire system if the deviation was recurrent in all repeaters.

The bandwidth of each of the 12 channels that comprise a microwave relay system extends from about 30 cps to better than 4 Mc. In this respect, the individual channels are better than the presently available long-haul coaxial circuits, and in comparing the performance of the two systems this difference must be borne in mind.

**12-8. Microwave Repeater Stations.** In the microwave relay system there are two basic types of equipment installations: one at terminal stations and the other at repeater stations. At terminal stations the video-frequency signals that are to be relayed are employed to modulate an FM transmitter<sup>9</sup> having a 70-Mc center frequency and an output power of approximately 20 milliwatts. As indicated in the block diagram, Fig. 12-26, all channels are routed through a centralized jack field for patching,

<sup>9</sup> Chaffee, J. G., and J. B. Maggio, Frequency-modulation Terminal Equipment for Transcontinental Relay System, *Elec. Eng.*, Vol. 70, No. 70, p. 880 (October, 1951).

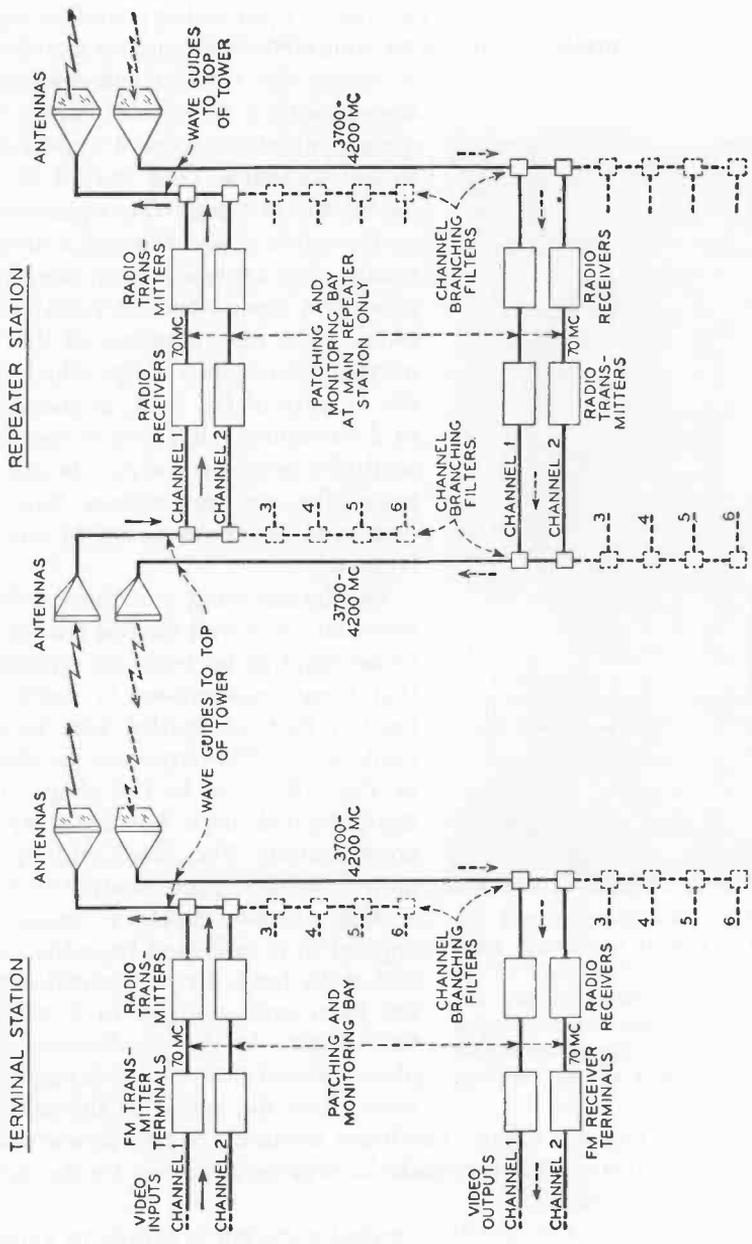


FIG. 12-26. Block diagrams of the transmitting and receiving equipment at both terminal and repeater stations of a microwave radio relay system.

switching, testing, and monitoring purposes. Upon being passed along to their respective transmitters, the 70-Mc intermediate-frequency signals are raised to microwave frequencies by mixing the intermediate-frequency signals with a microwave carrier frequency obtained from a crystal-controlled oscillator. The output of the modulator in which this operation is performed is passed through a filter to remove one sideband before being applied to a three-stage microwave amplifier. The output power of the last microwave amplifier stage, which is in the vicinity of 0.5 watt, is connected to a branching filter which serves to multiplex onto one waveguide and antenna the six transmitters that are employed for transmission in one direction.

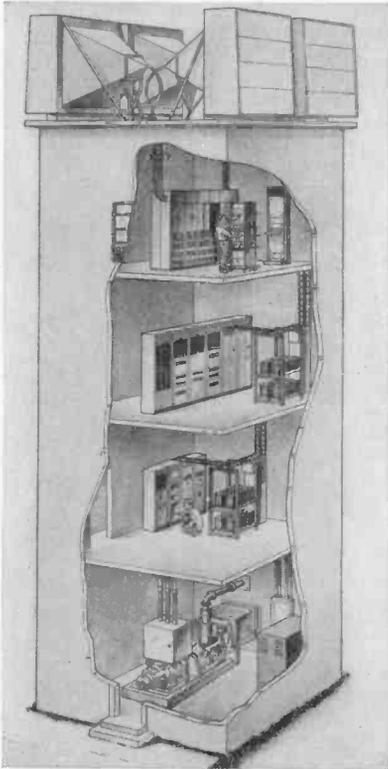


FIG. 12-27. This sketch shows the layout of a typical microwave relay station with its metal-lens type of antennas on the roof, the receiving and transmitting equipment on the upper floors, and the primary power supply on the ground floor of the building.

The transmitting and the receiving antennas employed for this service are broad-band metal lens-type structures that focus microwaves in much the fashion that an optical lens focuses light beams. The structure, as shown in Fig. 12-27, is in the shape of a straight-sided horn having a square cross section. The large end of the horn measures approximately 10 ft on a side. Radio-frequency energy is applied to or collected from the small end of the horn. Strips of metal within the horn are arranged in a manner that results in the production of a plane wavefront by delaying the waves near the center of the antenna

relative to those near the edges. The beam width at the half-power points of the antenna illustrated is just under 2 degrees as shown by the directivity pattern (Fig. 12-28).

Since the function of an auxiliary repeater station is simply to amplify the received energy and to direct it on the next leg of its journey, it is the practice in most signal transmission systems to take the incoming signals, amplify them directly, and pass them on. In microwave systems,

however, the amount of gain required cannot be readily achieved at microwave frequencies, and it is more efficient to go through the process of converting the microwave signals to an intermediate frequency for amplification purposes and then back to microwave frequencies for transmission to the next repeater. Therefore, after being routed to the proper channel by means of a branching filter (see (Fig. 12-26), each signal is converted back to a 70-Mc intermediate frequency by means of a heterodyning system that mixes the incoming signal with the output of a microwave oscillator. An automatic-gain-control system to compensate for transmission vagaries, aging vacuum tubes, and other variables is incorporated in the equipment.

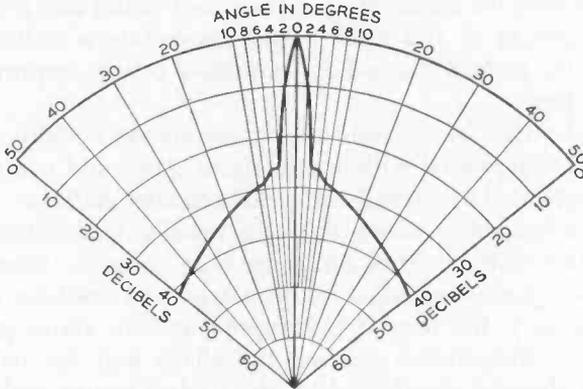


FIG. 12-28. Radiation pattern of a lens-type microwave antenna.

At auxiliary repeater stations, the 70-Mc intermediate-frequency signal is applied to a microwave transmitter in a manner analogous to that employed at terminal stations, as described above. At main repeater stations, the 70-Mc signals are made available for testing, monitoring, and switching through a jack field, similar to that employed at terminal stations. In either case, the microwave channel frequencies are normally shifted 40 Mc before being retransmitted to the next repeater location. At main repeater stations, however, provisions are made for patching the output of any receiving channel to any transmitting channel, should this become necessary, in order to free certain channels from service for testing or maintenance purposes.

The receiving equipment at terminal stations is shown in the lower left portion of Fig. 12-26. Here, in addition to channel branching filters and receivers similar to those employed at repeater stations, provisions are made for converting the 70-Mc intermediate-frequency signals back to

their original video frequencies. The output of the frequency-modulated receivers that are employed to perform this operation is connected to television program switching and distributing equipment or to telephone carrier equipment where the microwave relay system is being employed for telephone service.

The microwave relay system described does not make provisions for carrying the audio portion of a television program along with the video signal. Rather, the sound portion must be transmitted by facilities regularly available for handling broadcasting audio material. In general, in order to maintain the same velocity of propagation for both the visual and the aural portions of a television program, it is necessary to employ carrier transmission facilities for the audio signals. The microwave relay system could be employed for transmitting a combined sound and picture signal, but an arrangement of this kind would necessitate a reduction in the bandwidth of the picture channel and would, of course, require additional terminal facilities.

Just as in the case of coaxial cable transmission systems, microwave relay systems are provided with an elaborate alarm and control facilities to protect unattended or partially attended repeater stations. The system employs audio-frequency tones that are usually transmitted from the protected station to the control center by wire circuits. When an alarm condition arises (including failure of the alarm tone oscillator or the interconnecting circuit), the tone is interrupted and an alarm given at the control center. The station sending the alarm and the nature of the difficulty may then be ascertained by the control center with the aid of keyed audio pulses employing equipment similar to that described in Sec. 12-5, *Protective Devices*. A maximum of 42 indications can be sent back to the control center from an unattended microwave repeater station, and the control center can send a maximum of 10 remote-control orders to each of 12 unattended repeater stations.

**12-9. Terminal Facilities.** Regardless of whether coaxial cable or radio relay channels are employed for the intercity transmission of television program material, terminal facilities are required for switching and monitoring both the picture and the sound portions of the program material, for routine measurements of circuit performance, and for locating and clearing trouble when it occurs. Television switching centers<sup>10</sup> to provide the facilities for these and other activities are located in cities where television network service is available. The equipment employed at these centers may include (a) amplifiers and accessories for equalizing and

<sup>10</sup> Lewis, H. A., *Operating Control of Television Networks*, *Bell Labs. Record*, Vol. 27, No. 3, p. 99 (March, 1949).

adjusting the transmission level on the various local incoming and outgoing audio and video loops, (b) patching bays where both the local and the intercity audio and video circuits appear for routing to control positions, (c) control positions where each network is monitored and switched, (d) audio and video distribution amplifiers, and (e) order wire facilities for quick communication within the control center to various points along the television networks and to the broadcasting stations.

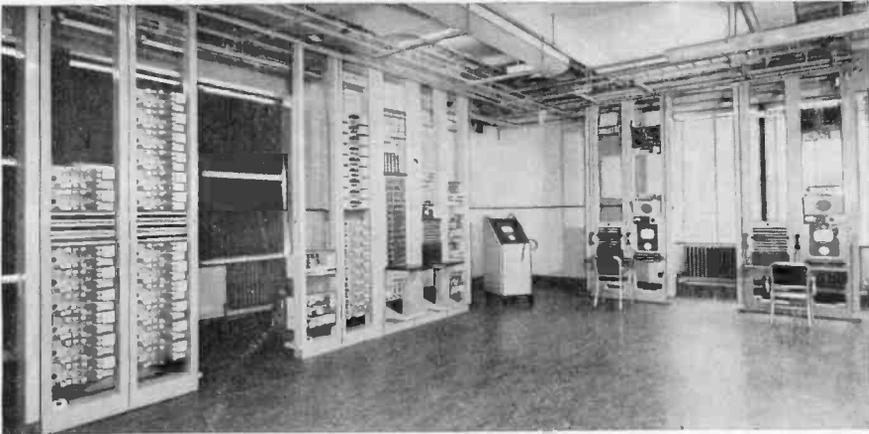


FIG. 12-29. Television network terminal switching center at Philadelphia. (Courtesy of Bell Telephone Laboratories, Inc.)

The extent of the facilities in any given city depends, of course, upon local needs. Those installed in one city are shown in Fig. 12-29. Here, the control positions are located at the right, while the remainder of the associated equipment is contained in the racks at the left. Incoming and outgoing video channels, both local and intercity, with necessary video amplifiers and associated equipment, are terminated on jacks in the video patching rack which is the third from the right in the group of five racks shown at the center of the illustration. Incoming and outgoing audio channels, both local and intercity, appear on jacks in the second rack from the right of the same group. On these jack fields, there are also audio and video trunks running to the control positions. Double patching is therefore required. Incoming circuits are first patched to a control position, and the trunks from the control position are then patched to the proper outgoing circuit. This is illustrated in Fig. 12-30 which is a simplified block schematic diagram showing typical patching arrangements at a switching center. The incoming audio and video circuits from station A are shown patched at the patching bay to a control position. There

they are patched to video distribution amplifiers and audio program amplifiers to obtain the desired number of outgoing feeds which appear at the control position. In the illustration there are two regular audio and video outgoing circuits established and, in addition, a spare feed for both.

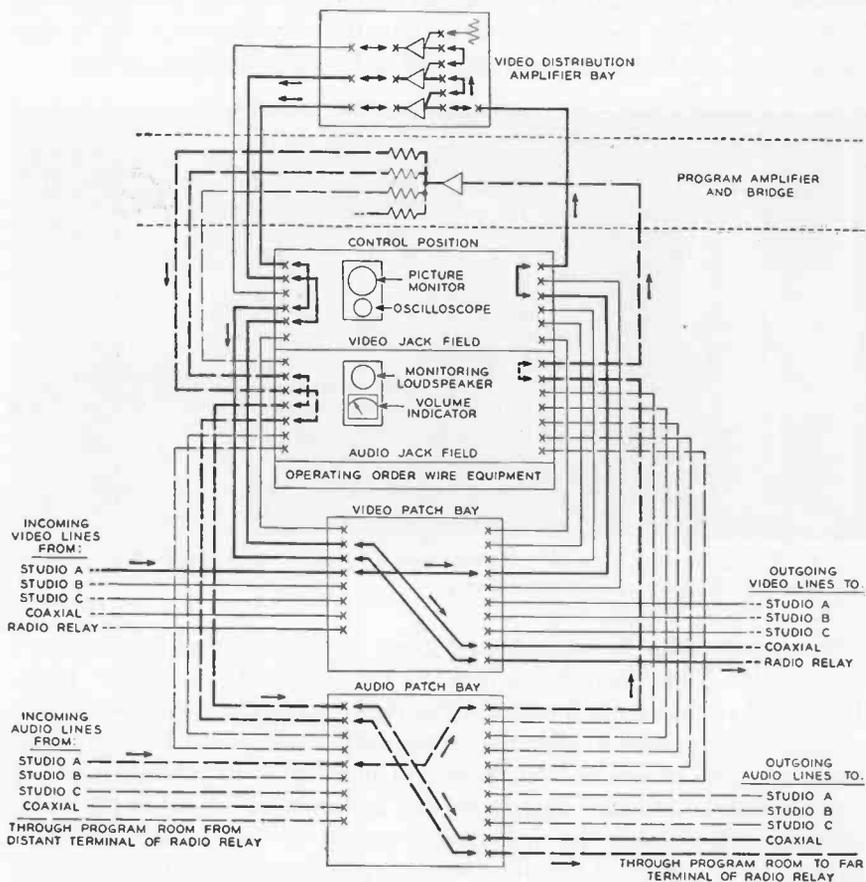


FIG. 12-30. Simplified schematic diagram of the patching arrangement used at a television network terminal switching center.

At the control position, these outgoing feeds are patched back to the main patching racks where, through additional patches, they are routed to the outgoing coaxial or radio relay circuits. As contrasted to broadcasting station practice, all video circuits are of 110-ohm impedance and balanced to ground.

Often, several program distribution arrangements, similar to the one illustrated, are set up in advance at the main patching panels. Then,

upon cue or at a predetermined time, the final patches are made at the control position to obtain the desired transmission paths.

In addition to the necessary audio and video jack fields, each control position contains a picture and waveform monitor similar to those described in Sec. 6-8, a standard volume indicator,<sup>11</sup> and a loudspeaker for monitoring the audio portion of the television program.

<sup>11</sup> Chinn, H. A., D. K. Gannett, and R. M. Morris, A New Standard Volume Indicator and Reference Level, *Proc. IRE*, Vol. 28, No. 1, p. 1 (January, 1940).

# Television Transmitters

A TELEVISION TRANSMITTER consists, in reality, of two complete transmitters: one for the picture signal, the other for the accompanying sound. Several systems have been proposed<sup>1</sup> and demonstrated for combining the two services onto one carrier, but none of these have been reduced to commercial practice. Consequently, a television broadcasting-transmitting station consists of an amplitude-modulated visual transmitter, a completely independent frequency-modulated aural transmitter, and various auxiliary facilities including antenna and transmission line systems, power-supply units, water cooling equipment (sometimes), r-f filters, audio and video terminal and measuring equipment, and allied components.

In the following sections the manner in which television stations are classified by government regulation in the United States is described, together with channel assignments in both v-h-f and the u-h-f portions of the frequency spectrum. The nature of the vestigial sideband transmission which is standard for visual transmitters is then explained, and the manner whereby it is attained in practice is described. The antenna systems and associated transmission lines in general use are also described, as is the method employed for multiplexing a picture and a sound transmitter on a common antenna system. The significance of negative transmission and the advantages of d-c restoration in visual transmitters are discussed, and typical picture and sound transmitters described.

**13-1. Station Allocation Principles.** The television broadcasting bands authorized by government regulations are located in two parts of the radio-frequency spectrum. One is in the v-h-f region and extends from 54 to 216 Mc; the second is in the u-h-f region and extends from 470 to 890 Mc. The v-h-f band is shared with other services and contains only twelve 6-Mc-wide television channels. The u-h-f band, on the other hand, is divided into 70 contiguous 6-Mc-wide channels. The v-h-f channels are numbered from 2 through 13 and the u-h-f channels from 14 through 83.

<sup>1</sup> Fredendall, G. L., K. Schlesinger, and A. C. Schroeder, Transmission of Television Sound on the Picture Carrier, *Proc. IRE*, Vol. 34, No. 2, p. 49P (February, 1946).

At one time the region between 48 and 54 Mc was designated as channel No. 1, but it was subsequently withdrawn from television service, without, however, renumbering the remaining channels. All v-h-f and u-h-f channels are assigned to commercial or to noncommercial educational television service. Table 13-1 summarizes the frequency allocation plan described.

TABLE 13-1. TELEVISION CHANNEL ASSIGNMENTS

Channel numbers	Frequency band	Frequency range (Mc)	No. of channels in group
2- 6	V-h-f, low-band	54- 88	5
7-13	V-h-f, high-band	174-216	7
14-83	U-h-f	470-890	70

**Channel Assignments.** The 12 v-h-f channels and the 70 u-h-f channels are assigned to the cities of the United States and its territories in accordance with a plan that adheres to a series of technical considerations designed to provide the maximum amount of interference-free service possible with the number of channels available. Some cities have only v-h-f channels, others have only u-h-f channels, and many have an intermixture of both.

**Allocation Rules.** The rules and regulations under which channel assignments are determined are rather extensive.<sup>2</sup> The basic considerations involved are presented below in order to indicate the general nature of the philosophy that governs the frequency allocation plan.

The fundamental objective of any allocation plan is, of course, to provide the maximum amount of useful coverage with the channels available. This entails, among other things, the avoidance of interference to a station within its service area from stations on the same and on other channels. Furthermore, in making television channels assignments, due consideration must be given to the avoidance of interference that may be caused by (a) picture-channel image frequencies, (b) sound-channel image frequencies, (c) radiation from the local oscillator of one receiver interfering with reception by another receiver, (d) intermodulation of two or more strong signals, and (e) two stations whose frequency difference equals the intermediate frequency used in a receiver.

*Co-channel interference, i.e.,* interference between stations on the same channel, is guarded against by maintaining a specified minimum separation between stations on the same channel. In recognition of the differ-

<sup>2</sup> Rules and Regulations of the Federal Communications Commission, U.S. Government Printing Office, Washington, D.C.

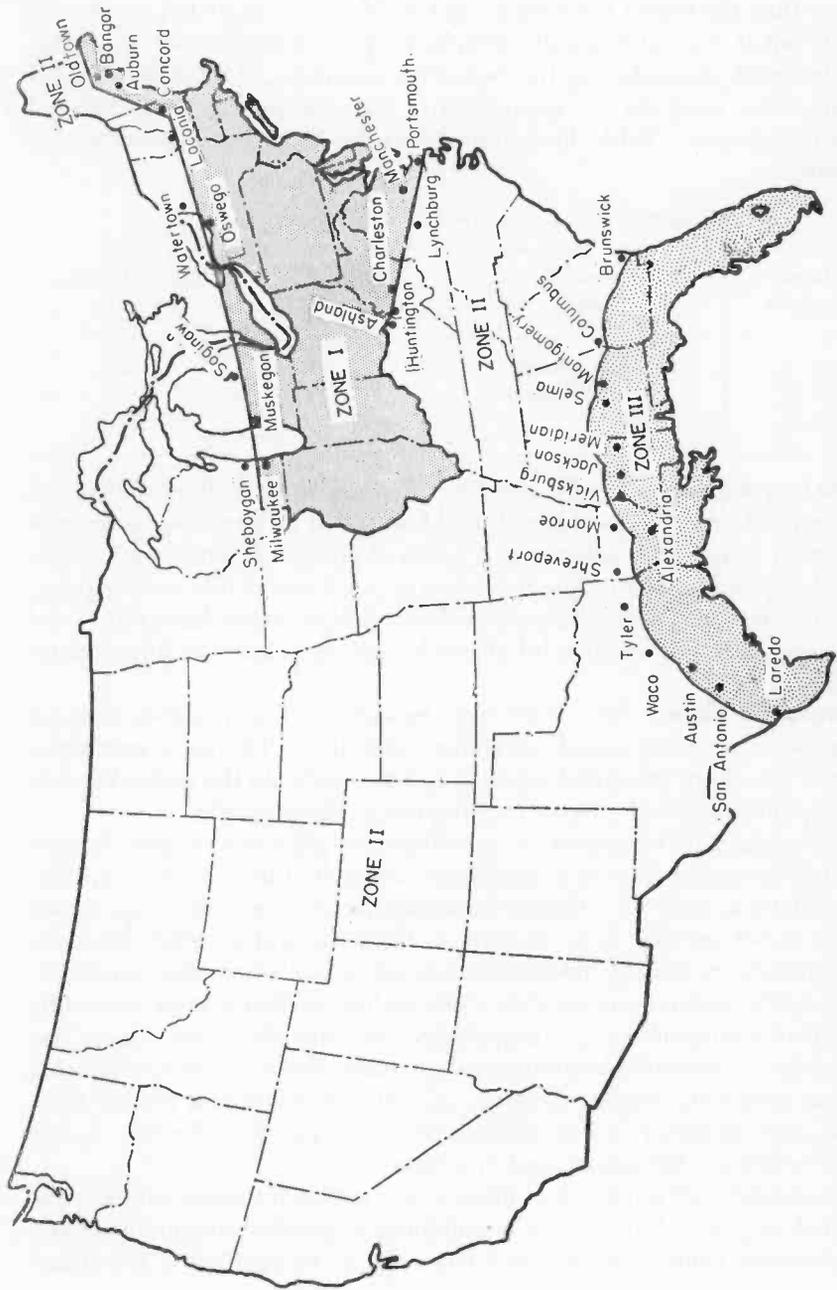


FIG. 13-1. In recognition of the differences in population density and the amount of tropospheric propagation, the country is divided into three zones, as shown, for television station channel allocation purposes.

ence in population density and in the amount of tropospheric propagation that exists in various parts of the country, different station separations are required in different parts of the country. For convenience in specifying minimum separations for co-channel stations, the country has been divided into three zones as shown in Fig. 13-1. Zone I, where the density of the population is the ruling factor, extends roughly from the Atlantic coast on the east to the Mississippi River on the west and from the Ohio River on the south to the 43.5 degree parallel on the north. Zone II includes all parts of the country not in Zones I and III. Zone III, where tropospheric propagation is the consideration, is roughly that area of the country within 150 miles of the Gulf of Mexico coast line. The minimum permissible separations between stations on the same channel are given in Table 13-2 for both v-h-f and u-h-f assignments. These separations are based upon the use of offset carrier frequencies which greatly reduce the interference between stations operating on the same channel. In both the v-h-f and the u-h-f bands, the carriers of adjacent stations in the same channel are offset from each other by plus or minus 10 kc. The operation of adjacent co-channel transmitters in this manner has been found to reduce the so-called "venetian blind" type of interference by a factor of 17 db.

TABLE 13-2. MINIMUM CO-CHANNEL AND ADJACENT CHANNEL STATION SEPARATIONS IN MILES

Zone *	V-h-f channels (2-13)		U-h-f channels (14-83)	
	Co-channel stations	Adjacent channel stations	Co-channel stations	Adjacent channel stations
I	170	60	155	55
II	190	60	175	55
III	220	60	205	55

\* See Fig. 13-1 for the boundaries of the zones.

*Adjacent channel interference* potentialities are taken into consideration by requiring adjacent channel separation between stations as given in Table 13-2. In this instance the spacings are the same for all zones but are different for the v-h-f and u-h-f channels, viz., 60 and 55 miles, respectively.

*Image-frequency interference* is not a problem in the v-h-f band since, normally, there is not another carrier removed from the desired one by twice the intermediate frequency (assuming the use of the industry stand-

ard 41.25-Mc intermediate frequency). In the u-h-f band on the other hand, the large number of contiguous channels presents the possibility of image-frequency interference. Consequently, in the u-h-f band, assignments are made upon the basis of maintaining a separation of at least 75 miles between stations that are 15 channels apart and 60 miles between stations 14 channels apart in order to avoid picture-image interference and sound-image interference, respectively.

*Receiver oscillator radiation interference* is avoided in the v-h-f band by those receivers employing the industry standard intermediate frequency of 41.25 Mc (although older receivers, employing 21-Mc intermediate frequencies, are potential offenders). In the u-h-f band, on the other hand, local oscillator radiation from one receiver may interfere with the reception of a second receiver that is tuned to a station seven channels removed from the one to which the first receiver is adjusted. Cognizance is taken of this possibility in the allocation of the u-h-f channels by maintaining a minimum separation of 60 miles between stations seven channels removed.

*Intermodulation interference* has not been a problem in the v-h-f television band, but steps must be taken to guard against it in the u-h-f band. This type of interference is created when the signals from two transmitters combine in some nonlinear element to form an interfering signal that falls within the acceptance band of a receiver. In television receivers, this type of interference is sometimes encountered when a strong undesired signal combines with a desired signal in the first detector and creates a beat frequency that falls within the pass band of the intermediate-frequency amplifier. Steps are, therefore, taken to avoid this type of interference by requiring a separation of more than 20 miles between stations that are assigned frequencies less than 6 channels apart.

*Intermediate-frequency beat interference* may be created when the signals from two stations combine to form a beat frequency which can be picked up directly by the intermediate-frequency amplifier in a receiver. Where a 41.25-Mc intermediate frequency is used, spurious signals of this type may be created by stations that are seven or eight channels away from the desired station. Since stations seven channels removed are separated by at least 60 miles to avoid local oscillator interference as set forth above, there is no danger of intermediate-frequency beat interference from this source. However, to guard against the possibility of stations separated by eight channels creating intermediate-frequency interference, it is required that they be separated geographically by at least 20 miles.

The seven minimum spacings enumerated above are summarized in Table 13-3, together with a listing of the channels concerned. In the

v-h-f band only the stations on three channels are involved in any given instance: the two immediately adjacent channels and the channel in question. In the u-h-f portion of the spectrum, however, when consideration is given to the assignment of a specific channel, the disposition of stations on as many as 19 channels may have a bearing upon the problem. This is illustrated by the last column of Table 13-3 where it is assumed that a station on channel No. 40 is of interest. As shown, the assignment of channel No. 40 to a given location immediately places restrictions upon the geographical locations of stations on channels 25, 26, 32, 33, 35 through 45, 47, 48, 54, and 55. Nevertheless, in spite of the interdependence of channel assignments, it is estimated that the 82 channels available are capable of accommodating more than 2,000 stations in approximately 1,300 communities throughout the country.

TABLE 13-3. MINIMUM STATION SEPARATION AS A FUNCTION OF CHANNEL ASSIGNMENT

Controlling type of interference	Channels involved	Minimum transmitter spacing (miles)		Typical example (channel No.)
		V-h-f	U-h-f	
Co-channel . . . . .	Same	170-220 *	155-205 °	40
Adjacent channel . . . . .	Adjacent	60	55	39 and 41
Picture-image frequency	±15 channels	. . . .	75	55 and 25
Sound-image frequency	±14 channels	. . . .	60	54 and 26
Receiver oscillator . . . . .	±7 channels	. . . .	60	47 and 33
Intermodulation . . . . .	±1 to 5 channels	. . . .	20	41-45 and 35-39
Intermediate-frequency beat . . . . .	±8 channels	. . . .	20	48 and 32

\* Depending upon zone (see Table 13-2).

**Grades of Service.** Two types of service, known as grade A service and grade B service, are authorized in the United States and its territories. Grade A service is so specified that a quality acceptable to the median observer is expected to be available for at least 90 per cent of the time at the best 70 per cent of receiver locations at the outer limits of this service. Grade B service on the other hand is expected to deliver an equal amount of service but to only 50 per cent of the receiver locations.

The two grades of service that are recognized are defined as shown in Table 13-4. The first part of this table gives the required median field strength in decibels above a field intensity of 1 microvolt per meter. For grade A service, the required field intensity for high-band v-h-f stations

is 3 db above, or 1.4 times, that of low-band stations. Furthermore, u-h-f stations are required to produce a field intensity 6 db above, or twice, that of low-band v-h-f stations. For grade B service, the required field strengths are considerably lower than that for grade A service, and the differentials are not the same.

The second part of Table 13-4 shows the permissible ratios between the median field intensity of the desired signal and the field intensities of the strongest undesired signals existing for 10 per cent of the time.

TABLE 13-4. GRADES OF TELEVISION SERVICE  
a. Required Median Field Strengths above 1 Microvolt per Meter

Grade of service	Channels 2 to 6	Channels 7 to 13	Channels 14 to 83
A	68 db	71 db	74 db
B	47 db	56 db	64 db

b. Permissible Co-channel Ratios of Median Desired to Highest Undesired Field Strength Existing for 10 per cent of the Time, Assuming Offset Carrier Operation

Grade of service	Channels 2 to 13	Channels 14 to 83
A	34 db	36 db
B	28 db	28 db

A zero decibel or 1-to-1 ratio is permitted between the median desired and undesired (adjacent channel) field intensities for both grades of service and for both the v-h-f and the u-h-f bands. In areas where equal signal intensities exist on both the desired and the adjacent channels, reliance must be placed completely upon receiver selectivity to discriminate against the undesired signals.

The television station separations, carrier powers, and antenna heights required by government regulation take into account the establishment of the grades of service described above.

**Directional Antennas.** It is common practice in AM broadcasting to employ directional antennas in order to avoid interference to stations located on the same and adjacent channels. The many stipulations that govern the assignment of television channels suggest the possibility of employing directional transmitting antennas to cope with some of the potential sources of interference and also to direct the bulk of the radiation toward populated areas and away from oceans, deserts, and other

unpopulated regions in those places where the geography is such as to favor this type of operation.

In television, however, the employment of directional antennas poses several problems not usually encountered in AM broadcasting. For example, television signals are in those portions of the frequency spectrum where waves are easily reflected by both man-made and geological features. Thus the problem of predicting the actual performance of a directional television transmitting antenna is a major one since it is dependent not only upon the directional properties of the radiator but also upon the reflections that will be experienced in practice. The detrimental effects of reflections may well become particularly obnoxious in directions of deep nulls in the radiation pattern of the transmitting antenna. If this should occur and if the nulls were originally planned so as to protect another television station in the direction of the null, the desired protection may not be realized.

A second problem peculiar to television transmitters, but not usually encountered with AM broadcasting installations, is the desirability of locating the television station within the city it serves rather than on its outskirts. When directional antennas are contemplated, there is often less flexibility in selecting antenna sites, particularly when it is also borne in mind that the creation of a hazard to aircraft must be avoided. Thus, to the extent that directional antenna sites are located away from cities, the problems of multipath distortion and shadows tend to increase.

Because of these and associated problems, applicable regulations contemplate the employment of directional transmitting antennas in television only in certain situations in order that a unique site may be used or for improvement of over-all service from a particular station. The use of a directional antenna does not permit noncompliance with normal service area requirements or a reduction in the basic service area. Furthermore, the use of a directional antenna having a null more than 10 db down is not permitted because of the difficulties mentioned above of predicting the performance in the presence of reflections. Finally, under no circumstances are directional transmitting antennas permitted for the purpose of reducing the minimum station separations detailed in the foregoing section. In other words, directional antennas are not countenanced for the purpose of making a channel available in a location where it would otherwise not be possible to employ the channel in question.

**13-2. Carrier Powers and Antenna Heights.** In order to provide the grades of service described in the preceding section, both lower and upper limits are placed upon the power radiated by a television broadcasting station. In both instances, the limits are set forth in terms of the effective radiated power (actual radiated power multiplied by the power gain of

the antenna) at a specified transmitting antenna height. The minimum power requirements on this basis, as a function of the population of the city in question, are given in Table 13-5. The antenna heights given are above average terrain, and the power associated therewith is for the purpose of establishing the service radius that must be attained for each size of city by both v-h-f and u-h-f stations. Where higher or lower antenna sites are used, the effective radiated power must be adjusted accordingly in order to establish a grade A service radius equal to that attained by the example cited. Although no minimum antenna height is specified in the regulations, high antennas are favored since studies show that increased antenna heights are much more advantageous than increased power.

TABLE 13-5. MINIMUM AND MAXIMUM POWER REQUIREMENTS  
a. Minimum Power Requirements

<i>Population of city, excluding adjacent metropolitan areas</i>	<i>Minimum effective radiated power * (kw)</i>	<i>Antenna height * (ft)</i>
1,000,000 and above	50	500
250,000-1,000,000	10	500
50,000-250,000	2	500
Under 50,000	1	300

\* Or equivalent (see text).

b. Maximum Power Limitations

<i>Antenna height (ft. above average terrain)</i>	<i>Zone I power levels (kw)</i>			<i>Zones II and III power levels (kw)</i>		
	<i>Channels</i>			<i>Channels</i>		
	2-6	7-13	14-83	2-6	7-13	14-83
Up to 1,000	100	316	1,000	100	316	1,000
1,200	54	170	1,000	100	316	1,000
1,400	33	102	1,000	100	316	1,000
1,600	21	67	1,000	100	316	1,000
1,800	14.5	45	1,000	100	316	1,000
2,000	10	32	1,000	100	316	1,000
2,500	4.8	15	700	70	215	700
3,000	2.6	8.4	500	50	160	500
4,000	1.0	3.3	300	30	95	300
5,000	1.0	1.6	210	21	68	210

The maximum effective radiated power that is authorized is also given in Table 13-5. Although minimum power requirements are the same for both v-h-f and u-h-f stations varying only with the size of the city, maximum power limitations are the same for all size cities but vary with channel assignments. The maximum permissible carrier powers are specified upon the basis of equalizing, as nearly as practical, the grade B service range of stations in the various bands and, thus, effectively utilizing the available spectrum space.

From the foregoing, it is seen that to provide comparable grade B service, a station in the high v-h-f band requires 3.16 times as much effective radiated power as a station in the low v-h-f band, assuming the same antenna height. Similarly a u-h-f station requires a tenfold effective power increase over a low-band v-h-f station. This is not so great a burden as it may first appear since the higher effective radiated power requirements of the higher frequency stations may, to a large extent, be obtained by higher gain antennas and higher towers, both of which are easier to construct for the higher frequency assignments than for the lower frequency (longer wavelength) channels.

As shown in Table 13-5 the antenna heights above average terrain associated with the maximum power limitations are different in zone I from those in zones II and III. This results from consideration of the fact that in zone I station separations are lower than in zones II and III and the cities themselves are closer together. Because of this, the v-h-f stations in zone I are permitted antenna heights only up to 1,000 ft above average terrain when using maximum power, whereas u-h-f stations in this zone, and all stations in zones II and III, may use antenna heights of 2,000 ft with maximum power. However, this limitation does not prohibit the employment of higher antennas. As a matter of fact, the use of higher antennas is encouraged although, where this is done, the maximum permissible power must be reduced as shown in Table 13-5 in order to avoid undue interference to co-channel and adjacent channel stations. However, the required power reductions are not such as to cause the loss of all the benefits afforded by antenna sites of more than 2,000 ft above average terrain.

In this instance the specific combination of effective radiated power and antenna height that is given has a different significance than in the case of minimum power requirements. First, where the antenna height is less than 500 ft, the effective radiated power is *not* permitted to exceed the value listed: 100 kw for low-band v-h-f and 316 kw for high-band v-h-f and 1000 kw for u-h-f channels. Next, to improve the quality of service, the use of antennas higher than 500 ft above the average terrain is encouraged. However, if an antenna height greater than 500 ft is used, the effec-

tive radiated power is limited to that value which will avoid interference with the grade A service radius of any other station, whether existing or provided for in the official table of assignments. The grade A service radius of the latter station is determined upon the basis of its operating at the maximum permissible effective radiated power and with a 500-ft antenna. In many instances, however, stations that might be subjected to interference when the height of a transmitting antenna is increased beyond 500 ft are geographically so far away that it becomes unnecessary, for any practical antenna height, to reduce the effective radiated power below the maximum permitted. Thus, for example, many of the stations utilizing the antenna structure on the top of the Empire State Building in New York, which reaches a height of 1,465 ft, can employ the maximum authorized power without interfering with the grade A service area of any other stations.

**13-3. Vestigial Sideband Transmission.** Amplitude modulation is employed for television picture transmission for the reasons outlined in Sec. 1-16. However, unlike the double-sideband amplitude-modulated transmission commonly employed for convention aural broadcasting purposes, television picture transmission is undertaken with a type of single sideband modulation. The use of single sideband techniques for television transmissions is a very valuable technique since it makes possible more efficient use of the available frequency spectrum than would be the case if double sideband transmission were employed. Or, looked at from another standpoint, single sideband picture transmission permits the transmission of a greater amount of intelligence (in the form of greater detail) in a channel of given width.

As is well known, in the normal process of amplitude-modulating a carrier, two sidebands, an upper and a lower one, are generated. Both of these sidebands contain the same information so that the elimination of one may be undertaken without affecting the extent of the information transmitted. The sideband energy is halved, of course, but in so far as the inherent content and resolution of a television picture are concerned, the transmission of one sideband causes no degradation. The loss in sideband energy will cause a reduction in the signal-to-noise ratio at the receiver, but this can be compensated for by increasing the energy in the single sideband that is transmitted. On the other hand, for a picture of given resolution, single sideband transmission results in a reduction of the required channel width by a factor of almost 2 and, at the same time, effects economies in receiver manufacture by permitting the use of i-f amplifiers having narrower bandwidths and higher gain per stage. The process introduces certain practical problems, however, particularly at the transmitting end of the system.

As already mentioned, the conventional method of amplitude modulation inherently creates two sidebands. Therefore, in single sideband transmission the undesired sideband must be suppressed before the modulated carrier is radiated. It is customary to effect elimination of the undesired sideband by the use of tuned circuits or by filters. However, since the transmission and phase shift characteristics of practical circuit ele-

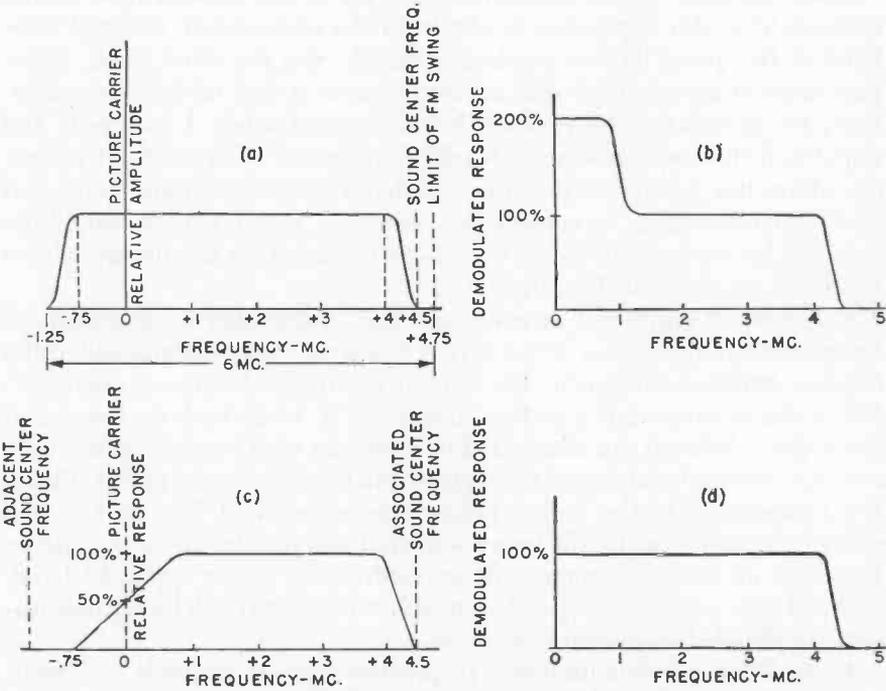


FIG. 13-2. Vestigial sideband picture transmission standards are shown at (a). The total sideband energy transmitted by this system is shown at (b). By employing a receiver having a response characteristic as shown at (c), the total received energy may be made uniform throughout the frequency band of interest, as shown at (d).

ments are not ideal, it is not feasible to completely discard one sideband and retain the other without causing undesirable phase shifts among components of the signal adjacent to the cutoff frequency. Therefore, as a practical matter, the cutoff frequency of the sideband elimination filter is *not* placed at the carrier frequency but rather at a sufficient distance away from the carrier, in the direction of the unwanted sideband, as shown in Fig. 13-2a, so as to avoid the possibility of introducing phase shifts in the components of the desired sideband. Since this system results in the transmission of all of the desired sideband, plus a portion of the undesired

sideband, it is known as a vestigial sideband transmission system. Examination of Fig. 13-2*a* shows that neither the carrier nor the upper sideband of the television picture signal is attenuated. Likewise the lower sideband is transmitted unattenuated at frequencies close to the carrier but is rather abruptly attenuated at a sufficient distance from the carrier so as to avoid phase shifts of the components in the vicinity of the carrier.

Since the same phase shift problem exists in the circuits used in the receiver, it is also impossible to eliminate the unnecessary vestigial sideband at this point by any practical method. On the other hand, if the pass band of the receiver were made the same as that of the transmitter, then, for modulation frequencies below approximately 1 Mc, both the upper and the lower sidebands would be received whereas, for frequencies above this point, only the upper sideband would contribute to the end result. Under these circumstances, twice as much energy would be received for components in the 0- to 1-Mc region as for frequencies above this band, as shown in Fig. 13-2*b*.

The method employed to overcome this undesirable accentuation of components in the region of the carrier frequency is sometimes called the receiver attenuation system. By utilizing a response-frequency characteristic in the receiver similar to that shown in Fig. 13-2*c* both the lower and the upper sidebands are attenuated in a manner which results in the total received energy being equal throughout the band as shown in Fig. 13-2*d*. For components in the region below approximately 1 Mc, part of the energy is contributed by the lower sideband and part by the upper; above this point, all received components are contributed by the upper sideband. The methods employed in practice to achieve vestigial sideband transmission are detailed in following sections.

**13-4. Sideband Attenuation.** In practice various methods of attenuating the undesirable sideband may be used. Where a low-level modulation system is employed, advantage may be taken of the existence of a number of tuned circuits in the broad-band linear r-f amplifier stages that are required in order to obtain the desired output power. By tuning each amplifier stage off-center by exactly the right amount, the over-all response can be adjusted to provide the desired attenuation of the lower sideband while maintaining the required pass band for the upper sideband. An advantage of this mode of operation is the ability to adjust the transmitter for operation on any channel within its tuning range. A practical embodiment of this principle is described in Sec. 13-10.

A second method of achieving the desired sideband attenuation is to employ a filter<sup>3</sup> between the output of the modulated stage in the trans-

<sup>3</sup> Brown, G. H., A Vestigial Side-band Filter for Use with a Television Transmitter, *RCA Rev.*, Vol. V, No. 3, p. 301 (January, 1941).

mitter and the load into which this stage operates. This method lends itself to use with transmitters employing high-level modulation systems since these do not employ a multiplicity of tuned circuits that can be individually tuned off-center. However, the achievement of the entire attenuation in one filter places a severe requirement upon the unit both as to its response-frequency characteristic and its power-handling capacity. The former design restriction makes it necessary to custom-build each filter for a particular operating frequency; consequently, a vestigial sideband filter designed for one channel cannot be simply readjusted for use on another channel. The latter design restriction (*i.e.*, power-handling capacity) and other considerations sometimes make it advisable to employ a vestigial sideband filter between a modulated driver stage and a class B linear amplifier output stage rather than directly between the output of a transmitter and its associated antenna. Among other things, this arrangement permits the sideband filter to operate at a lower power level and thereby places less stringent requirements upon its power-handling capacity.

The appearance of a typical vestigial sideband filter for the v-h-f television band is shown in Fig. 13-3. This unit, which is intended for use with visual transmitters having peak power outputs of 5 kw or less, is approximately 3 ft wide, 3½ ft deep, and 7 ft high and weighs almost ¾ ton. Vestigial sideband filters for u-h-f television transmitters are considerably smaller, of course.

Electrically, the sideband filter may be a combination of two *m*-derived filters connected in parallel, as shown in Fig. 13-4*a*. The upper arm of the filter is a conventional half-section, high-pass, *m*-derived filter which is so designed as to permit transmission of the upper sideband and the desired portion of the lower sideband, as shown in Fig. 13-2*a*. The lower arm of the filter is a half-section low-pass *m*-derived filter that passes the



FIG. 13-3. A vestigial sideband filter for the low-frequency v-h-f channels. (Courtesy of Radio Corporation of America.)

undesired portion of the lower sideband and absorbs the energy in a resistor whose value is such as to terminate the filter correctly and to prevent reflections. Incidentally, not a great deal of energy need be dissipated by this resistor compared to peak power output of a transmitter. Both because of the duty cycle of a television signal and because of the relatively small amount of energy usually found in the high-frequency components (which are the ones diverted to the resistor load), less than 100 watts is likely to be involved in a transmitter having a peak output power of 5 kw.

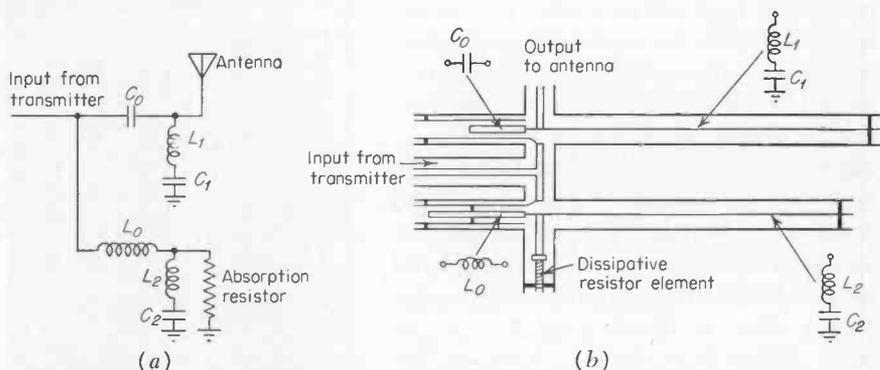


FIG. 13-4. (a) Equivalent circuit of a vestigial sideband filter with lumped circuit constants representing the coaxial transmission line elements actually used, as shown by the schematic drawing (b).

A vestigial sideband filter, because of its location in a transmitting system, usually must operate at relatively high power levels and, in addition, is subject to relatively high peak voltages. For this reason construction of the filter with conventional lumped constants presents some design problems. Fortunately, because of the high frequencies involved, these can be overcome by the use of transmission line sections to simulate the inductive and capacitive elements that are required. As is well known, transmission lines shorter than one-quarter wavelength present a capacitance reactance, while those longer than one-quarter wavelength present an inductive reactance. Resonant quarter-wave lines, on the other hand, may be used to simulate series-tuned elements such as those shown in the shunt filter arms,  $L_1C_1$  and  $L_2C_2$  of Fig. 13-4a. Accordingly, the configuration of a vestigial sideband filter employing coaxial transmission lines might take the form shown in Fig. 13-4b, the elements shown being those necessary to create a filter of the type presented in Fig. 13-4a. In practice, a somewhat more elaborate filter arrangement is often used, as shown in Fig. 13-5. This is basically the same type of filter as described above

with added sections in order to more nearly approach idealized transmission characteristics.

In addition to a vestigial sideband of the type illustrated, it is customary to include a so-called notch filter in the network branch that passes the desired sideband to the antenna. This notch filter is designed to supplement the characteristics of the vestigial sideband filter and provide additional attenuation at the frequency corresponding to the sound carrier of the adjacent lower frequency television channel.

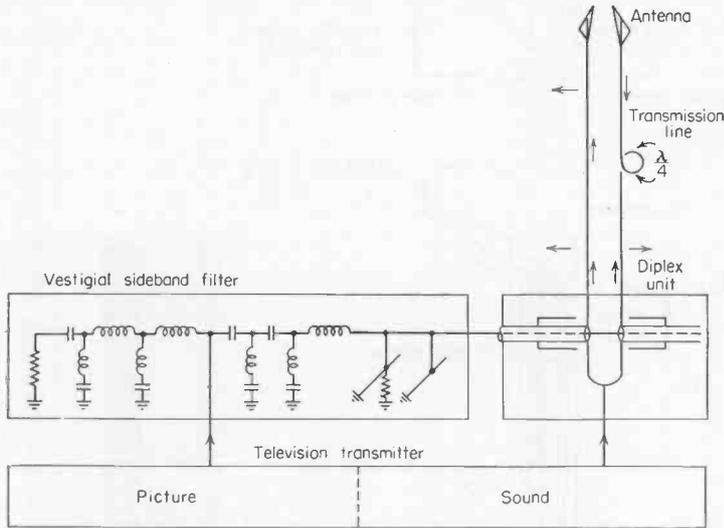


FIG. 13-5. Schematic circuit showing the relationships between a picture and a sound transmitter, a vestigial sideband filter, a diplexer unit, and transmission lines and antennas.

**13-5. Antenna Diplexer.** A unit that is often closely associated, circuit-wise, with the vestigial sideband filter is the antenna diplexer. This is a required component in television transmitting installations where a common antenna is used for both the visual and the aural transmissions. Its purpose is to combine the outputs of the visual and the aural transmitters into a single channel for transmission to the antenna without permitting either one to feed appreciable energy to the other. Another requirement that is often met by the diplexer unit, is feeding the two equal but separate loads that are commonly presented by the type of antenna systems used extensively for television transmitting purposes. Finally, for the reasons explained below, the diplexer is often called upon to convert the single-ended output of the visual transmitter to a double-ended or balanced-to-ground output.

A typical diplexer for the v-h-f television bands is shown in Fig. 13-6c. Like vestigial sideband filters, antenna diplexers must be built for specific operating frequencies. The unit illustrated is commonly used for v-h-f channels and is capable of handling 5 kw of power from both the aural and the visual transmitters. The physical size of the unit is a function of

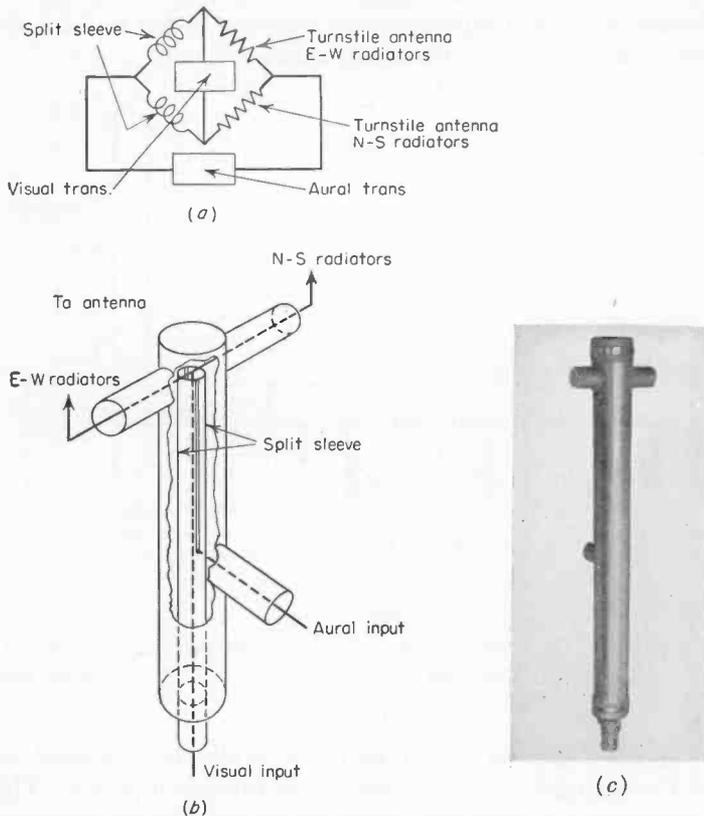


FIG. 13-6. A schematic diagram of the circuit employed in an antenna diplexer is shown at (a). An arrangement of the coaxial elements that duplicates this circuit arrangement is shown at (b). A photograph of an actual unit is shown at (c).

the channel for which it is designed. The main body of this diplexer is constructed of  $3\frac{1}{8}$ -in.-diameter copper tubing, and the over-all length ranges from about  $9\frac{1}{2}$  to 3 ft for units designed for channels 2 to 13. As is to be expected, for u-h-f applications very much smaller diplexer units can be constructed.

The diplexer illustrated makes use of the well-known Wheatstone bridge principle in order to achieve the desired isolation between the

two transmitter inputs. This arrangement also lends itself to symmetrically feeding the two identical loads that are often presented by the television transmitting antennas (see Sec. 13-6). As shown in Fig. 13-6*a*, the output of the visual transmitter is applied across one pair of bridge points while that of the aural transmitter is applied to the other pair. The two antenna feeds constitute two adjoining arms of the bridge while suitable circuit elements, in the form of split sleeves, make up the bridge arms opposite the antennas. When the arms of the bridge are in perfect balance, any energy applied to one pair of bridge points does not appear at the other pair. Therefore, by carefully balancing the bridge arms, none of the output of the visual transmitter will appear across the output terminals of the aural transmitter, and vice versa.

Examination of Fig. 13-6*a* reveals that the antenna load presented to the aural transmitter is unbalanced-to-ground or single-ended, whereas that of the visual transmitter is balanced-to-ground or double-ended. The output of each transmitter is normally single-ended; consequently, that of the visual transmitter must be converted to accommodate the double-ended or symmetrical load. This is accomplished with a balun, a device for converting a *BAL*anced circuit to an *UN*balanced one (or vice versa); hence the name.

One form taken by a balun in a diplexer is illustrated in Fig. 13-7*a*. As shown, the generator is connected to the single-ended input to the device, which, by proper proportioning of the elements of the balun, is able to accommodate the double-ended antenna load at *A* and *B*. The equivalent circuit of the balun is shown in Fig. 13-7*b* with circuit notations corresponding to those in Fig. 13-7*a*.

The television antenna diplexer may be connected to the antenna and the aural and visual transmitters, as shown in Fig. 13-5. The vestigial sideband filter with its associated notch filter is inserted between the visual transmitter and the input to the diplexer as indicated in the figure.

**13-6. Transmitting Antennas.** Television transmitting antennas are called upon to meet a large number of exacting requirements in both the electrical and mechanical categories. Of the electrical considerations, the more important ones include (*a*) horizontal polarization of the radiated waves, (*b*) a bandwidth of at least 6 Mc, (*c*) an omnidirectional or circular radiation pattern in the horizontal plane, (*d*) sufficient gain or directivity in the vertical plane to permit attainment of required effective radiated power with reasonable transmitter output power, and (*e*) adequate insulation to handle the peak voltages that will be applied to the unit. Mechanically, the requirements include (*a*) structural strength to withstand anticipated wind, snow, and sleet loads, (*b*) sleet-melting facilities where sleet is likely to be encountered, (*c*) low wind resistance to

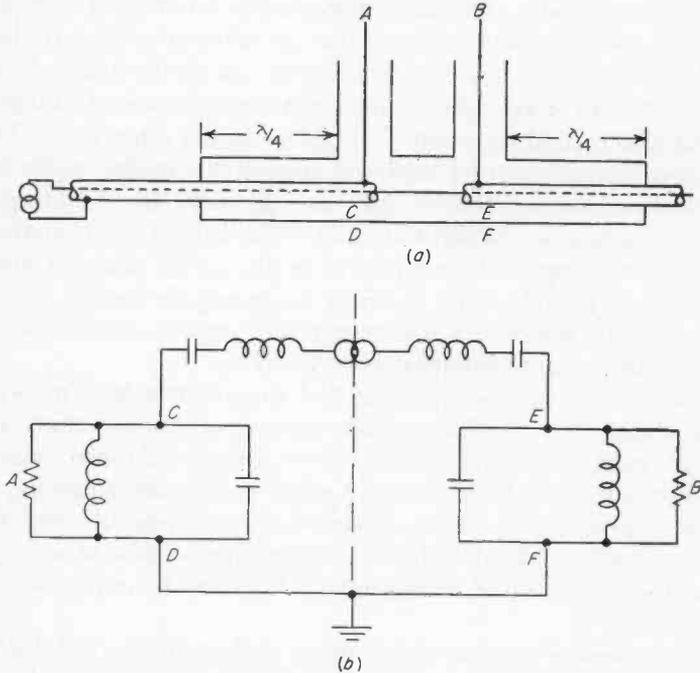


FIG. 13-7. A balun (*i.e.*, a device for converting a *balanced* to an *unbalanced* circuit, or vice versa) composed of coaxial elements is shown at (a), while the equivalent circuit in terms of lumped circuit constants is shown at (b).

minimize structural requirements of supporting towers, (d) immunity to damage from lightning, and (e) ease of erection.

**V-h-f and U-h-f Transmitting Antennas.** Transmitting antennas for the v-h-f television channels, 54 to 88 Mc and 174 to 216 Mc, commonly consist of a number of individual antenna elements arranged in an array suitable for obtaining the desired bandwidth, gain, and directivity pattern. The individual radiating elements are excited by a branching-type feeder system, the number of branches usually being at least equal to the number of antenna elements. Turnstile and screen-backed dipole antennas are commonly used for this service and, for the higher frequency v-h-f channels, gains of twenty times or less are employed in practice. For the lower frequency channels the size of the antenna system in a vertical direction limits the maximum gain that it is practical to obtain. This stems from the relation that exists between the distance from the highest to the lowest radiator and the height of the antenna system, as a whole, above the surrounding terrain. If the antenna system were erected in free space (*i.e.*, a very long distance from the earth), the addition of layers of radia-

tors, properly spaced, would increase the gain in proportion to the number of layers. In actual practice, however, with an antenna mast of a given height, the addition of antenna layers brings the lowermost antennas closer and closer to the ground. As the ground is approached, the radiating elements contribute less and less to the effectiveness of the antenna.

On the other hand, there are limits to tower heights beyond which it is not practical to go for both structural and economic reasons. In general, the limiting condition, beyond which no additional gain is realized, exists when the distance from the ground to the center of the radiating system is about twice the distance between the lowest and the highest radiators. For a channel 2 antenna having a gain of about twenty times, a mast height of about 350 ft would be required for the antenna system itself, and the top of the mast would have to be at least 900 ft above ground if the afore-mentioned conditions were to be met. For this and other reasons (*e.g.*, structural and economic), antenna gains of this magnitude are not generally employed for the low-frequency v-h-f channels; rather the gain is usually limited to ten times or less.

The extension of v-h-f antenna practice to the u-h-f field is not generally followed because of the higher gains desired and the resulting complexity of the feeder system when a large number of elements are employed. In addition, the higher frequencies and the corresponding shorter wavelengths lend themselves to other approaches. Slotted and helical antennas have been developed, therefore, for u-h-f applications with considerably simplified transmission-line feeding systems. In the following paragraphs two typical v-h-f television transmitting antennas are described together with two u-h-f units.

**Turnstile Antenna.** One type of antenna which has proved very satisfactory in practice and which is in widespread use in v-h-f band applications is the so-called superturnstile antenna (Fig. 13-8). The evolution of the turnstile antenna can be traced from slot radiation theory with the aid of Fig. 13-9. Two parallel conductors, each a half wavelength long, short-circuited at the ends and fed by a generator at their centers are

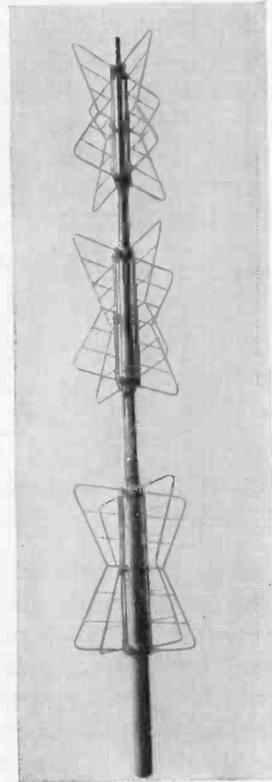


FIG. 13-8. A superturnstile transmitting antenna designed for v-h-f television channel use. (*Courtesy of Radio Corporation of America.*)

shown in Fig. 13-9*a*. This configuration results in a voltage wave being set up as shown by the dotted line. However, if the spacing between the wires is small compared to a wavelength, negligible radiation will take place. In Fig. 13-9*b*, the two conductors are assumed to have become the edges of a slot in a large conducting sheet. The voltage distribution is the same as that shown previously, but in this case currents will flow horizontally so that radiation will take place from both the front and the back of the sheet. Because of radiation resistance, the magnitude of the current rapidly decreases with distance from the slot and becomes negligible at distances of about one-quarter wavelength from the slot. Accordingly, it is possible to limit the extent of the sheet to a one-quarter wavelength, as shown in Fig. 13-9*c*, without materially affecting the radiation from the slot.

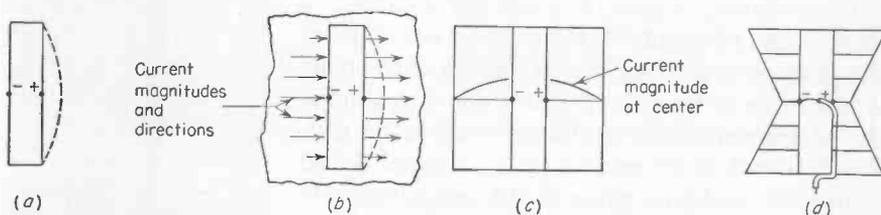


FIG. 13-9. The evolution of the turnstile antenna may be traced with the aid of these sketches.

This unit makes an effective radiator with several desirable properties including (*a*) the ability to ground, for supporting purposes, the zero potential mid-points at either end of the slot and (*b*) vertical and horizontal radiation patterns and impedance characteristics that closely approach those of a dipole. However, by taking advantage of the vertical dimension of the sheet radiator, even more desirable characteristics can be obtained. If the width of the sheet is reduced at the center, as shown in Fig. 13-9*d*, the current flow in the middle section will be reduced or, more to the point, the current at the top and the bottom will become relatively greater than that at the center. As a result, the vertical radiation pattern becomes more nearly that of two horizontal dipoles spaced a half wavelength apart vertically. At the same time, the impedance characteristic is broadened so that it is nearly constant over a wide range of frequencies. Finally, to reduce wind resistance, an open construction, such as shown in Fig. 13-8, may be used without altering the electrical characteristics of the antenna, provided the spaces are small compared to a wavelength.

Coaxial transmission lines may be used to feed an antenna of the type described by connecting the center conductor to one side of the antenna

and the outer conductor to the other, as shown in Fig. 13-9*d*. The transmission line can then be run down along the slot and onto the supporting mast at either the upper or the lower mid-point without the need for any insulation or isolating device.

By mounting two turnstile antennas at right angles to each other (see Fig. 13-8) and feeding one antenna 90 degrees out of phase with the other, the figure 8 pattern that is typical of a single dipole becomes essentially circular or nondirectional in the horizontal plane. The manner in which east-west and north-south antennas (or any pair at right angles to each other) may be fed is shown in Fig. 13-5 where it will be noted that one transmission line is made a quarter of a wavelength longer than the other in order to obtain the necessary 90-degree phase shift in one set of antennas with respect to the other.

Several layers of turnstile antennas can be stacked on a pole, as shown in Fig. 13-8 to achieve moderate values of gain. One layer has a gain of approximately 1.2 times over that of a half-wave dipole, consequently two layers will have a gain of about 2.4 times, four layers about 4.8 times, and six layers (the maximum usually found in practice) a gain of approximately 7 times. The number of turnstile antennas that can be stacked is usually limited by structural considerations. Although six sections for the high-frequency v-h-f channels require a pole only about 40 ft above the top of a tower or building, a similar number of sections for a low-frequency channel would occupy approximately 100 ft of pole. Since there are practical limits to the height of unguied poles carrying structures subject to wind, snow, and sleet loads, it is not generally feasible to carry the stacking of turnstile antennas beyond the limits indicated. Further, it will be recalled, the turnstile antenna is basically a slot radiator, and the slot cannot be arbitrarily widened to accommodate a larger diameter mast.

**Screen-backed Dipole Antenna.** Under the circumstances outlined in the preceding paragraph, if higher gains are required, resort must be made to types of antenna structures that lend themselves to mounting on tower-type structures having three or more corner legs and associated bracing members. One type of antenna which has proved itself satisfactory for this type of construction is shown in Fig. 13-10. This is basically a dipole antenna, mounted in front of a ground screen, but with the shape of the dipole modified so as to achieve a bandwidth greater than that normally obtained with a dipole and commensurate with the requirements of television transmitting antennas.<sup>4</sup>

The reflecting screen narrows the pattern of each dipole radiator in the vertical plane and, in addition, keeps the radiation out of the tower, *i.e.*,

<sup>4</sup> Gihring, H. E., Practical Considerations in the Use of Television Super Turnstile and Super-gain Antennas, *RCA Rev.*, Vol. 12, No. 2, p. 159 (June, 1951).

prevents coupling between the antenna and the tower or objects therein. If the antennas are mounted on the four sides of a square tower, as shown, and fed in the proper phase relationships, a circular radiation pattern can be obtained. However, in an installation of this type, a tower must be employed which has a uniform cross section (at least over the portion supporting the antenna elements); furthermore, the width of the tower should be equal to a one-half wavelength.

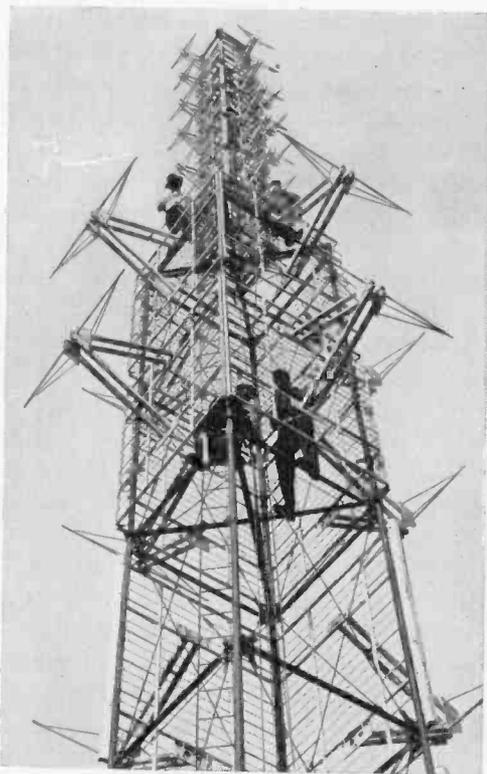


FIG. 13-10. Two screen-backed dipole antenna systems in the process of erection on a common mast. (Courtesy of Radio Corporation of America.)

If, for some special application, a directional rather than a nondirectional pattern is required, the dipoles may be fed with different phase relationships or used in a configuration other than a square or both.

In any event, in order to sharpen the vertical pattern and thereby achieve a gain in the amount of energy radiated in a horizontal direction, the screen-backed dipoles may be stacked in layers, with vertical spacing between dipoles of slightly less than one wavelength. Under these

circumstances, electrical excitation may be undertaken with transmission lines, all of equal length, joining all east-west antennas to one junction box and all north-south units to another. Two transmission lines may then be run from the two junction boxes to the transmitters (via a diplexer) just as for turnstile antennas.

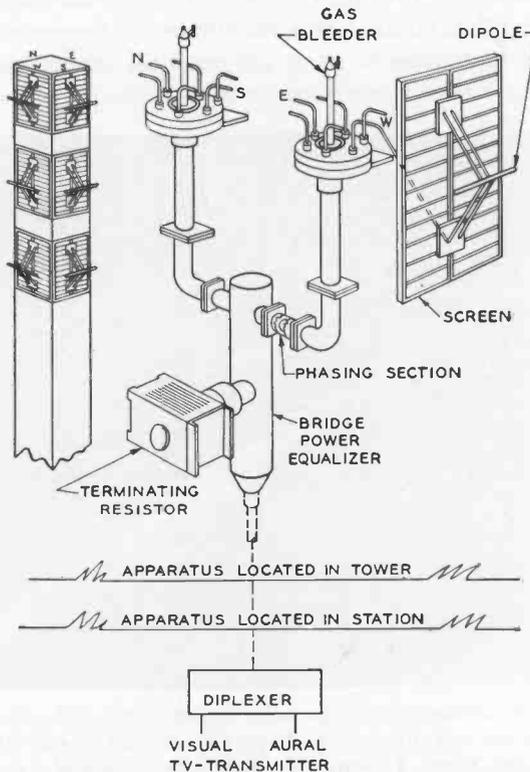


FIG. 13-11. One method of feeding a screen-backed dipole, a turnstile, or similar antenna system which requires only one transmission line from the diplexer to the antenna system.

An alternate method of feeding the screen-backed dipole antennas (which principle is applicable also to turnstile units) is shown in Fig. 13-11. In this arrangement, only one transmission line is required from the diplexer (presumably located in the station building adjacent to the transmitters) to the antenna system. For antennas on high towers, this latter arrangement can result in a considerable saving in transmission line. At the antenna end of the transmission line, a bridge circuit, similar to that used in the diplexer (see Fig. 13-6) is employed for the dual purpose

of diverting the power from the single transmission line to the antennas and for equalizing the amounts of power fed to each group of antennas.<sup>5</sup>

**Slot-type Antenna.** Because of the greater difficulty of developing a given amount of power at the ultrahigh frequencies as compared to the very-high frequencies, greater antenna gains are generally desirable for the latter applications. Fortunately, since the physical length corresponding to a wavelength is considerably smaller in the former case than in the latter, relatively high antenna gains are practical at ultrahigh frequencies without resort to unreasonable antenna dimensions.

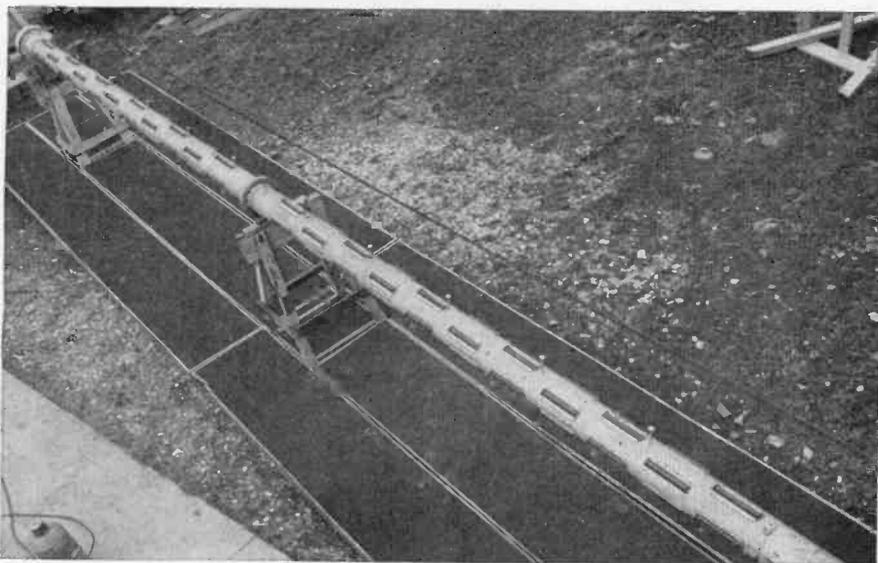


FIG. 13-12. A slot antenna suitable for u-h-f transmission applications laid out over a ground plane for test and adjustment. In practice the antenna is mounted vertically on top of an antenna mast. (Courtesy of Radio Corporation of America.)

However, multielement antennas similar in design to those employed for v-h-f applications require an unreasonable number of transmission line branches when a sufficient number of elements are used to obtain gains of twenty times or more. For example, a multielement antenna of conventional design with this amount of gain would require about 90 transmission line branches. On the other hand, the slot antenna shown in Fig. 13-12 is one type that has been developed to avoid multitudinous transmission line branches.<sup>6</sup>

<sup>5</sup> Masters, R. W., A Power-equalizing Network for Antennas, *Proc. IRE*, Vol. 35, No. 7, p. 735 (July, 1947).

<sup>6</sup> Fiet, O. O., UHF Antenna System for TV Transmission, *RCA Rev.*, Vol. 11, No. 2, p. 212 (June, 1950).

The particular antenna illustrated is designed for operation at approximately 530 Mc and consists of a steel tube having a  $10\frac{3}{4}$ -in. outside diameter and a  $\frac{1}{2}$ -in.-thick wall. Two tubes, each 20 ft long, are joined together by means of flanges to form the complete unit. The radiator consists of a series of one-half wavelength slots, four to a layer, equally spaced around the perimeter of the tube. Successive layers of slots are spaced approximately one wavelength between the centers of the slots. Each layer of slots is rotated 45 degrees with respect to the preceding layer in order to achieve an omnidirectional pattern in the horizontal plane. The antenna illustrated has a total of 22 layers or 88 slots distributed along its length.

Radio-frequency power is applied to the slots by means of a  $3\frac{1}{8}$ -in.-diameter copper tube mounted coaxially within the outer steel tube. Probes fastened on the inside of the steel tube and oriented toward the central conductor serve to excite the slots. Probes are fastened to the inside of the steel tube at the center of each slot along one of its edges. The current passing through the probe capacitance passes through the driving point impedance of each radiating slot and thereby excites the antenna. To achieve the required broad banding, an additional set of radial probes is inserted between each layer of slots.

In order to avoid any tilt or other dissymmetry in the vertical directional pattern with small changes in operating frequency (as would be the case with an end-fed array), the antenna system as a whole is driven from its center point. Radio-frequency power from the transmitter is carried to this driving point by means of a coaxial transmission line which, within the antenna, is formed by placing an inner conductor in the lower half of the  $3\frac{1}{8}$ -in. copper tube already in the center of the slotted steel tube. Should it be desirable, because of the nature of terrain, to tilt the vertical pattern of the antenna, this may be accomplished by shifting the feed point from the center of the array, thereby producing a phase difference between the currents in the upper and the lower halves of the antenna.

The measured gain of the particular u-h-f slot antenna described, when operating at approximately 530 Mc, is slightly in excess of seventeen times. As is the case for any high-gain omnidirectional antenna, the vertical radiation pattern is very sharp, the bulk of the radiated energy being confined to a beam a few degrees wide.

**Helical Antenna.** The helical antenna<sup>7</sup> is another approach to the problem of obtaining a high-gain antenna for u-h-f applications while avoiding a multiplicity of transmission line branches for feeding separate antenna elements. The antenna system shown in Fig. 13-13 employs as

<sup>7</sup> Krause, L. O., Sidefire Helix UHF-TV Transmitting Antenna, *Electronics*, Vol. 24, No. 8, p. 107 (August, 1951).

the basic radiating element a helical conductor, supported by a centrally located metallic mast, each turn of the helix being two wavelengths in circumference. The antenna is excited by a radiation-attenuated traveling-wave helical current, only one feed point being used for a five-wavelength-long antenna bay.

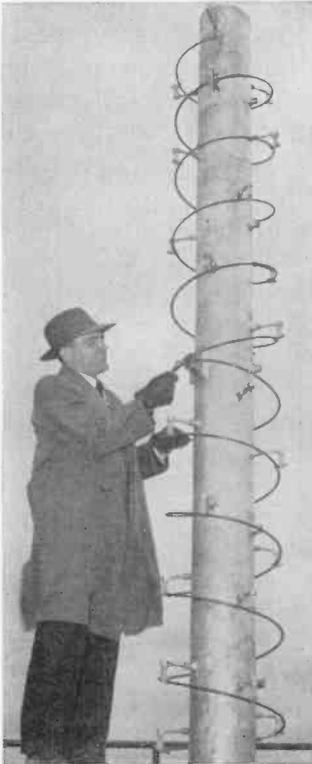


FIG. 13-13. One bay of a helical antenna designed for u-h-f television applications. (Courtesy of General Electric Company.)

The far end of the helical conductor may be either open or short-circuited with negligible effects from reflections since only a very small amount of energy reaches the end point of the antenna, the bulk of it having been radiated en route. Thus the entire length of the helix serves both as a radiator and as a feeder for successive portions of the antenna.

In order to achieve the desired radiation pattern, the pitch and diameter of the helix are carefully controlled so that the currents at like points in each turn of the helix are in phase. This is accomplished by making each turn an integral number of wavelengths as measured at the velocity of propagation along the helix.

Horizontal polarization is achieved by virtue of the fact that the bulk of the traveling wave of current is represented by its horizontal component. Such vertically polarized radiation as does occur (a small vertical component is inevitable because of the pitch of the helix) may be largely canceled out by employing the helices in pairs, each pair consisting of a right- and a left-hand helix, placed end to end and fed at the junction.

The antenna shown in Fig. 13-13 is a portion of a four-bay helical antenna system that produces a power gain of twenty times. Antenna systems of this type, designed to handle a total power input of 50 kw, permit achievement of the 1,000 kw of effective radiated power that u-h-f television stations are permitted to radiate. The beam width of the vertical pattern for an antenna gain of twenty times is about 2.5 degrees between half-power points while for a gain of ten times a beam width of about 6 degrees is realized.

**13-7. Transmission Lines.** Coaxial transmission lines are used almost exclusively for transferring r-f power from one unit of a television transmitter to another, from the final r-f power amplifier to the vestigial side-band filter (if used), the diplexer, the harmonic filters (if employed), the antenna and to similar circuit elements. Coaxial transmission lines are manufactured in a number of sizes and shapes to accommodate many different power and installation requirements. In addition, various fittings and accessories are available to meet the needs encountered in practice.

TABLE 13-6. COAXIAL TRANSMISSION LINES  
(Characteristic impedance = 50 ohms)

Size (in.)	a. Power capabilities (kw)					60-cycle flashover potential (volts r-m-s)
	50 Mc	100 Mc	200 Mc	500 Mc	1,000 Mc	
<i>Ceramic Insulation</i>						
1½	16	10	7	Not recom- mended	Not recom- mended	11,000
3½	64	42	27			18,000
6½	235	166	118			30,000
<i>Teflon Insulation</i>						
1½	20	11	7	6	4	...
3½	80	50	32	18	12	...
<i>b. Loss per 100 ft (db)</i>						
Size (in.)	50 Mc	100 Mc	200 Mc	500 Mc	1,000 Mc	
<i>Ceramic Insulation</i>						
1½	0.16	0.23	0.35	Not recom- mended	Not recom- mended	
3½	0.10	0.15	0.23			
6½	0.39	0.06	0.08			
<i>Teflon Insulation</i>						
1½	0.14	0.21	0.30	0.47	0.66	
3½	0.07	0.10	0.15	0.24	0.34	
6½	0.03	0.05	0.07	0.11	0.17	

**V-h-f Transmission Lines.** The standard impedance of coaxial transmission lines employed for television r-f applications is 50 ohms. The diameter of the transmission line employed for a specific application is a function of the operating frequency, the power-handling requirements, and the length of the line involved as related to the amount of loss that can be tolerated. The mechanical and electrical properties of several representative coaxial transmission lines are given in Table 13-6. The "size" of a

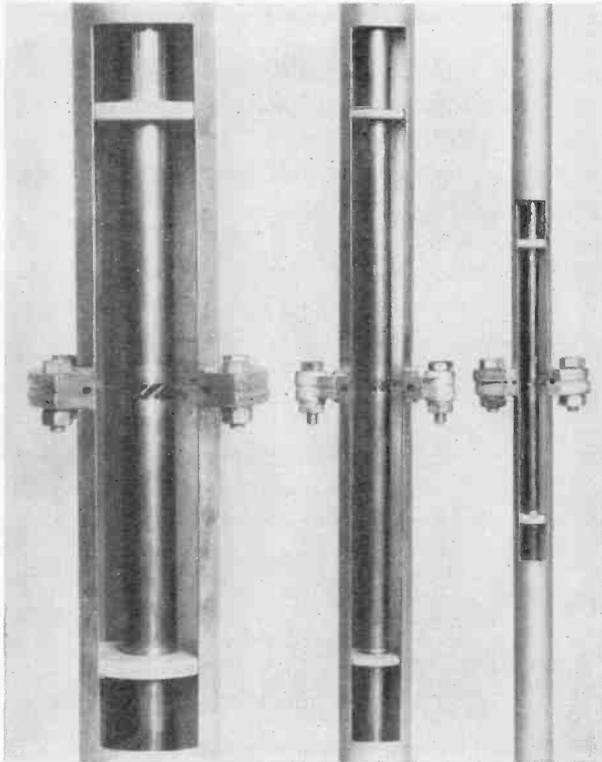


FIG. 13-14. Cutaway samples of  $\frac{7}{8}$ -,  $1\frac{1}{8}$ -, and  $3\frac{1}{8}$ -in.-diameter hard-tempered coaxial transmission lines showing the connection flanges, the inner conductors and their couplings, and the insulating wafers. (Courtesy of Communication Products Co.)

coaxial line is the outside diameter of the outer conductor which is usually made of copper tubing having a wall thickness commensurable with the diameter of the line and the service in which it is intended to be used. The power-handling capabilities given in the table (for several specific frequencies) are based upon a standing-wave ratio of unity. In practice, an adequate safety factor must be employed to account for other than an ideal standing-wave relationship. In this respect allowance must also be

made for abnormal standing-wave ratios that may be encountered during tuning-up procedures or as the result of the failure of some elements in the transmission system. Furthermore, the selection of a transmission line size may be influenced by expectations as to future power-handling needs as may be required by an authorized increase in transmitter carrier power.

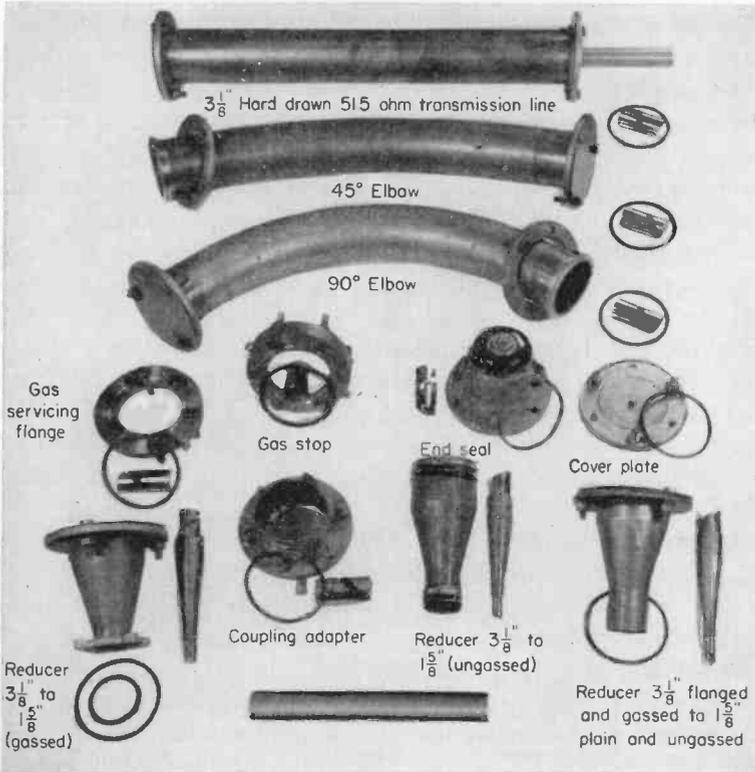


FIG. 13-15. A representative group of fittings of the type available for all standard sizes of transmission lines. (Courtesy of Communication Products Co.)

Coaxial transmission lines are made of both soft- and hard-tempered copper. The former is suitable for bending around obstructions without the need for employing elbows or other fittings, but sections of the line must be connected together and to equipment components by solder-type connections which do not lend themselves to ready disassembly for inspection and repair. On the other hand, hard-tempered transmission line (Fig. 13-14) may be obtained with connection flanges (usually silver soldered to the outer line) which permit the line and associated fittings to be readily bolted together. In addition a special solderless type of connector is available for connecting together the inner conductors of two

transmission lines. These connectors are of a spring-loaded type that permits the inner conductor to slide for a sufficient distance to compensate for line expansion and contraction, thus eliminating the need for special expansion joints. Representative fittings that may be obtained for use with flanged transmission lines are shown in Fig. 13-15.

It is common practice to operate coaxial transmission lines that are installed out of doors under pressure using either an inert, dry gas, such as nitrogen, or compressed dry air. Several advantages accrue from this practice including the maintenance of a dry atmosphere within the line thereby reducing the probability of a voltage breakdown or a reduction of the insulation resistance. Further, should a small leak develop in the line, the gas pressure will aid in preventing moisture from entering the line until repairs can be made. By means of suitable gauges or an automatic alarm system, warning may be given when the amount of gas escaping from the pressurized line is such as to indicate a leak of serious proportions.

Where nitrogen is used for pressurizing transmission lines, it is usual to obtain the gas in steel flasks or cylinders. These are available from commercial sources in containers that range from 5 to 200 cu ft in capacity. Where dry air is employed, it is common practice to install dehydrating equipment that is capable of delivering dried air in sufficient quantities to meet the needs.

**U-h-f Transmission Lines.** Transmission lines of the types described above, while entirely adequate for v-h-f service, are not usually satisfactory for u-h-f applications. The difficulty stems from the uniformly spaced ceramic insulators (usually 12 to 18 in. apart) that are employed to support the center conductor. At ultrahigh frequencies these wafers act as lumped shunting elements at equally spaced intervals and give the line a characteristic not unlike that of a wave filter with attenuation bands that fall within the u-h-f region. As with any filter configuration, the impedance fluctuates rapidly with frequency, particularly in the region of the cutoff frequency and, in fact, may be reactive over much of the u-h-f television band. A transmission line of this type is not suitable for television transmitting service where the standing-wave ratios must be held within narrow limits and where a nearly constant load resistance should be maintained over a relatively wide band of frequencies.

Several solutions to the problem have been proposed, and some of them placed into practice.<sup>8,9</sup> One method compensates for the shunt capaci-

<sup>8</sup> Comes, R. W., A Coaxial Line Support for 0-4000 Mc, *Proc. IRE*, Vol. 37, No. 1, p. 94 (January, 1949).

<sup>9</sup> Petersen, D. W., Notes on a Coaxial Line Bead, *Proc. IRE*, Vol. 37, No. 11, p. 1294 (November, 1949).

tance introduced by the insulating wafer by an ingenious mounting arrangement that creates a small series inductance. By carefully proportioning the amount of this series inductance with respect to the capacitance introduced by the insulating wafer, the impedance variations of the line can be reduced to a negligible minimum over a wide bandwidth. The constructional method employed to achieve this is shown in Fig. 13-16*a*. The insulating wafer is mounted in an undercut space in the center conductor, the configuration being such that the shunt capacitance  $C_{SH}$  of the insulator is counteracted by the added series inductance  $L_S$ .

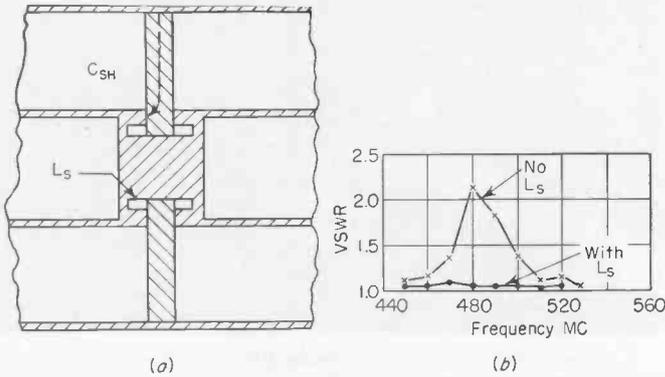


FIG. 13-16. At (a) there is detailed the construction of a coaxial transmission line that incorporates a small amount of added series inductance  $L_S$  to compensate for the lumped capacitance  $C_{SH}$  introduced by the insulating wafer. The standing-wave ratio in a portion of the u-h-f spectrum for a conventional and a compensated line is shown at (b). (After Cornes.)

This solution obviously requires a special type of inner conductor and presents certain construction complications. However, the effectiveness of the arrangement is shown by Fig. 13-16*b*, which charts the standing-wave ratio over almost a 100-Mc range in the u-h-f region for both a compensated and a noncompensated  $3\frac{1}{8}$ -in. transmission line.

Another solution to the problem is the employment of an insulating material for the wafers whose electrical properties are better fitted for u-h-f work than ceramic dielectrics. One suitable material is a tetrafluoroethylene resin plastic (trade-named Teflon) whose dielectric factor is only about one-third and its dissipation factor about one-tenth that of most ceramics. Furthermore, the material is arc-resistant, repellent to water, and practically unburnable and unbreakable.

The appearance of the *center* conductor of a Teflon-insulated transmission line intended for u-h-f applications is shown in Fig. 13-17. Such residual shunt capacitance as the Teflon wafer contributes is compen-

sated for by means of a radial or longitudinal depression (or both) in the inner conductor of the line which forms a compensating series inductance in the region of the Teflon support. Thus a transmission line having a very uniform impedance characteristic over a wide band of frequencies is achieved. The attenuation as a function of frequency and the power-handling capabilities of Teflon-insulated transmission lines of several sizes are given in Table 13-6.

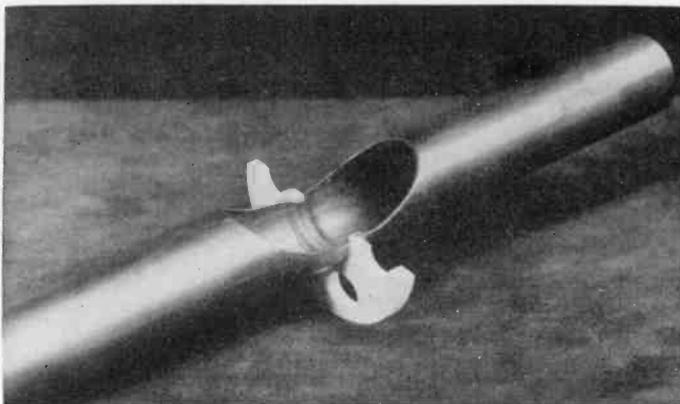


FIG. 13-17. A cutaway view of the inner conductor and supporting wafer of a coaxial transmission line showing another method of compensating for the lumped shunt capacitance introduced by the supporting dielectric. (Courtesy of Communication Products Co.)

**13-8. Negative Transmission.** The polarity of the video modulation of television transmitter carriers standard in the United States (and many other countries) is such that an *increase* in the picture brightness results in a *decrease* in the carrier amplitude. This method, termed "negative" transmission, is employed (rather than one wherein a signal in the white direction causes an increase in modulation) because of the advantages it offers, as detailed in Sec. 1-17.

The appearance of a negatively modulated television carrier is shown in Fig. 13-18. The waveforms at the left end are representative of those existing when an entirely black signal is being transmitted, as during the vertical blanking interval or whenever the picture signal is faded out to black. The waveforms in the center are representative of a typical picture signal containing whites, blacks, and intermediate grays. Finally, the waveforms on the right are those that exist when an all-white signal is being transmitted.

Examination of the figure shows that the maximum or peak carrier level is the same at all times and is determined by the amplitude of the syn-

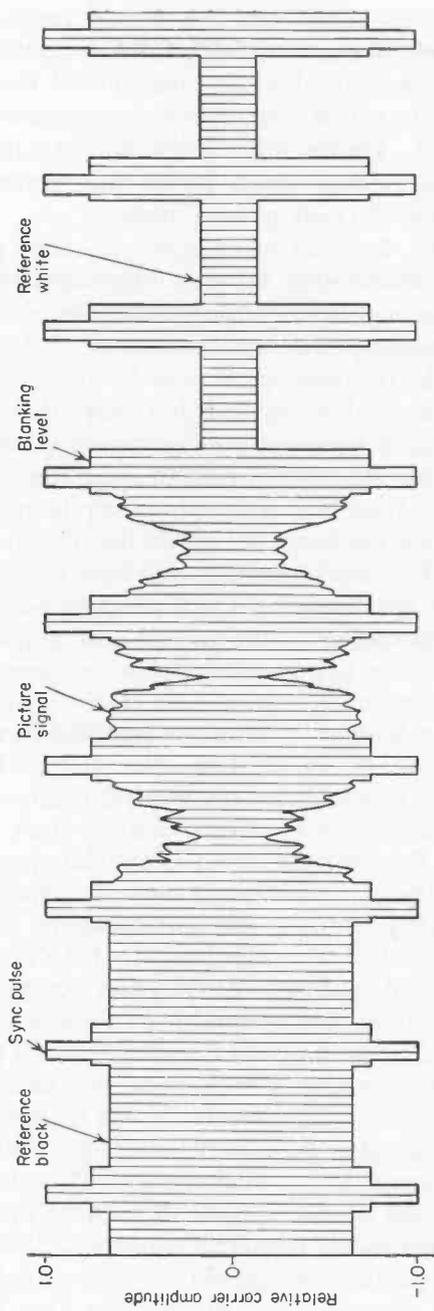


FIG. 13-18. The appearance of a negatively modulated television carrier showing how synchronizing pulse peak amplitudes correspond to maximum modulation levels and a reference white signal to the minimum modulation level permitted by government regulations.

chronizing pulses. On the other hand, the average carrier amplitude is a function of the kind of information that is being transmitted. As shown by the figure, when a black signal is being transmitted, the average carrier power is a maximum, the actual figure being approximately 60 per cent of the peak power output. On the other hand, when an all-white signal is being transmitted, the average carrier power is a minimum and in the vicinity of 15 per cent of the peak power output.

**13-9. D-c Insertion.** In addition to specifying the "polarity" of the transmission and the relationship between blanking level and peak r-f amplitude, government regulations stipulate that the blanking level shall always represent a specific power level, regardless of changes in the picture content. Since the relationship between blanking level and the synchronizing signal level is also specified, it follows that the tips of the synchronizing signals also represent a definite peak power level.

The regulation specifying maintenance of synchronizing signals at a fixed level results not from any peremptory requirement of television receivers but rather from the beneficial effects that this mode of operation has upon utilization of available power output from the transmitter. The process of bringing all synchronizing signal peaks to a common reference level (normally corresponding to the peak power output of the transmitter) amounts, of course, to reinserting the d-c component. When this is done, the effective power output of a given complement of transmitting tubes is approximately doubled. This stems from the fact that, when a-c transmission is practiced, the modulation level must be held sufficiently low for the transmitter to accommodate, without overloading, video signals whose peak intensities are constantly shifting from one side of the a-c axis to the other. For example, when an all-white background with a single vertical (or diagonal) black line is being transmitted, the appearance of waveform corresponding to one horizontal line may be as shown in Fig. 13-19*a*. In this illustration, the position of the a-c axis is approximately as shown by the dotted line. At the other extreme, the waveform corresponding to an all-black background with a single vertical (or diagonal) white line would be as shown in Fig. 13-19*b*. If a television visual transmitter were to be modulated with these two waveforms, without restoration of the d-c component, it would have to be capable of handling the maximum swing of either waveform both above and below the a-c axis. As shown, this amounts to a total swing of 15 units. On the other hand, examination of the two waveforms shows that the total swing of either waveform in itself is only 10 units. Therefore, if the d-c component is restored and, consequently, the tips of the synchronizing signals are all brought to a common reference level, as shown in Figs. 13-19*c* and 19*d*, then the transmitter's power-handling capabilities need be sufficient to han-

dle only the 10 units of amplitude inherent in either signal. The 15-to-10 ratio illustrated is on a voltage basis and, consequently, represents a power gain  $(15/10)^2$ , or somewhat in excess of 2 to 1.

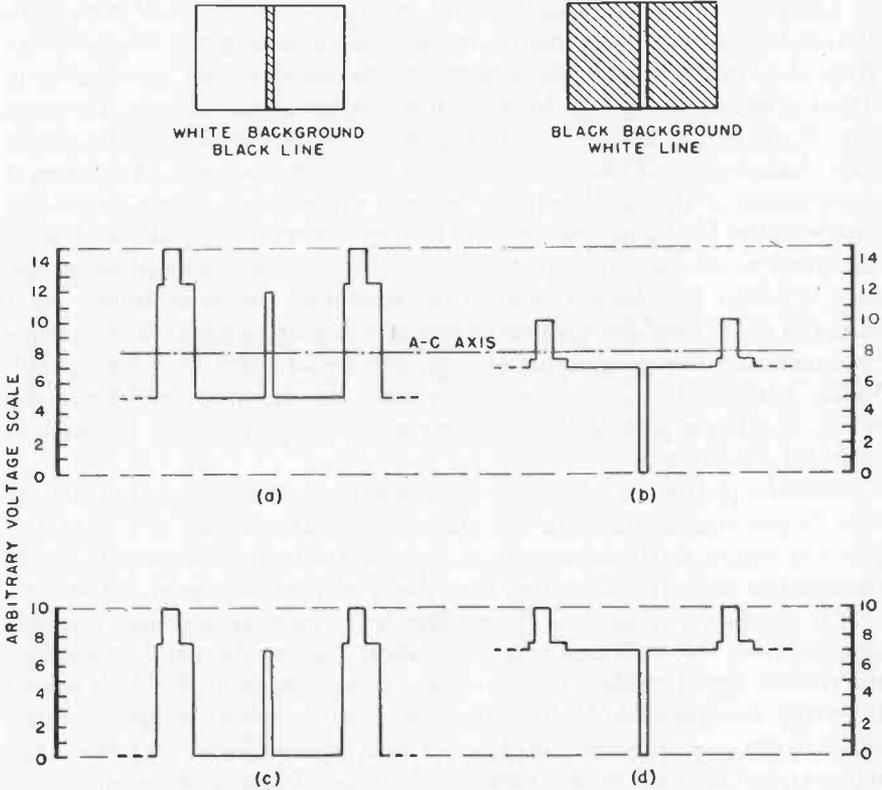


FIG. 13-19. The waveforms for a vertical black line on a white background, and vice versa, are shown without benefit of d-c restoration at (a) and (b), respectively, with d-c insertion at (c) and (d). Note the difference in peak-amplitude handling capabilities required in each case.

Certain other advantages accrue from the establishment of black level in the transmitter including (a) greater output from a given receiver i-f amplifier system before overloading occurs (for the same reasons as those just detailed for transmitters), (b) the possibility of employing an a-g-c system in the receiver that is referenced either to the amplitude of the synchronizing signal peaks or the blanking level, (c) more satisfactory synchronizing performance in the receiver in the presence of changes in the average picture brightness, and (d) the transmission of a definite

carrier power level for the synchronizing signal, the blanking signal, and each gray-scale value in the picture.

The last-named advantage of d-c restoration in transmitters is of considerable importance in practice because of the tendency of most transmitter amplitude characteristics to depart from perfect linearity at high modulation levels. It also points up an advantage of negative transmission. With d-c insertion and black-negative transmission, the synchronizing signal always corresponds to maximum carrier amplitude, as shown in Fig. 13-18, and is therefore in the region where nonlinearity of the amplitude characteristic is likely to be encountered, if it is present. However, if compression of the synchronizing pulse is experienced, it can be readily compensated for by modulating the transmitter with a signal that has an abnormal synchronizing-to-picture signal ratio in the proportions necessary to secure the desired ratio at the output of the transmitter. As a rule, the video amplifier portion of visual transmitters incorporates means for increasing the synchronizing-to-picture-signal ratio (see Sec. 13-10, *Video Amplifier*). In addition, the stabilizing amplifier (see Sec. 6-7) which is often a part of the video terminal equipment may be used to augment the process.

Since the picture signal usually occupies the region from approximately 0 to 75 per cent modulation and the synchronizing signal the 75 to 100 per cent region, such nonlinearity as does exist at high amplitudes in visual transmitters seldom affects other than the synchronizing signal. However, should the performance of a transmitter be so poor as to cause compression at levels below 75 per cent modulation, this would manifest itself in the picture signal as black compression. Compression in the black region is usually considered to be less objectionable than white compression because in the average scene the object of most interest is usually toward the white end of the gray scale. However, because of this, white compression or clipping is very undesirable. The FCC regulations recognize the difficulty of maintaining complete linearity down to 0 per cent modulation (which ideally would correspond to a white signal) by permitting the minimum depth of modulation to be maintained as high as 15 per cent if necessary.

**13-10. V-h-f Television Transmitter.** Both high- and low-level methods of modulation are employed in television transmitters designed for both the v-h-f and the u-h-f bands. Each method has its desirable characteristics, and neither can be said to have an outstanding advantage over the other; witness the existence, in daily use, of numerous transmitters of both types.

The features of low-level modulation include (a) avoidance of high-power video stages for driving the modulator, (b) use of receiving-type

tubes in the modulator, (c) elimination of vestigial sideband filter and its custom tailoring to the channel involved, (d) ability to operate on any channel within the tuning range of the transmitter, (e) low a-c power consumption, (f) low tube costs, and (g) compactness. In Fig. 13-20

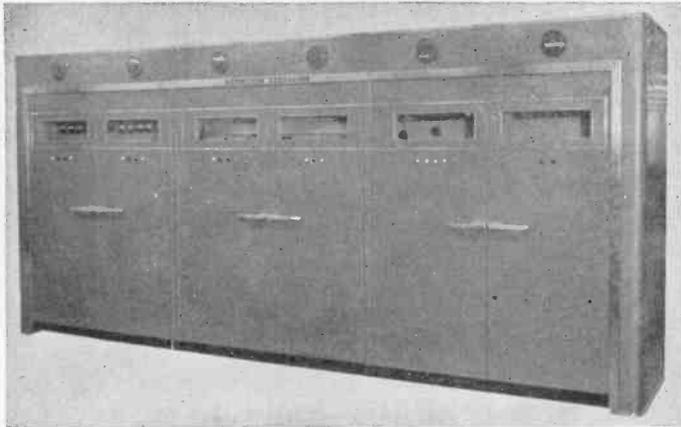


FIG. 13-20. A low-level-modulated v-h-f transmitter capable of producing a 5-kw picture signal and a 2.5-kw sound signal. (Courtesy of General Electric Company.)

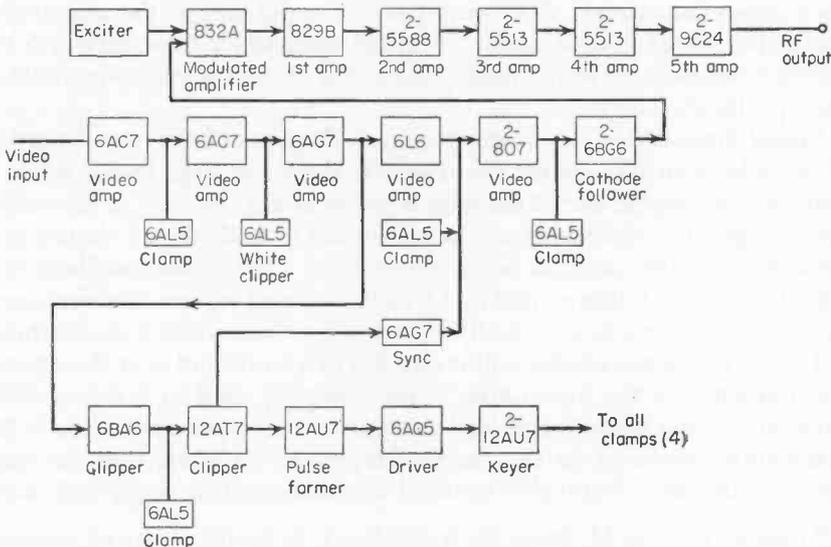


FIG. 13-21. Schematic block diagram of the low-level-modulated visual portion of the television transmitter shown in Fig. 13-20.

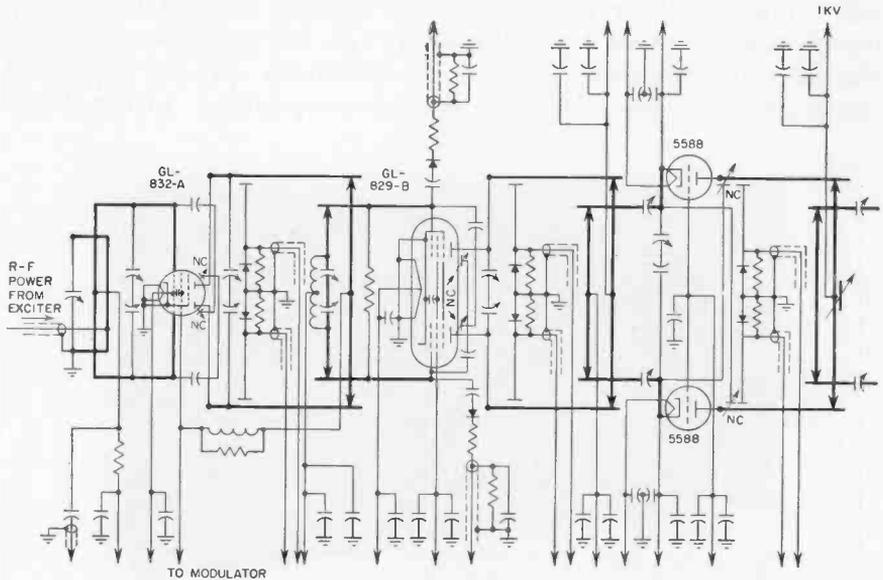


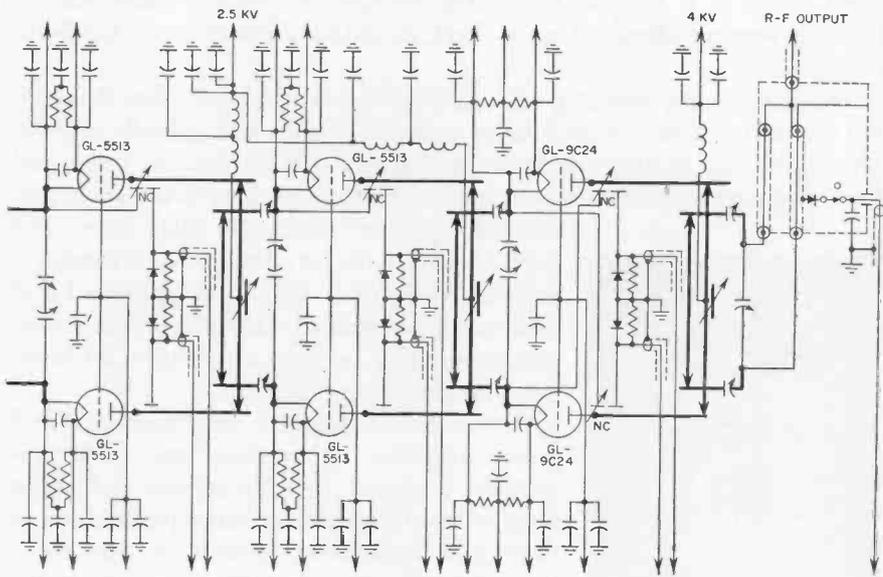
FIG. 13-22. Simplified circuit diagram of the r-f amplifier portion

there is shown a transmitter,<sup>10</sup> intended for channel 7 to 13 operation and employing low-level modulation in the visual section, which illustrates the points enumerated. The output power capability of the amplitude-modulated visual portion of the television transmitter illustrated is 5 kw during synchronizing signal peaks, while that of the frequency-modulated aural portion is 2.5 kw.

**Visual Transmitter.** A schematic block diagram of the visual portion of the television transmitter illustrated is shown in Fig. 13-21, while a simplified schematic circuit diagram is given in Fig. 13-22. As shown by these diagrams, receiving-type tubes are used in both the r-f exciter and the video amplifier portions of the transmitter. The crystal oscillator is a 6J5 tube which is followed first by a 6V6 buffer, next by two doublers, each employing 1614 tubes, and finally by a tripler which utilizes an 815 tube.

The output of the exciter unit is about 3 to 5 watts and is at the operating frequency of the transmitter. This energy is used to drive an 832A modulated stage whose plate load is adjusted for approximately an 8-Mc bandwidth (centered on the carrier frequency) in order that the tube may operate into a reasonably constant impedance when being modulated

<sup>10</sup> Downie, J. W., L. M. Ewing, H. B. Fancher, J. E. Keister, Design of Television Transmitters for Low Level Modulation, *Tele-Tech*, Vol. 6, No. 12, p. 44 (December, 1947).



low-level modulated v-h-f visual transmitter shown in Fig. 12-20.

at video frequencies. Once modulation is accomplished, however, the bandwidth of following amplifiers need be only about 4.75 Mc wide in order to produce the vestigial sideband signal that is standardized by regulations. As a matter of fact, by limiting the bandwidth of the linear stages following the modulated stage, the unwanted portion of the lower sideband (see Sec. 13-3) is eliminated without the need for employing a special vestigial sideband filter for this purpose. Rather, each amplifier stage acts as a section of a filter which in its entirety produces a transmission characteristic of the desired shape. A feature of this type of vestigial sideband attenuation is the facility with which the transmitter may be adjusted for operation on any channel within its tuning range without the need for first constructing a vestigial sideband filter for a particular channel.

Following the modulated amplifier, there are five linear r-f stages which build the modulated signal up to a peak power output of 5 kw. The first amplifier following the modulated stage is a grounded-cathode stage employing an 829B tube. This stage effectively prevents the impedance-frequency characteristics of the following 4.75-Mc circuits from reacting unfavorably upon the 8-Mc circuit into which the modulated stage operates. Without this isolation stage, the load impedance into which the modulator operates would not be uniform over the entire double side-

band width of 8 Mc because of the reflected impedance characteristic from subsequent circuits that, in effect, would be shunted across the 8-Mc circuit.

The second amplifier stage is a push-pull grounded-grid class B amplifier employing a pair of 5588 tubes with tuned plate and cathode circuits. The bandwidth of this and successive stages is 4.75 Mc. In these and following circuits, three-quarter wave inductive coupling is used together with one-quarter wavelength plate lines. The third and fourth linear r-f stages each employ a pair of 5513 tubes also in a grounded-grid push-pull arrangement while the fifth and final power amplifier employs a pair of 9C24 tubes in a similar arrangement.



FIG. 13-23. The flanged end of this 9C24 grounded-grid power amplifier tube connects to its plate, the ring seal that separates the two glass portions of the envelope connects to its grid, and the metal cap connects to the cathode. The overall diameter of the tube is  $3\frac{7}{8}$  in. and its length  $7\frac{1}{2}$  in. (Courtesy of General Electric Company.)

The tubes employed for grounded-grid power amplifier applications are usually especially designed for this service and differ from conventional power tubes particularly in their grid structures. Instead of wire leads from the grid assembly within the tube to the glass seal, a conical flange is used to connect the grid to a ring seal, as shown in Fig. 13-23, in order to achieve the lowest possible grid-lead inductance. This type of construction is essential since the grid lead forms a common impedance through which both the r-f plate and filament currents flow and which should be kept to an absolute minimum in order to minimize common coupling. In addition, the type of construction described shields the upper end of the filament structure from the anode.

To minimize filament-to-plate capacitance further, a cap covers the bottom of the grid basketlike structure. Thus the cap, grid, and supporting structure completely enclose the filament and isolate it from the anode. This shielding is so effective that in a tube of the 9C24 type (used as the final amplifier in the transmitter described) no neutralizing is required for channel 2 to 6 operation and only a very little for channel 7 to 13 operation.

In order to ensure adequate attenuation of the unwanted portion of the lower sideband (see Fig. 13-2a), the filtering effects of the tuned circuits in the transmitter proper are supplemented by two tuned traps. One is

coupled to the output line from the transmitter and is tuned to a frequency 1.25 Mc below the carrier. The second trap is in the top of the balun and is tuned to the 1.75- to 2.0-Mc region and serves to attenuate further the undesired lower sideband.

**Video Amplifier.** One of the features of a visual transmitter employing low-level modulation is the relatively small amount of power required for modulation purposes. For example, in the transmitter being described, it is necessary to raise the 1-volt peak-to-peak, input video signal only to about 80 volts, peak to peak. This is accomplished by means of a five-stage video amplifier (see Fig. 13-21) that employs relatively inexpensive receiving-type tubes.

The video amplifier circuits are more or less conventional except for the addition of clampers and a "white" clipping circuit. This latter consists of a series clipping diode which is connected between the second and the third stages in a manner which provides a means for controlling the amplitude of excessive peaks in the white direction. By this method, the possibility of spurious peaks of high amplitude in the white direction causing overmodulation of the carrier may be avoided. The point at which this circuit sharply clips white-going signal peaks is adjustable and can be readily set, therefore, so as to prevent overmodulation in the white or downward direction.

As shown in the block diagram, Fig. 13-21, the grids of the second and fifth video amplifiers and that of the modulator are clamped in order to effect d-c restoration. In each instance a 6AL5 dual diode is employed in a bridge-type clamping circuit which, with the aid of keying pulses, clamps the respective grids to a reference potential during the back-porch interval of each synchronizing pulse.

The keying pulses necessary for this operation are developed by a chain of tubes beginning with a 6BA6 clipper to whose input circuit there is applied a portion of the black-positive composite signal existing at the output of the third video amplifier stage. This tube is operated in a manner that clips off most of the picture signal but permits the entire synchronizing signal to pass to the next clipper, a 12AT7 tube. Here the resulting black-negative signal is clamped by a bridge-type dual-diode clamper which also operates during the back-porch interval. By establishing a definite reference level for the signal, this clamper ensures operation of the first section of the dual-diode 12AT7 clipper at a constant point on its characteristic so that its output is almost constant throughout a relatively wide range of input signal amplitudes.

The black-positive output of the first section of the 12AT7 clipper is applied to the grid of the second section, where the d-c bias is set by grid rectification, with the result that the remaining video portion of the

signal is clipped off completely, leaving only the black-negative synchronizing pulses. These are applied to the first section of a 12AU7 dual triode where the synchronizing signal peaks are amplified, clipped, inverted in polarity, and then applied to the second section of the tube. Here the black-positive synchronizing signals are differentiated in a nonlinear manner by the combined action of a resistor-capacitor network and the grid circuit of the tube.

The signal appearing in the plate circuit of the section of the 12AU7 tube is a heavily clipped positive pulse (delayed with respect to the synchronizing pulse that created it) and a decaying negative spike. This signal is applied to the grid of a 6AQ5 driver tube where the d-c bias is again set by grid rectification; consequently the negative spike is clipped and the positive input pulse is amplified and inverted. The negative pulse in the plate circuit of the 6AQ5 driver tube occurs after every horizontal, vertical, and equalizing pulse and is applied to the pair of 12AU7 dual triodes that form the keyer stage. From the plate and cathode circuits of these tubes, equal and opposite keying pulses are obtained simultaneously for application to the four bridge-type clampers previously mentioned.

To compensate for possible compression of the synchronizing signal in the modulation process, a synchronizing preemphasis circuit is also included in the video amplifier portion of the transmitter described. The increase of synchronizing signal amplitude with respect to the picture signal amplitude is accomplished by taking a portion of the synchronizing signal output of the first section of the 12AT7 clipper described above and applying it to a 6AG7 synchronizing signal amplifier stage. The amplified synchronizing signal thus obtained is added to the output of the 6L6 amplifier stage in the video amplifier chain where it is combined with the signal existing at this point and thereby increases the relative amplitude of the synchronizing signal portion of the composite signal.

**Aural Transmitter.** The aural transmitter associated with the visual transmitter described above is a frequency-modulated unit capable of developing an r-f output of 2.5 kw; it is contained in the right-hand cabinet of the assembly shown in Fig. 13-20. The transmitter is capable of being modulated over a range of  $\pm 50$  kc although, in practice, a frequency swing of only  $\pm 25$  kc is employed in accordance with existing regulations.

As shown in the block schematic diagram, Fig. 13-24, a crystal-controlled phasitron type of exciter<sup>11</sup> is employed followed by a series of six multipliers. The total multiplication of this chain (which consists of three

<sup>11</sup> Adler, R., A New System of Frequency Modulation, *Proc. IRE*, Vol. 35, No. 1, pp. 25-31 (January, 1947).

doublers and an equal number of triplers) is 216 times; consequently, the frequency of the crystal is in the vicinity of 1 Mc for aural transmitters operating on the high channels of the v-h-f television band.

Following the multipliers there are three intermediate power-amplifier stages consisting of (a) a push-pull grounded-cathode 832 stage, (b) a push-pull grounded-grid stage utilizing two 5588 tubes, and (c) a similar stage using a pair of 5513 tubes. The output power amplifier also consists of a pair of 5513 tubes connected in push-pull in a grounded-grid circuit.

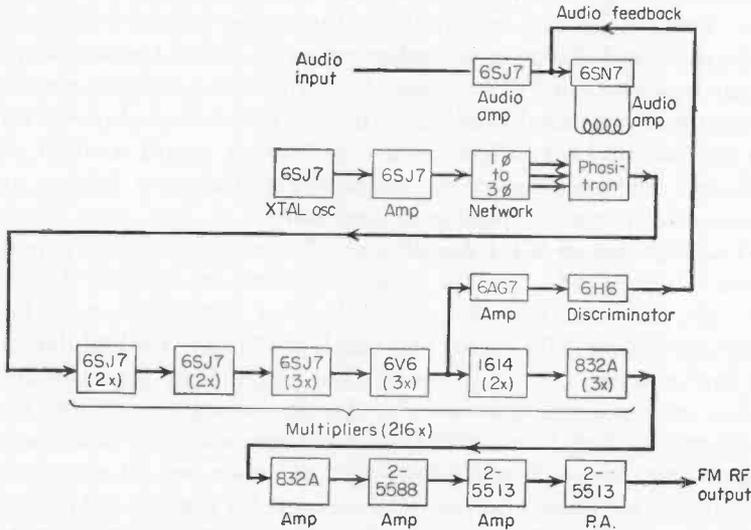


FIG. 13-24. Schematic block diagram of the FM aural transmitter portion of the television transmitter shown in Fig. 13-20.

Output coupling is obtained via a balanced loop, the reactance of which is tuned out by means of a suitable capacitor. An untuned balun is employed to transform the balanced output circuit to an unbalanced one in order to accommodate conventional coaxial transmission lines.

In both this portion of the transmitter and the visual section, especially arranged peak-reading vacuum-tube voltmeter circuits, sometimes called reflectometers, are used. These circuits provide means (a) for measuring the standing-wave ratio, (b) for measuring the relative power output of the transmitter, and (c) for protecting the transmission line against damage as a result of a high-voltage surge, such as might be caused by a lightning hit on the antenna. The pickup coils used for the vacuum-tube voltmeters are so designed that, when coupled to a properly terminated line (i.e., one on which no standing waves exist), the voltage induced in the pickup coil, as a result of current flowing down the line, equals the

voltage resulting from capacitive coupling of the coil to the line. Under these circumstances, the indication provided by the vacuum-tube voltmeter is proportional to the sum of these two voltages. If, however, the polarity of the current flowing down the transmission line is changed (or the connections to the pickup coil are reversed), the vacuum-tube voltmeter will indicate the difference between the two voltages. Since the current flowing from the transmitter is of opposite polarity to that which may be reflected back to the transmitter because of a mismatch, it is possible to determine the magnitude of both the outgoing and the incoming waves. Two pickup coils are therefore used, one oriented to indicate the incident wave and the other the reflected wave. Thus the standing-wave ratio may be ascertained at any time. In addition, the incident-wave measuring circuit may be used to indicate the relative amount of power flowing to the antenna and the reflected-wave measuring circuit used to actuate a protective device whenever the magnitude of the wave flowing toward the transmitter exceeds a predetermined value.

**13-11. High-power V-h-f Amplifiers.** The employment of high output power is an effective method for improving television service. In order to achieve the maximum effective radiated power levels authorized by government regulation (100 kw for low-band and 316 kw for high-band v-h-f visual transmitters) output powers in the range from approximately 20 to 50 kw are required. Fortunately, the decreasing power-output capability of transmitting tubes with increasing frequency is counteracted by the increasing ease with which high-gain antennas can be constructed as the frequency increases and their over-all size for a given gain decreases.

Visual transmitter output levels in the range mentioned can be achieved by supplementing basic 5- and 10-kw transmitters with a one-stage linear amplifier (see Fig. 13-25). Aural transmitter requirements may be met by the addition of a one-stage class C amplifier to a 2.5- or 5-kw basic transmitter. Amplifiers of this type, combined with practical v-h-f antenna gains, make it possible to achieve the maximum authorized effective radiated power levels.

Both air-and water-cooled tubes have been used in high-power aural and visual amplifier stages. In general, the amplifier units complete with auxiliaries occupy about as much floor space as the basic transmitters and add several tons of load to the floor. Depending upon their output power levels, amplifiers of the type under discussion require from 60 to perhaps 100 kw of a-c power over and above that required by the basic transmitter. These factors should be kept in mind when designing new transmitter plants or surveying available premises, and even though full authorized power levels are not contemplated initially, provisions to expand whenever desirable will often prove to be good insurance.

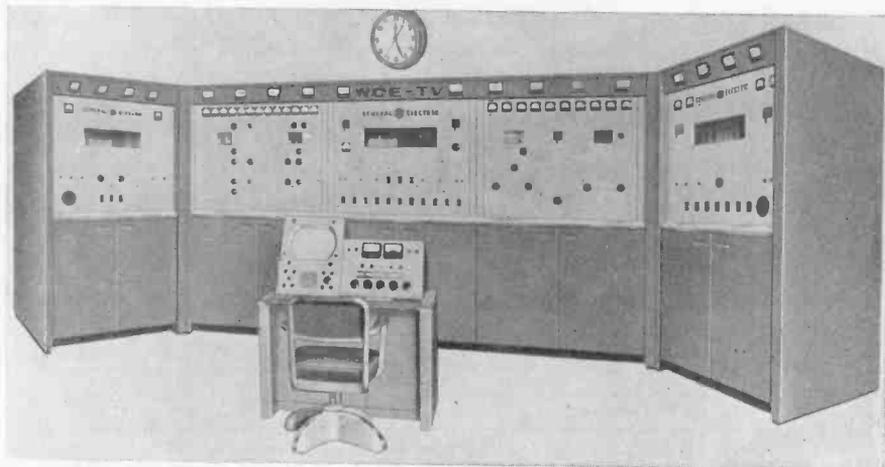


FIG. 13-25. A v-h-f television transmitter capable of developing 35 kw of visual power and 17.5 kw of aural power. (Courtesy of General Electric Company.)

**13-12. U-h-f Television Transmitter.** The development of even moderately high power in the u-h-f television band is usually accomplished with some difficulty, even at the low-frequency end of the band, when conventional tubes and circuits are employed. This results from the conflicting requirements of conventional tubes designed for ultrahigh frequency, which, on the one hand, require close spacing of elements to minimize transit time and to shorten r-f circuit connections and, on the other hand, require large high-emission cathodes and large heat-dissipating surfaces to cope with the increased tube and circuit losses. To avoid these transmitting tube difficulties, one low-level-modulated u-h-f television transmitter employs a klystron type of velocity-modulated tube<sup>12</sup> rather than a tube of the conventional negative-grid type. This transmitter is capable of developing 10 to 15 kw of power with a single tube in the output stage. This is sufficient to permit a 300-kw effective radiated power level to be attained with high-gain transmitting antennas of practical design (see Sec. 13-6).

**Visual Transmitter.** A schematic block diagram of the klystron transmitter mentioned is shown in Fig. 13-26 and a simplified circuit diagram in Fig. 13-27. A series of three frequency-tripler stages are employed to multiply the output of the crystal oscillator to within one-fourth of the final visual carrier frequency. Two cavity-type frequency-doubler stages, each employing a 4X150A tetrode, then multiply the frequency to the desired carrier value. The output of the last doubler is applied to a driver

<sup>12</sup> Preist, D. H., C. E. Murdock, and J. J. Woerner, High-power Klystrons at UHF, *Proc. IRE*, Vol. 41, No. 1, pp. 20-25 (January, 1953).

stage, also employing a 4X150A tube, which is grid-modulated by means of a clamper-type visual modulator stage. The modulated output of the driver stage is then applied to the multicavity Z-1891 klystron tube (Fig. 13-28) that was especially developed for this relatively wide modulation-band service.

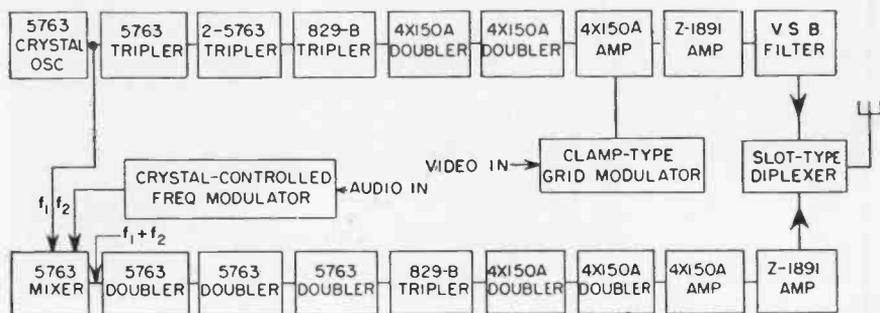


FIG. 13-26. Schematic block diagram of a low-level-modulated u-h-f transmitter employing klystron power amplifiers of the type shown in Fig. 13-28.

The resonant circuits for the klystron stage are integral with the tube and are adjustable to permit tuning to the desired channel and for achieving the required bandwidth. Cooling of the tube is accomplished by circulating both water and forced air, in separate cooling systems. A feature of the tube is the fact that, although the cathode is designed for exceptionally long life as compared to conventional u-h-f tubes, the cathode may, upon reaching the end of its useful life, be replaced by returning the tube to the manufacturer for factory processing. Power gains in excess of 50 times are realizable with the Z-1891 klystron when used as a power amplifier in a circuit having a 5-Mc bandwidth, and the noise and distortion figures are comparable to those obtainable with conventional low-frequency, high-power tubes.

In the transmitter illustrated, advantage is taken of the tuned r-f circuits in the cavity circuits of the driver and amplifier stages to partially attenuate the undesired lower sideband. Completion of this process is accomplished by means of a conventional vestigial sideband filter, as shown in the block schematic diagram, Fig. 13-26. A slot-type diplexer is then employed to combine the output of the aural transmitter with that of the visual transmitter for transmission to a common antenna over a single transmission line.

**Aural Transmitter.** The aural portion of the u-h-f television transmitter being described derives its basic frequency from the same crystal that is employed for the visual portion of the transmitter. This is accomplished, as shown in Fig. 13-26, by generating a frequency-modulated aural signal

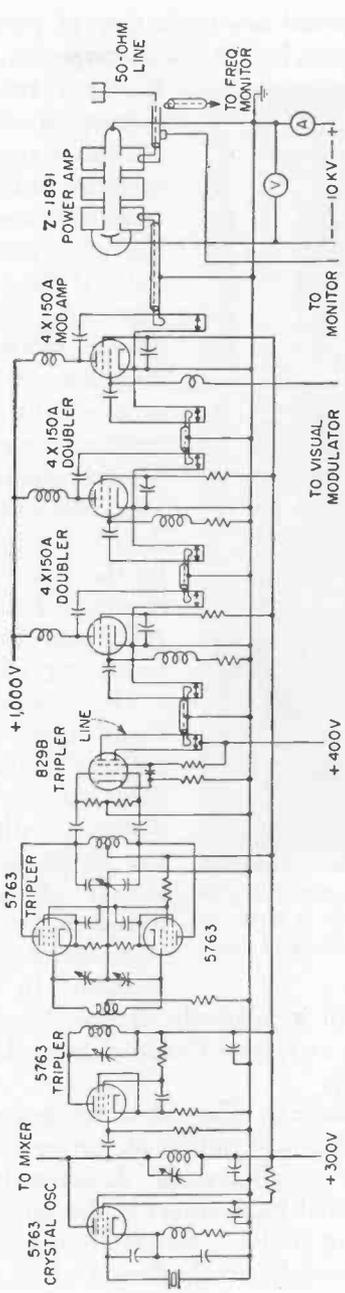


FIG. 13-27. Simplified circuit diagram of the u-h-f transmitter shown in the block diagram in Fig. 13-26.

by a direct crystal-controlled saw-tooth type of phase modulator. This frequency-modulated signal, low in center frequency compared to that of

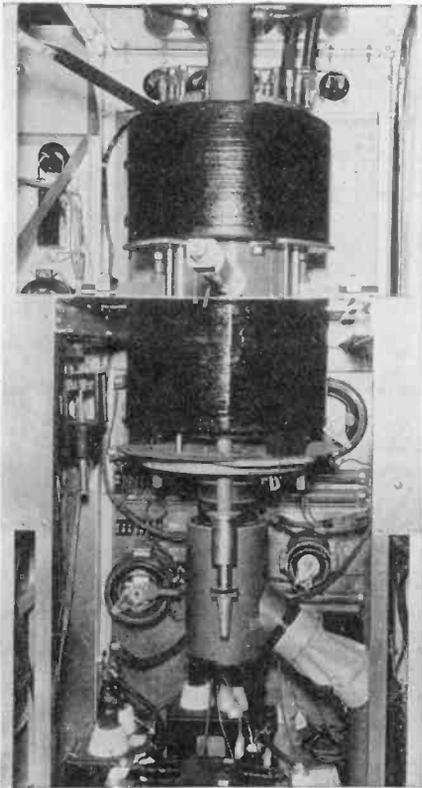


FIG. 13-28. A klystron-type power amplifier tube with its focus coils in a transmitter cubicle. (Courtesy of General Electric Company.)

the visual transmitter's crystal frequency, is added to a portion of the latter signal in a mixer stage in order to obtain the controlling frequency source for the aural carrier. This method ensures the visual and the aural carrier frequencies being maintained in a fixed 4.5-Mc relation with respect to each other, which fixed separation is especially desirable when reception is undertaken by means of intercarrier receiver methods. With the arrangement shown, any drift in carrier frequencies caused by the visual transmitter's crystal results in both carriers drifting in the same direction while always remaining 4.5 Mc apart.

The center frequency of the aural signal is multiplied by a series of doubler and tripler stages in a manner similar to but not identical with that employed for the visual portion of the transmitter. A 4X150A cavity-type tetrode is used to drive the output stage which also employs a Z-1891 klystron. In this instance, however, since the bandwidth is relatively narrow, the power gain may be extremely high, as much as several thousand times being practical without evidence of instability.

**13-13. Visual Demodulator.** The use of r-f demodulators for obtaining samples of the modulated r-f output of conventional amplitude-modulated aural transmitters is well known. A device to perform a similar function for television visual transmitters is also an important adjunct to any television transmitting station. Although an r-f demodulator for an aural transmitter is a relatively simple device, often consisting of only a single tube, a demodulator for a visual transmitter may employ 20 or more tubes exclusive of its power supply.

A demodulator for a visual transmitter is usually designed to convert a portion of the r-f output of the transmitter to video frequencies for operation of (a) an output picture monitor, (b) an output waveform monitor, and (c) measuring equipment for determining specific operating characteristics of the transmitter. Basically a visual demodulator is a wide-band, well-shielded, exceedingly stable, very high quality television re-

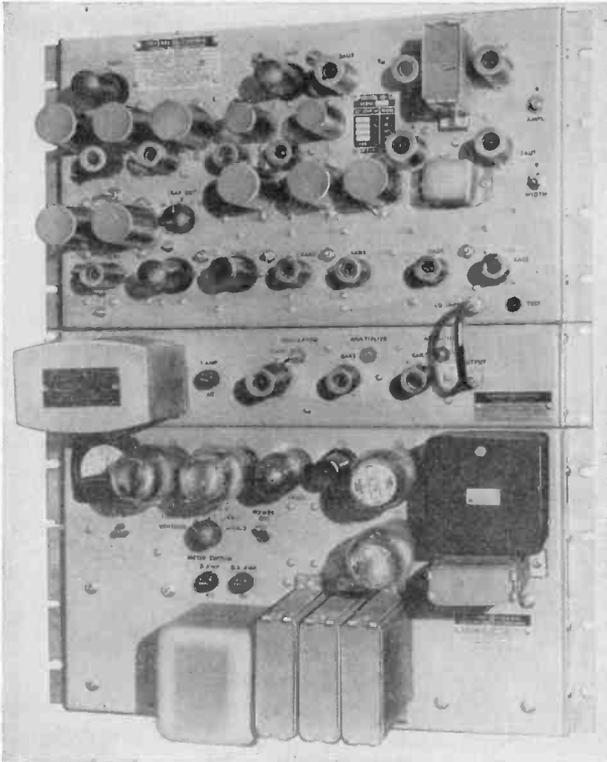


FIG. 13-29. A crystal-controlled visual demodulator unit for use at v-h-f television transmitting stations which provides means for monitoring both the picture and the waveform of the picture signal being radiated. (Courtesy of General Electric Company.)

ceiver without a picture tube, its associated sweep and high-voltage circuits, or the sound-reproducing section. A unit of this type is shown in Fig. 13-29 (complete with its power supply) while a block schematic diagram of the device is given in Fig. 13-30. The unit consists of a superheterodyne receiver, employing a crystal-controlled local oscillator, a wide-band i-f amplifier, a crystal second detector, and a video amplifier that provides two output signals, one for driving a waveform monitor and

the second for a picture monitor. A special feature of the r-f demodulator illustrated is a keyed local-oscillator cutoff circuit that disables the local oscillator during the vertical retrace period of alternate fields. This procedure results in a reference trace on the waveform oscilloscope that corresponds to zero carrier amplitude, the 30-cps repetition rate of the trace being ample for the trace to appear continuous to an observer.

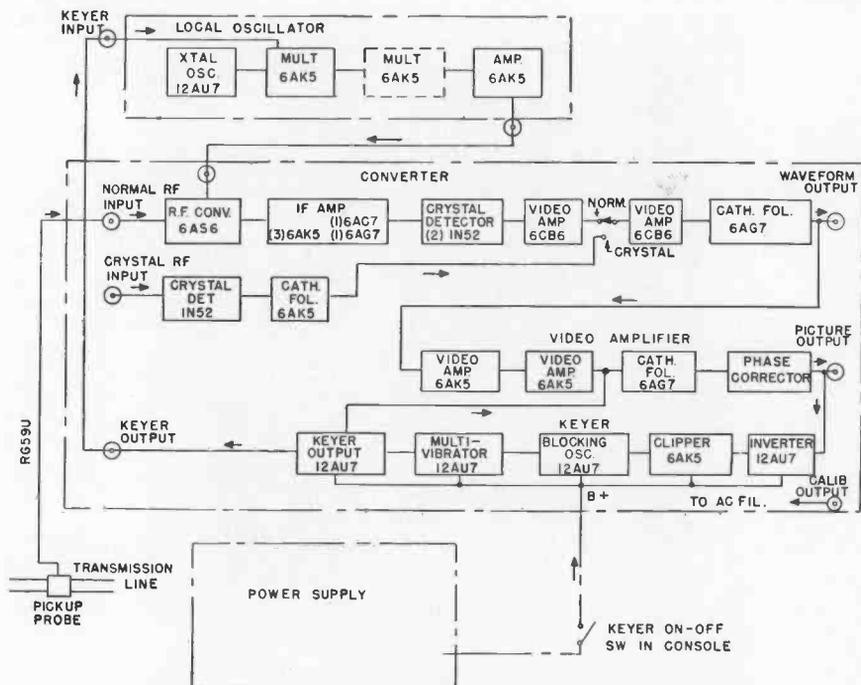


FIG. 13-30. Schematic block diagram of the v-h-f visual demodulator shown in Fig. 13-29.

Since zero carrier corresponds to a white picture signal, it is necessary to employ a portion of the keying signal to insert a special blanking signal in the picture monitor video amplifier circuit during the interval that the local oscillator is disabled (and the received signal is that corresponding to zero carrier).

## Studio Building Planning

THE PLANNING of each television studio or transmitter layout is largely an individual design problem since the extent of any given plant is a function of a great number of factors. These include the size of the community which the station serves, the magnitude of the program operation, the pretentiousness of the establishment, the foresight, ingenuity, and means of the management, the pattern set by the competition, and similar considerations. In as complex an undertaking as the planning of a television station, there is no single layout that is the ultimate, since there are a great many ways in which the various required working areas may be joined together and provide an efficient arrangement. There are, on the other hand, an even greater number of ways in which they may be assembled and prove very inefficient from an operations standpoint. The services of an experienced and qualified specialist are, therefore, indicated since the pitfalls for the uninitiated may prove many times more costly (from both an initial capital investment and a continuing operating expense viewpoint) than the nominal fee of a consultant.

No attempt will be made here to develop an "average" plant. Rather, the discussion will cover the more important matter of establishing the fundamentals pertaining to the technical facilities that should be given consideration in any television broadcasting studio plant, regardless of its size.

**14-1. Telecine Projection Rooms.** The term "telecine" originally pertained to the television reproduction of motion-picture film. Its connotation is now generally broadened to include the television reproduction of stills in the form of slide and opaque materials. Even a station that has no local origination facilities of its own, but relies wholly on network or other remote sources of program material, has need for telecine facilities in order to make local identification announcements at regular intervals. Therefore, even before a station acquires a live-talent studio, it is quite likely to make provision for telecine facilities. For this reason, telecine room requirements are presented first in this chapter.

**Centralized vs. Diversified Facilities.** Telecine facilities are usually concentrated in one room and arranged to serve all studios and remote pickup points requiring the use of film or slide material. Separate telecine equipment for each television studio may, like turntables, eventually be used. However, this is not likely to come to pass for a long time because, unlike their audio counterpart, good telecine facilities are both relatively complicated and expensive.

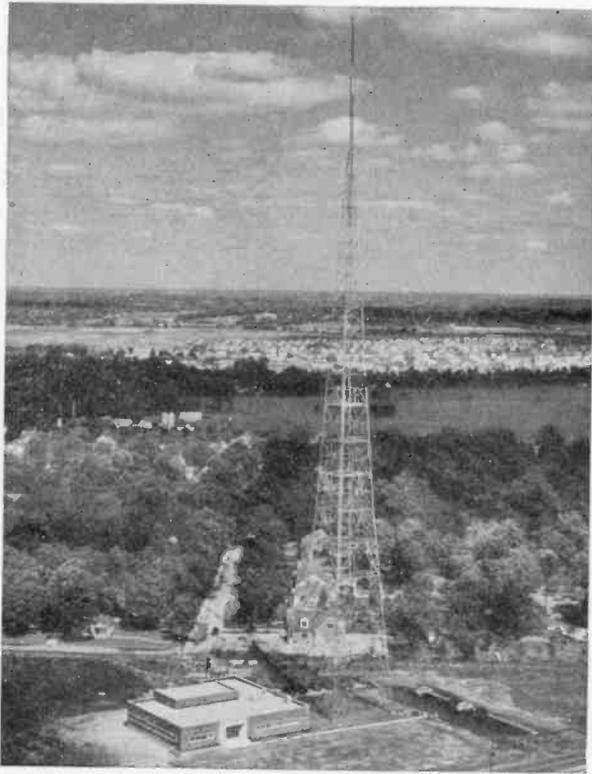


FIG. 14-1. The judiciously sited and efficiently arranged studio and transmitter building of WHIO-TV in Dayton is located immediately adjacent to a tower that supports both TV and FM transmitting antennas. (Courtesy of WHIO-TV, Dayton, Ohio.)

Separate telecine facilities for every studio cannot usually be justified since every program does not make use of every type of film, slide, and opaque reproducing equipment. It is, therefore, wiser to acquire only sufficient equipment of each type to carry peak loads (making allowances for equipment that may be out of service for repair) and to concentrate these facilities in one place. Not only is this arrangement economical of equipment, but it also makes more efficient use of floor space and operat-

ing personnel. Further, in the event of the failure of a particular piece of equipment, a quick substitution can usually be made (where there are a number of similar types of equipment available) and the production thus permitted to proceed.

**Multiplexing of Cameras.** Although a good case can be made, from an operations standpoint, for providing every piece of projection equipment with its own camera chain as shown in Fig. 14-2, the cost is usually such as to preclude its adoption except in large installations and for those projectors which are used so frequently as to warrant a camera chain of their own. The one projector that is used very frequently in a television station is the one employed for local station identification, program introduction notes, opening and closing performer credits and between-show announcements all of which are usually in the form of either slides or opaques. Because a camera assigned to this service is in such continuous use, little is to be gained by multiplexing other projectors on it.



FIG. 14-2. Each of the three 35-mm projectors and the equal number of 16-mm projectors in this corner of the CBS Television City telecine room is provided with its own film camera chain.

The combination of projectors that should be multiplexed upon a given film camera chain sometimes poses a problem. This is particularly true where 16-mm, 35-mm, opaque, and slide projectors are all involved. If the suggestion made above to allocate a camera chain exclusively to the still projector is followed, the assignment of camera chains resolves itself simply to determining whether a pair of 16-mm machines should be used on one camera and a pair of 35-mm machines on another, or if one 16-mm and one 35-mm should be used with each camera. At first glance the former arrangement might seem the more logical, but the latter has many advantages that make it very attractive.

Where two like projectors (*e.g.*, two 16-mm or two 35-mm machines) are multiplexed upon the same camera chain, as shown in Fig. 14-3, it is possible to run multireel pictures all on one chain, making other chains available for rehearsals, auditions, or maintenance. However, this arrangement precludes the possibility of testing or previewing the upcoming reel. Furthermore, and perhaps even more important, if a station has only one pair of 16-mm projectors and only one pair 35-mm projectors (or perhaps none) then, if a camera chain carrying a pair of like projectors should fail, the program must necessarily be completely interrupted until repairs can be made.

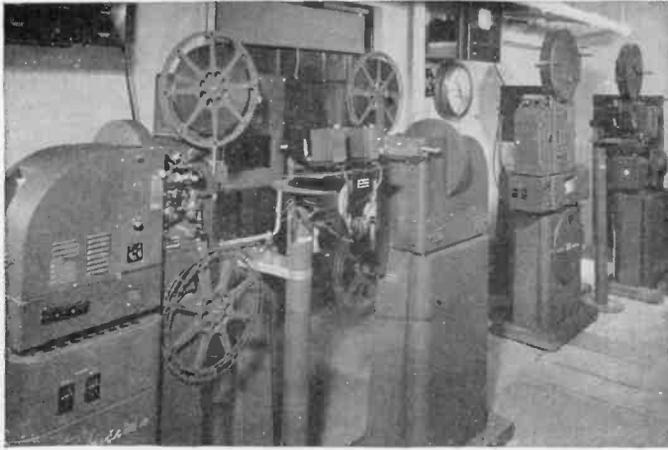


FIG. 14-3. In this telecine room two 16-mm film projectors, together with a pair of slide projectors, are multiplexed upon one film camera (left foreground) while two 35-mm film projectors and a second pair of slide projectors are similarly associated with a second film camera (right background). (*Courtesy of WENR-TV, Chicago.*)

On the other hand, if a 16-mm and a 35-mm (or other type) projector are diplexed on a camera and two or more such groups are installed, then, should one camera fail, the reel can be shifted to another machine with little loss of time. Further, in an emergency, multireel shows can be run by filling in (with announcements employing stills) the time necessary to unload and reload the one good channel. In addition, assuming that both chains are in good operating condition, the arrangement just suggested completely frees the second projector for rehearsal or other purposes when only one reel or partial reels are being broadcast. In the final analysis, the allocation of projectors between film camera chains can be determined only after a careful survey of the method of operation that is preferred by

the station in question, the number of full or partial-reel shows as against multireel pictures, the number and kind of projectors that must be accommodated, the number of camera chains that are available, and, last but not least, the amount of space that may be allocated to telecine facilities.

Of the various types of diplexers described in Sec. 9-11, the fixed mirror, where applicable, is probably the best from the standpoint of program operations since no one need be in attendance at the projectors at the instant a switch-over is to be made from one machine to another. Assuming that the projectors are provided with remote-control means for starting and stopping the machines (as are practically all television projectors), then either machine may be put on the air at the will of those in the control room which has jurisdiction over the equipment involved. On the other hand, where it is necessary to move a multiplexer or a film camera at the instant of change-over, another operator must be on hand in the telecine room and carefully coordinate his activities with those of the video switcher. It is to be noted that, where a fixed-mirror diplexer is used, the projectors should be equipped with automatic dousers (see Sec. 9-9) in order to avoid the possibility of the picture being projected on the mosaic of the film camera tube when not wanted.

**Telecine Floor Arrangements.** All motion-picture projectors load from the right side as viewed while facing the screen. Because of this, when grouped around any kind of multiplexer, it is not possible to arrange the projectors so as to avoid a good deal of walking around projectors in getting from the working side of one machine to that of another. Such being the case, about the only considerations that need be given to laying out a telecine room are (*a*) symmetry of layout, if this is deemed important from the viewpoint of reducing operating errors, (*b*) obstacle-free direct paths to the rewind room and film storage vaults, (*c*) ample, but not excessive, space around the equipment for operation, maintenance, and repairs, (*d*) the arrangement of projection optical paths that will not be accidentally blocked by an operator or passer-by, and (*e*) the limitations of the available space.

In laying out a telecine room, sight should not be lost of the fact that the audio, the video, the intercommunication and sometimes the projector itself require considerable rack space to accommodate facilities associated with the film camera, the projector sound system, and, sometimes, the source of picture illumination. In addition, it is advisable to provide both a visual and an aural monitor which may be seen and heard (some projectors are rather noisy), respectively, from the projectionist's operating position. The floor arrangements of representative telecine rooms are shown in Figs. 14-2 to 14-4.

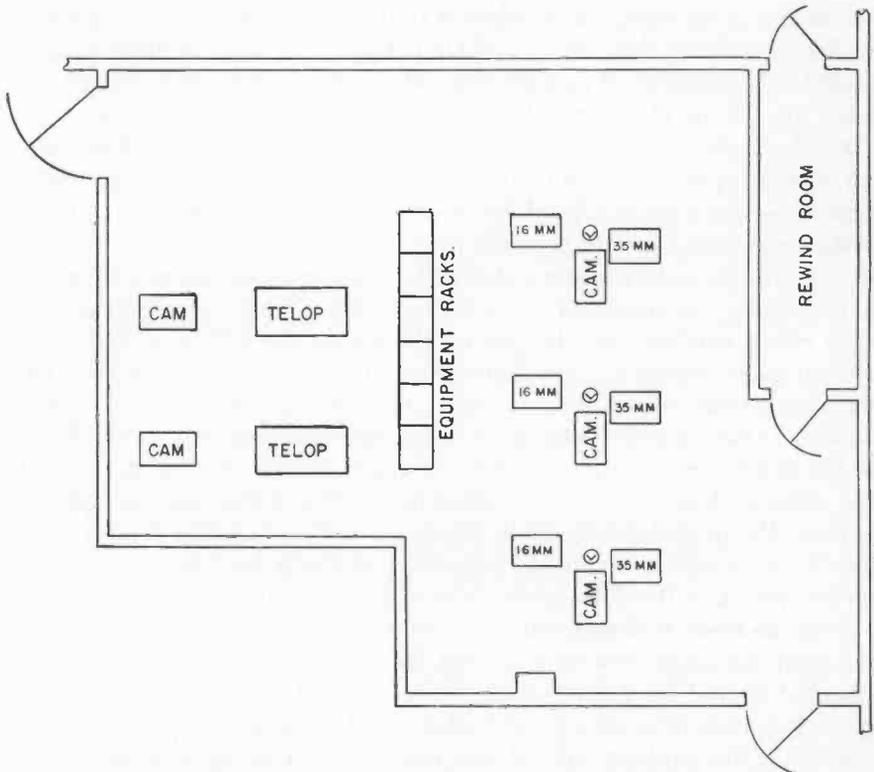


FIG. 14-4. In this arrangement a 16-mm and a 35-mm film projector are multiplexed (with the aid of fixed-mirror duplexers) on each of three television film cameras. On the other hand, a separate camera chain is provided for each of the two telops because of the high load factor these opaque projectors enjoy.

**Rewind Room.** A rewind room (Fig. 14-5), with accessories for handling and repairing film, is an invaluable asset since an air-conditioned room of this kind can provide a more dust-free environment for handling film than the telecine room proper where considerable in-and-out traffic is usually unavoidable. For efficient operation, rewind rooms require certain minimum facilities for handling film. Where 16-mm film is involved, the following accessories are suggested:

- a. Racks and cabinets for film storage.
- b. Work table of convenient height, usually 39 in.
- c. Film rewinders and flanges for handling film that is mounted only on cores.
- d. Film splicer and splicing cement.

- e. Appliance for making motor and change-over cue marks on film (see Sec. 10-5).
- f. Film notcher to cope with broken film sprocket holes.
- g. Spare projection reels.
- h. Sound-track blooming ink.
- i. Receptacle for disposal of scrap film.
- j. Film-handling gloves.
- k. Film footage measuring device (optional).

Where 35-mm film is also to be handled, the above supplies, except for items *h*, *i*, and *j*, may be duplicated in the correct size for the larger film. This list of material is adequate only for splicing on leaders, splicing together short lengths of film, and making emergency repairs. If film editing is to be undertaken, considerably more elaborate facilities and space are required than are afforded by the average rewind room.



FIG. 14-5. A neatly arranged rewind room containing the various accessories required for efficient film-handling operations. Note the explosionproof lighting fixtures and switches, the fireproof construction of all furniture and fittings, and the water sprinkler system. (Courtesy of WCAU-TV, Philadelphia.)

**Building Regulations.** Depending upon the locality, different building codes will be encountered concerning premises where motion-picture film is to be handled. As a rule, if only 16-mm film is to be handled, there are few, if any, special regulations since all 16-mm film is of the safety or slow-burning type.

On the other hand, where 35-mm film is to be handled, the building regulations may be numerous in spite of the fact that practically all such film now manufactured in this country is also of the safety type. In many instances, civil authorities require observation of the same building code where only 35-mm safety film is handled as when 35-mm nitrate film is involved. This, of course, works many hardships and will undoubtedly take generations to correct. Furthermore, because of local interpretations of regulations, it is best to confer with the proper civil authorities for any specific building project where it is contemplated that 35-mm film will be handled.

Among the regulations governing 35-mm film projection installations that are commonly encountered (but by no means universal) are the following:

- a. Vapor- or explosionproof lights and light switches (see Fig. 14-5) are usually required and, of course, all wiring must conform to established regulations.
- b. Two or more exits of specified size and location are often required for rooms housing 35-mm film and the associated equipment.
- c. Approved cabinets or vaults for 35-mm film storage are often required. In some cases these cabinets or vaults must be equipped with an approved water sprinkler head and a vent to the outside of the building for possible fumes or gases.
- d. The amount of 35-mm film in storage in a film equipment room is sometimes restricted to a definite maximum quantity.
- e. An approved type of 35-mm-film scrap container is generally required.
- f. The walls and ceiling of the 35-mm-film equipment room usually must be constructed of noncombustible material having a fire rating of at least 3 hours.
- g. Fire extinguishers and other fire-fighting equipment are often required at specific locations in the film equipment room.
- h. A 35-mm-film equipment room must usually be inspected and licensed by the proper civil authorities.

**14-2. Telecine Control Rooms.** For the most part there is no reason for the layout of a telecine control room to differ materially from that of a control room associated with a live-talent studio (see Sec. 14-6). As a

matter of fact, in the interests of simplifying personnel training, equipment operation, and maintenance problems, it is desirable to make all control rooms as nearly identical as practical.

The location of a telecine control room with respect to the telecine projection room is quite flexible since there is no need for the regular occupants of the control room to see into the projection room, assuming that a good intercommunication and signaling system is available. Conversely, the ability to see from the control room into the projection room (and vice versa) is no substitute for an adequate intercommunication and signaling system. The only restriction as to the relative location of the control and the projection rooms is the advisability of keeping the length of the numerous control and video cables as short as feasible. In addition, vision is desirable, although not imperative, into the announcer's booth that is usually associated with each telecine room.

The telecine control room of a broadcasting station is sometimes incorporated into the master control room or, where it is separate from the master control room, it often assumes the role of a submaster control room. This results from the fact that, at the end of practically every program, use is made of the telecine facilities either for the transmission of station identification or for short announcements that are scheduled in between regular programs. In addition, during that portion of the operating schedule where a station is receiving its program material from a network, it is often the practice to route the network program through the telecine control room in order that local announcements may be readily integrated with the network presentations. Thus it is seen that the telecine control room is one of the most used facilities of the average television broadcasting station. This fact should be kept in mind in allocating space for this operation, in planning its location with respect to contributing departments of the station, and in arranging the avenues of approach to the telecine control and projection rooms.

**14-3. Telecine Announcer's Booth.** A small booth, although one that is large enough to accommodate several persons and to have good acoustics, is an invaluable adjunct for a telecine installation. Provisions need not be made for camera pickup of those in the booth unless it is desirable to make use of this facility also as a news or interview studio. Aside from this latter possibility, the announcer's booth associated with a telecine room is useful for origination of (a) the aural portion of local announcements, (b) running commentary to accompany newsreels or other film that does not have a sound track, and (c) the aural portion of programs or announcements that are built around stills.

Vision from the control room to the announcer's booth is required where hand signals are still employed for cueing the announcer. However,

stations with adequate intercommunication facilities usually rely upon verbal cueing of the announcer, via his intercommunication headset, since this form of communication does not require the announcer to look up from his script to catch hand cues. Furthermore, he can be cued at any time (and with detailed instructions if necessary) regardless of whether he happens to be watching the program director or not. Since an announcer may already be attempting to follow the visual program material via a picture monitor, in addition to reading his script, it is almost adding insult to injury to ask that he also watch for hand signals from the program director. In any event, where reliance is placed upon an intercommunication system for cueing an announcer, direct vision from the control room into the announcer's booth is not a necessity; primarily it serves the purpose of informing those in the control room whether the scheduled occupants of the announcer's booth are in their places.

**14-4. Television Studios.** A television studio may consist of nothing more than a sufficiently large space, with adequate but a minimum of lighting equipment, and a control room in which portable television facilities can be set up when necessary. At the other extreme, the live-talent studios at network origination points are sometimes elaborate affairs, incorporating a large and flexible lighting installation complete with an extensive lighting control system, air-conditioning, sound-effects facilities, motor-operated camera cranes, observation galleries, background projection facilities, an announcer's booth, and a large control room permanently equipped with studio-type audio and video equipment.

The question of studio size is usually one of considerable concern. From the viewpoint of ease of erecting sets and being readily able to wheel camera pedestals and microphone booms from one set to another, the larger the studio, the better, barring a studio the size of an armory. On the other hand, the smaller the studio, the less the cost of construction and the lower the air-conditioning and other operating costs. If the studio is too small, there may not be sufficient space to accommodate the lighting equipment, to erect other than the simplest of sets, or to accommodate more than the smallest of camera pedestals and microphone booms. Unlike aural broadcasting studios, there are no ideal dimensions nor ratio of dimensions for a television studio. There are, however, certain dimensional ranges that, in the light of commonly used electrical, electronic, and mechanical equipment, are logical modules.

**Studio Height.** The optimum height for a television studio is a dimension on which it is reasonably easy to set limits. There must be sufficient height to accommodate the type of lighting fixtures that are to be used which, in turn, must be high enough to be out of the field of view of the camera no matter how high it may be raised or trained. In small studios

where simple tripods are in use (which do not afford the convenience of permitting vertical raising or lowering of the camera during a broadcast), the camera lens is often no more than 4 or 5 ft above the studio floor. On the other hand, if a large camera crane is used, the camera may, on occasion, be raised as high as 10 ft off the floor. Camera pedestals and small cranes reach intermediate heights between these two, as detailed in Sec. 6-9. The lighting fixtures should, of course, be sufficiently elevated to avoid interference with the largest camera crane and the cameraman that rides thereon.



FIG. 14-6. For interview-type programs only 8-ft-high scenery flats and a minimum of space and stage properties are required. Simple, broad patterns are used to avoid either large monotone or excessively "busy" wall areas.

Another factor that must be given consideration in determining the maximum required ceiling height for a television studio is the height of the sets that are to be built in the studio. For the most part, sets only one story high are employed although, of course, there are exceptions. As shown in Fig. 14-6, some sets are only 8 ft high, although a more common height is 10 ft which is high enough so that most normally employed camera angles do not include an area above the top of a set. Large sets, however, may require 12 ft-high backgrounds (Fig. 6-19) or a black velvet drop above sets of lower height, if the area above the set is not to be seen in long shots.

Taking into consideration the maximum probable set and camera

heights, it is seen that provisions should be made for locating general lighting fixtures at least 10 ft and preferably somewhat higher above the floor. (Effects lights, of course, may be required at any height from the floor up to the maximum available.) Since provision must be made above the lighting fixtures for their mountings, for wireways, sprinkler systems, acoustical treatment, and other necessities, it is evident that the *minimum* ceiling height should be in the vicinity of 14 ft. If a lighting bridge or catwalk is contemplated, then additional head room is required.

The maximum ceiling height that should be employed is also worth careful consideration. If the height is materially greater than necessary, both the acoustical treatment and the air-conditioning of a studio may become both a problem and an expensive operation. Except where provisions must be made for extraordinarily high sets, it does not seem necessary to provide ceiling heights of more than about 20 ft even where large camera cranes are to be used and overhead catwalks are to be provided.

**Studio Size.** The question of studio size cannot be bracketed quite so neatly as that of studio height although certain fundamental dimensions can be established from which logical studio floor sizes may be established. There is no such thing, of course, as an "average" set, but a consideration of the types of scenes most frequently reproduced will help to establish the probable set dimensions that may be expected. For the simple interview type of program, only sufficient space is needed for a few chairs and occasional furniture (see Fig. 14-6) unless additional space is required for a special display or demonstration. In order to accommodate a variety of camera angles, even the most elementary set requires partial sides in addition to the usual backdrop. Thus the floor space required by an elementary set of this type may be about 6 by 10 ft.

On the other hand, the kind of scene encountered in more ambitious productions is usually that of a room or a series of rooms of the size normally encountered in residences and office buildings. If the scene is laid outdoors, a limited expanse is usually portrayed (see Fig. 14-16). Less frequently, the interior or exterior of an automobile, bus, train, airplane, boat, or other conveyance may be employed. For all these sets, floor space comparable to the real thing (or a portion thereof) is usually required, particularly in respect to the width of the set. However, the depth may sometimes be reduced to perhaps two-thirds that of an actual area, depending upon the camera angles that are to be employed. From this it is evident that each set may require a floor space measuring about 15 by 20 ft. However, to facilitate setting up the set and to accommodate back and other types of effects lighting, it is not generally feasible to build a set right up against a studio wall. Rather, a passageway of at least 5 ft

is desirable so that a total floor area of about 20 by 20 ft is often occupied by a single set. Furthermore, many productions require several sets but, unlike the theater or motion pictures, there is generally little opportunity in television to reconstruct sets during a broadcast. Under these circumstances, sufficient space must be provided to accommodate simultaneously all the sets required for a given production.

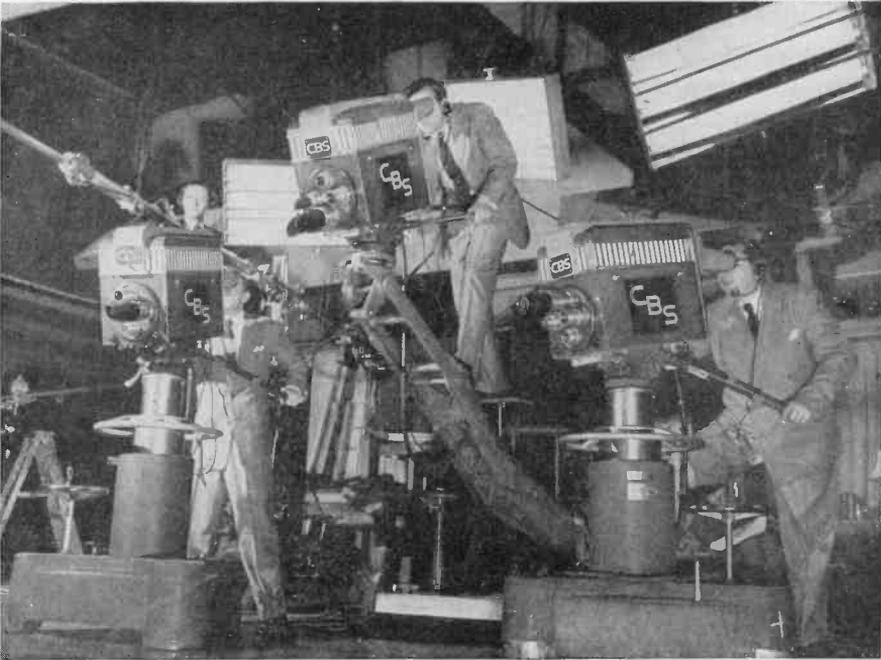


FIG. 14-7. Ample clear floor space must be provided in front of studio sets to permit the free movement of the relatively large camera pedestals (left and right), camera cranes (center), and microphone booms (background).

In addition to the amount of space occupied by the sets themselves, an adequate working area must be provided in front of the sets for the camera tripods, pedestals or cranes, and the microphone booms required for the pickup. These vehicles are by no means small (see Fig. 14-7 and Secs. 6-9 and 6-10) and adequate space must be provided for manipulating them. Further, where a multiset production is involved, adequate space (and advanced planning) must be provided to permit the cameras and the microphone booms to be wheeled from one set to another without crossing over in front of a camera that is on the air. A depth of *at least* 10 ft, preferably 15 ft, should be allocated across the front of a set for the camera and microphone boom working areas.

The dimensions suggested are intended primarily as guides to the kind of areas encountered in television studios, and wide variations will be found, of course. However, from the dimensions suggested, it is seen that a studio to accommodate two "average" sets along one wall should be at least 40 ft long and 30 ft wide. A second pair of facing sets may be arranged along the opposite wall without the need for quite doubling the width of the studio, however, since the center working aisle can serve the sets on both sides of the studio; *i.e.*, an over-all width of about 50 ft will usually serve. Furthermore, a studio of this width provides an opportunity to construct extra-deep sets should the necessity arise, with the cameras working with their backs to one wall rather than out in a center aisle.

**Studio Acoustics.** The acoustical problem in television studios is quite different from that in aural broadcasting studios. In the latter, the acoustical characteristics are determined largely by the configuration of the studio, the nature of the wall, ceiling, and floor treatment, the number of studio occupants, and the extent of the furnishings provided for their accommodation.

In television work, on the other hand, the acoustical atmosphere is created largely by the nature of the set in the immediate vicinity of the microphone. Much the same practices are followed in the production of motion pictures although here the problem is considerably simplified as compared to television work. In film production, the picture and the sound are sometimes recorded at different times and in different places. Thus the sound can be recorded under acoustical conditions that are not limited by photographic requirements. In television, however, because of its instantaneous nature, these procedures are only occasionally employed. Furthermore, unlike motion-picture production, television programs must often continue uninterrupted for periods of 30 minutes or even more without much, if any, opportunity for rearranging the acoustics of the set. These two factors, coupled with the fact that, during simultaneous picture and sound production, the microphone must be kept out of the picture area, make the television sound pickup problem somewhat difficult.

Still another problem must be given consideration in the acoustical design of a television studio. Unlike aural broadcasting practices, there is always a great deal of movement in a television studio by others besides those in the cast. The floor director, for instance, may move from one vantage point to another, the camera tripods, pedestals, or cranes are almost continually on the move, as to a lesser extent are the microphone booms. Finally, stagehands, electricians, off-stage costumers and makeup experts, sound-effects personnel, and others all have responsibilities that often require activities on their part in the same studio with the program

that is being broadcast. To minimize the unwanted noise arising from these necessary activities, it is usually desirable to employ as much sound-absorbing treatment in a television studio as possible.

Considerations of this nature have led to the practice of making a television studio acoustically dead and relying upon the individual sets to create the desired acoustical environment in the vicinity of the microphone. The required extensive sound absorption is usually accomplished by covering the ceiling and walls of a television studio with very highly absorbent acoustical material. The reverberation time of a television studio is, therefore, usually quite low, judged by aural broadcasting optimums.

Again, unlike aural broadcasting practices, little effort is generally made in a television studio to present a finished appearance to the studio walls and ceiling. Rather, the acoustical treatment often consists simply of muslin-covered blankets of acoustical material which, where advisable, are supported with an open-mesh wire netting. Since the walls of a television studio quickly become covered with sets and the ceiling with lighting grids, there is little justification for finishing the walls in other than a neat but inexpensive manner.

**Sound Isolation.** Although the type of room acoustics usually considered desirable for television studios is markedly different from that in an aural broadcasting studio, the sound-isolation or insulation problem is quite similar. In some respects the sound-isolation problem is more severe since larger studio areas are usually involved and, in addition, the microphone is usually farther from the source of sound (see Sec. 6-10, *Microphone Types*) than in aural broadcasting practice.

In planning a television studio layout, the sound-isolation problem can be materially lessened by judicious location of the studios with respect to each other and in relation to areas from which noise may arise. For example, whenever possible, the placement of studios immediately adjacent to each other should be avoided since the attenuation of the common wall may not prove adequate. In a situation where two studios must be located side by side, conventional floating-type sound-insulation construction is usually desirable. In this respect, it is to be noted that little sound isolation is to be expected from noises originating below a studio by merely floating the floor, or from noise sources above by floating the ceiling, or from adjacent areas by floating only the walls. Unless full ceiling, floor, and wall isolation is practiced, sounds can enter the studio area via building columns, floor joists, ceiling beams, and other structural members.

The placement of studios immediately adjacent to each other may often be avoided by placing control rooms, storage spaces, and other areas between the studios. Corridors may also be used to separate studios from

each other, but in this instance proper care must be taken to treat the corridors acoustically in order to subdue normal traffic noises therein.

To minimize noise from outdoors (trucks, trains, airplanes, and thunder), it is desirable to avoid placing a studio against an outside wall or immediately under a roof. Since television studios always employ artificial light and usually are air-conditioned (or, at least, mechanically ventilated), there is no need for direct openings to the outdoors. Such outside space may be better utilized by assignment to supporting activities which are in a position to enjoy the sunshine and fresh air sometimes available from such areas. Although *direct* access to the outside is not essential, provisions should be made to bring in automobiles and other large objects to at least one of the television studios in a group. Naturally, this can be most readily accomplished with ground-floor studios, and building openings and corridors should be planned accordingly, as was done for the studio layout shown in Fig. 14-8.

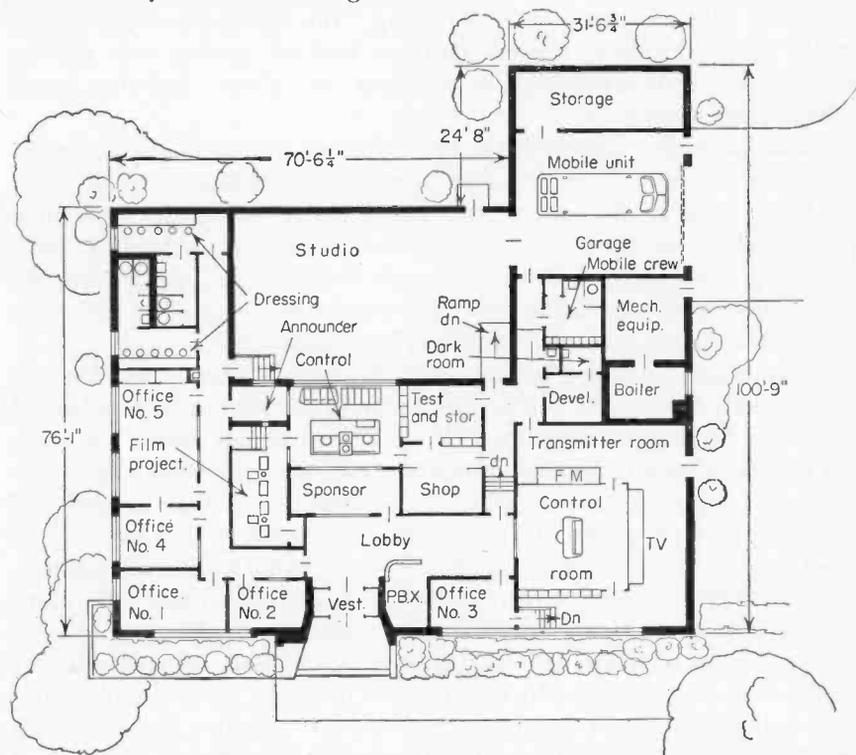


FIG. 14-8. This well-designed studio and transmitter building provides direct access to the studio floor from the street level, thereby facilitating the movement of automobiles, large stage properties, and scenery into the studio. (Courtesy of WHIO-TV, Dayton, Ohio.)

Where television studios are located with their roofs exposed to the sky, particular attention must be paid to potential noise from airplanes and thunder. A layer of offices, dressing rooms, or equipment rooms that are not potential sources of noise, placed over the studio ceiling, will materially reduce the possibility of disturbance from air-borne noises.

**Studio Floors.** Television studio floors require just as careful consideration as studio size, acoustics, and lighting. An uneven floor is worthless since it will prohibit dolly shots (wheeling in or away from a scene while on the air) both from the viewpoint of causing the picture to jump during the wheeling operation and also because of the difficulty of moving a tripod or pedestal freely and evenly in any desired direction.

Squeaky floors and floor surfaces that are noisy as the result of normal camera, microphone, and staff movements are also unsuitable for television purposes. This often makes uncovered wooden floors less desirable than concrete since, although the wood floor may be free from squeaks, it may be unduly noisy because of the movement of persons, equipment, and stage properties. However, wooden floors with a covering of rubber, linoleum, or other material may be very satisfactory if they are solidly constructed, are free from squeaks, present an even surface, and are capable of withstanding the probable floor loading. Wooden floors offer the possibility of nailing sets in place rather than sandbagging their bases.

Smooth concrete floors, when covered with a suitable surfacing material, are probably the best for television studio use. Bare concrete floors have one advantage over covered floors in that camera cranes and microphone booms roll over them more easily than when a floor covering is used. On the other hand, properly designed camera cranes and microphone booms can be readily maneuvered on smooth covered floors (Figs. 14-6 and 14-7) which have advantages offsetting the easier wheeling of heavy equipment on bare floors. Chief among these are the relative quietness of a covered floor, the easier maintenance, and the cleaner surface that may be obtained.

There are, of course, many types of floor coverings including sheet rubber and linoleum, rubber and asphalt tile, various plastic materials, and cork. Carpets and rugs, although sometimes satisfactory for the areas used by the actors, cannot be used on any portion of the floor where a camera or microphone support is likely to be wheeled. In the selection of a floor covering, consideration should be given to its sound-absorbing properties, its susceptibility to cigarette burns, its ability to recover from depressions made by concentrated floor loads, its color (a light color reflects often needed light under the chin and eyebrows), its resistance to abrasion, scuffing, and gouging, the maintenance problem, and the cost. As might be expected, there is no one material that is superior in all these

respects and, as a result, the importance of the various properties enumerated must be weighed and a decision reached on this basis.

**14-5. Studio Lighting.** Unlike motion-picture work, once a television program begins, it cannot be interrupted, even momentarily, in order to change the intensity or direction of the lighting. As a rule, this requires that the set be illuminated in a manner that will permit both long and close-up shots and, in addition, shots from any angle without mutual interference between lights.

**Floodlights.** In order to provide the base light required in television, use is made of either incandescent or fluorescent floodlights. As explained in Sec. 7-4, either type of source may be used interchangeably or together, provided the camera tube is fitted with a suitable light filter.

For a given light intensity, incandescent floodlights produce more heat than fluorescent floodlights. On the other hand, incandescent light sources are more amenable to producing specific directional characteristics and, therefore, are more useful in special lighting situations. Usually, fluorescent sources must be located reasonably close to the scene they are to illuminate (Fig. 14-6) whereas, by choosing the proper directional characteristics, an incandescent light source can be a considerable distance away.

In general, the choice between fluorescent and incandescent base lighting will depend upon the headroom available, the distance from the scene to the lighting fixtures, the heat load that the air-conditioning system will handle (or the studio occupants will tolerate), the amount and kind of power available (a-c or d-c), the type of fixtures on hand, and the whims of those responsible for the selection.

One type of incandescent floodlight, known as a "scoop," is shown in Figs. 14-9 and 14-16. Fixtures of this type come in various sizes ranging from about 10 to 18 in. in diameter, for accommodating lamps from 250 to 2,500 watts in size, and produce either concentrated (relatively), intermediate, or widespread patterns. The inner or reflecting surface of the fixture is usually a matte finish to aid in obtaining good light diffusion. Depending upon their design, scoops are usually intended for use at distances of from 10 to a maximum of perhaps 20 ft from the set.

Typical fluorescent types of floodlights are shown in Figs. 14-6, 14-7, and 14-16. The fixtures consist of rectangular pans ranging from about 43 to 64 in. long, from 16 to 44 in. wide, and  $3\frac{1}{2}$  to 5 in. deep. The housing accommodates from three to six lamps of either the slimline or preheat fluorescent types. Back of each fluorescent tube there is mounted a parabolic specular (mirrorlike) reflector which results in the unit as a whole producing a wide uniform distribution curve. They are usually intended for use at distances of from about 10 to 15 ft from the set. Some

of the six-lamp slimline units are arranged for operation with two, four, or all six lamps.

The noise produced by the ballasts in fluorescent lamps requires special consideration. Although individually the ballasts may not produce appreciable noise, when mounted in a fluorescent fixture the sound radiation may be considerable. Furthermore, a rather large number of separate fluorescent fixtures are often used, and the combined audible hum can become intolerable. The situation is further aggravated by the fact that



FIG. 14-9. An incandescent floodlight or "scoop" that is used extensively for providing the kind of base light required for television sets. (Courtesy of Display Lighting, Inc.)

microphones are often suspended in the general vicinity of the fluorescent lights. The solution to the problem is either to remove the ballasts from the fixtures and mount them in some remote location or to employ only ballasts which are known to be relatively quiet (some manufacturers rate their different types for their audible noise output) and which are mounted so as to minimize the generation of air-borne noise.

In all cases, provisions must be made for cutting out defective fluorescent lamps to avoid the possibility of erratic operation developing during an air show. This can be done by employing either so-called "no-blink" starters or trigger-start ballasts. The former units are designed to lock themselves out when faulty tube operation develops. The latter require

no auxiliary starter units, a cathode heater winding being incorporated in the ballast itself.

**Strip Lights.** Strip lights are a special form of floodlight and are sometimes employed for providing base light on backgrounds, walls, and similar surfaces. They supply a shadowless illumination of low intensity distribution in a uniform manner along their length. As their name implies, they consist either of a strip of incandescent lamps in a long troughlike metallic housing as shown in Fig. 14-10 or simply of a row of sockets for internal reflector-type lamps. The trough-type strip lamps are fitted with either polished or matte-finished reflectors (or a combination of both) producing either narrow or medium individual beam widths.



FIG. 14-10. Strip lights, employing a row of incandescent lamps in a troughlike reflector, provide shadowless illumination distributed in a uniform manner along their length. (Courtesy of Kliegl Bros., Inc.)

Trough-type strip lamps are made to accommodate from 6 to 15 lamps and range in length from about 3 to 8 ft. For improving the diffusion of both strip lamps and incandescent floodlights, inside frosted lamps may be used and, where still more diffusion is required, the opening of the reflector may be covered with a spun-glass filter.

**Spotlights.** In order to achieve the different lighting effects that are so essential to a good television picture (see Sec. 7-4), various spotlights are employed. These fixtures, which are used for producing back light, modeling light, key light, and eye light, employ either plano-convex or Fresnel lenses for concentrating the light into the shape of beam required. Spotlights are usually housed in ventilated metal cases that are generally cylindrical in form (see Figs. 14-11 and 14-12) and employ lenses from 3 to 16 in. in diameter. The projection lamps used with these fixtures range in size from 75 to 5,000 watts. Spherical specular reflectors are used in spotlights and their spacing from the lamps is often adjustable by means of an external handle in order to provide some degree of control over the beam width.



FIG. 14-11. Incandescent spotlights in sizes ranging from 75 to 5,000 watts are used extensively for back light, modeling light, and key light in television studios. (Courtesy of Kliegl Bros., Inc.)

**Spotlight Accessories.** The usefulness of spotlights may be greatly enhanced by the employment of various accessories that have been developed to exploit the art of lighting fully. Among the attachments that are frequently used with spotlights are adjustable irises, fixed masks, adjustable framing shutters, "barndoors," spot shades, and diffusers.

Adjustable irises are employed for the purpose of controlling the beam size and intensity. Fixed masks are employed for the same purposes and, in addition, can be used to control the shape of the beam by employing openings of various configurations.

Adjustable framing shutters can be fitted to the front of a spotlight for the purpose of adjusting and shaping the light beam. In effect, they serve the same purpose as fixed masks although they are much more practical since they obviate the need for keeping on hand a supply of easily misplaced masks of various sizes and shapes.

Barndoors are simply hinged baffles (see Figs. 14-13 and 14-16) attached to a ring that can be fastened to the face of the spotlight and rotated to any desired angle. They serve to prevent light from spilling upon the camera lens, backgrounds, or other areas where the light is not wanted. When four-way barndoors are used (see Fig. 14-14), rectangular light beam shapes can be created.



FIG. 14-12. A small incandescent spotlight mounted on the front of a television camera is an effective way to provide eyelight on close-ups. The two tally lights in the lower corners of the camera front provide a visual cue to performers indicating when the camera is in use.

A spot shade is the lighting equivalent of the camera lens shade; *i.e.*, it is a circular shade that may be placed over the front of a spotlight which, without reducing the spread of the light beam, prevents light from spilling outside of the main spotlight beam. Fixed framing masks of the type mentioned above are sometimes fitted to the front of a spot shade in order to control the size and shape of the projected light beam. They may also be used between the spot shade and the spotlight, in which instance patterns having softer edges are formed.

So-called color frames are also used on the front of spotlights for the purpose of holding color filters and spun-glass diffusers. Although useful for color-television purposes, color light filters are of no value in a monochrome television system.

**Lighting Fixture Supports.** The problem of providing an ideal means for supporting the numerous lighting fixtures found in the average televi-

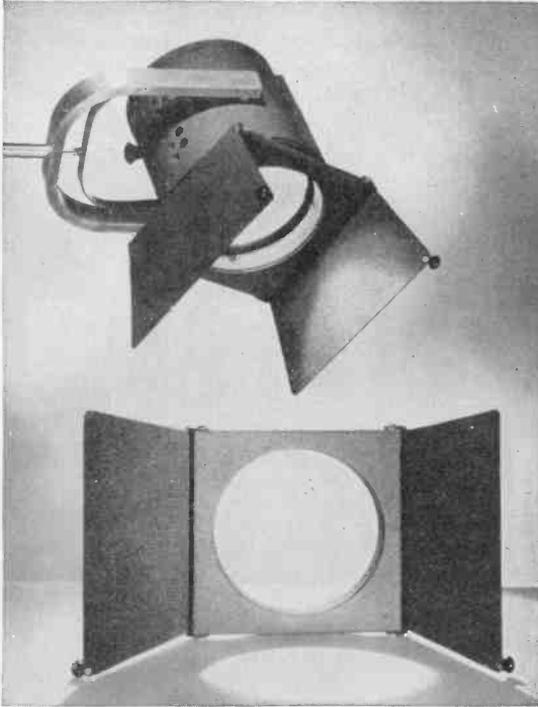


FIG. 14-13. Hinged light baffles or "barndoors" are used extensively on incandescent spotlights to shape the beam cast by these fixtures. (Courtesy of Display Lighting, Inc.)

sion studio is not an easy one to solve. Among the considerations that should be kept in mind are (a) the desirability of keeping as many of the fixtures off the studio floor as possible, (b) the need for being able to readily locate fixtures over any portion of the studio floor, (c) the ability to raise and lower the fixtures, preferably without having to enter upon the set to do so, (d) the ceiling height available, and (e) the type of power distribution system that will be used.

Television studios are usually congested with large pieces of equipment, sets, stage properties, and other items that are unavoidably on the floor. For this reason, and since floor stands supporting lighting fixtures would further restrict camera movement and camera angles, it is best to locate all possible lighting fixtures overhead. This can usually be done with success with all fixtures except a few of the effects lights. It is important, however, that the structural arrangement employed for overhead support of the fixtures be so designed that lighting can easily be located at any desired point over a set. Unlike motion-picture practice, television

sets are erected and struck all within a matter of a day or so. Since the time that can be allotted to arranging the lighting must be in keeping with this pace, it is necessary that some permanent overhead arrangement be provided that will permit ready location of the fixtures wherever desired.

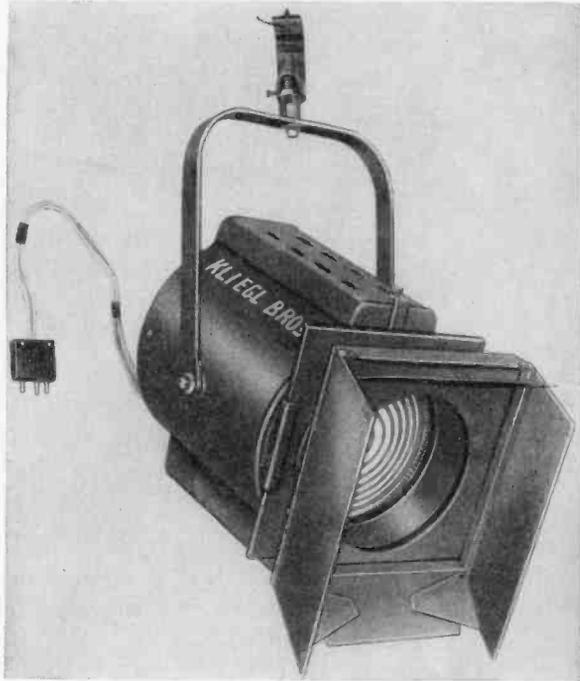


FIG. 14-14. Four-way barn doors make it possible to confine a beam of light to a rectangular area. (Courtesy of Kliegl Bros., Inc.)

Two basic types of mountings which permit adjustment of the fixture height are in general use. One consists simply of a vertical rod or pipe (see Fig. 14-15) which is fastened to the overhead support by means of a suitable fitting and which may be raised, lowered, or rotated and then clamped in the desired position. A safety device should be incorporated in all devices of this type to prevent accidental dropping of the fixture to the studio floor in the event of a failure of the clamp or if it should slip while being adjusted. It is customary to employ rods having lengths ranging from about 4 to 12 ft depending upon the particular application in hand.

A second type of hanger for lighting fixtures is the spring-balanced pantograph device such as shown in Fig. 14-16. These units can be shortened to a length of about 11½ ft or extended to a length of some 12 ft,

their design being such as to prevent side sway even when fully extended. Balancing springs are included in the device to accommodate fixture loads ranging from about 10 to 50 lb and are so designed as to provide a constant tension throughout the entire extension range of the pantograph. Thus the fixture may be raised or lowered with little effort and will remain at the height to which it is set. Provisions are made at the bottom of the device for rotating the fixture attached thereto through a 360-degree angle in the horizontal plane. The fixtures themselves are usually equipped with a mounting yoke that permits tilting the units to the desired angle in the vertical plane, *e.g.*, see Figs. 14-11 and 14-14.

The type of overhead structure most commonly used for supporting television studio lighting fixtures is an open horizontal grid of iron pipe arranged in the form of rectangles or squares (Fig. 14-17) having sides from 4 to 6 ft long. Thus a lighting fixture may be hung over any specified portion of the studio floor within a matter of a few feet at the very most. Pipe having nominal sizes of 1½ to 2 in. is usually employed for the construction of overhead grids, the size depending upon the anticipated loads, the extent of the intermediate ceiling supports, and similar factors. A very satisfactory method of assembling a pipe grid is by means of pipe clamps designed especially for the erection of pipe scaffolds, towers, and similar structures. When assembled in this manner, the configuration of a pipe grid may be changed at any time if operating experience indicates the need for modifications or where a special studio set requires a temporary change in the normal grid arrangement.

Many of the factors influencing the height of a lighting grid above the studio floor are found in Sec. 14-4, *Studio Height*. In general, a lighting grid should be at least 12 ft off the floor, preferably higher. On the other hand, heights above about 16 ft seldom serve a useful purpose in a television studio and may, in fact, make the problem of handling lighting fixtures unnecessarily difficult.

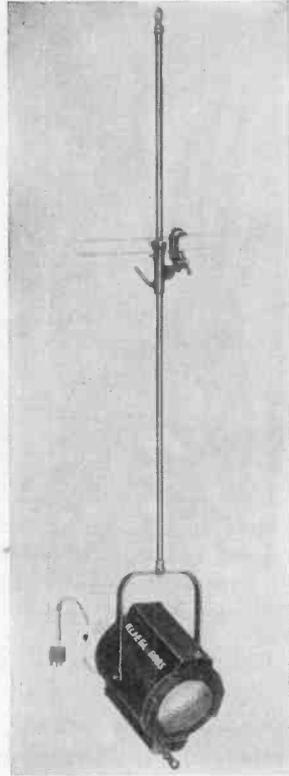


FIG. 14-15. One type of hanger that may be used for fastening lighting fixtures to an overhead grille. Hand-operated clamps permit the fixture to be mounted at the desired height and faced in the required direction.

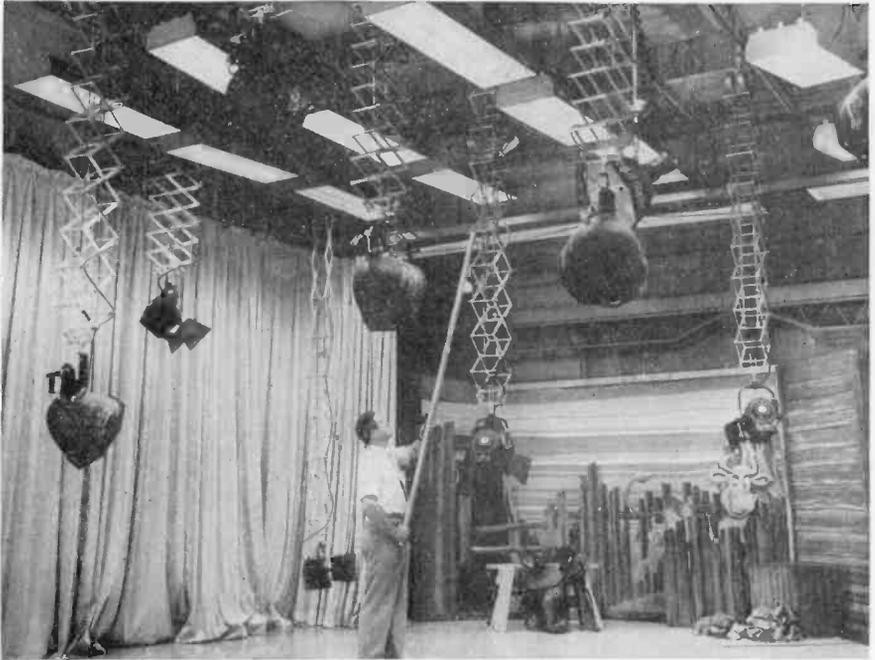


FIG. 14-16. The spring-loaded pantograph is a readily adjustable type of hanger for lighting fixtures. In this particular installation, instead of an overhead grid, the pantographs are supported by a monorail system that permits them to be easily moved to any point under the rail. (Courtesy of WCAU-TV, Philadelphia.)

**Catwalks.** Catwalks above a lighting grid (where ceiling heights are sufficient to permit their installation) are very desirable in that, through their use, adjustment of lighting fixtures can sometimes be undertaken without the need of interrupting a rehearsal for the placement of ladders or other means for reaching the fixtures from the floor. On the other hand, since *all* the operations pertaining to the lighting can seldom be accomplished from a catwalk, its use does not completely eliminate the need for working on the fixtures from the floor. Rather, a catwalk may be considered as an adjunct that can save valuable rehearsal time and even permit lighting changes while a program is in progress. Further, it is useful during activities involving the hanging of scenery from the pipe grid.

Ideally, a catwalk should be so designed as to permit access to any portion whatsoever of the lighting grid. If a given amount of catwalk is to serve a maximum amount of grid area, it is evident that it should *not* be placed around the periphery of the studio since in this position it can serve only an area on the side of the catwalk away from the wall. The same amount of catwalk located away from the walls will permit reaching

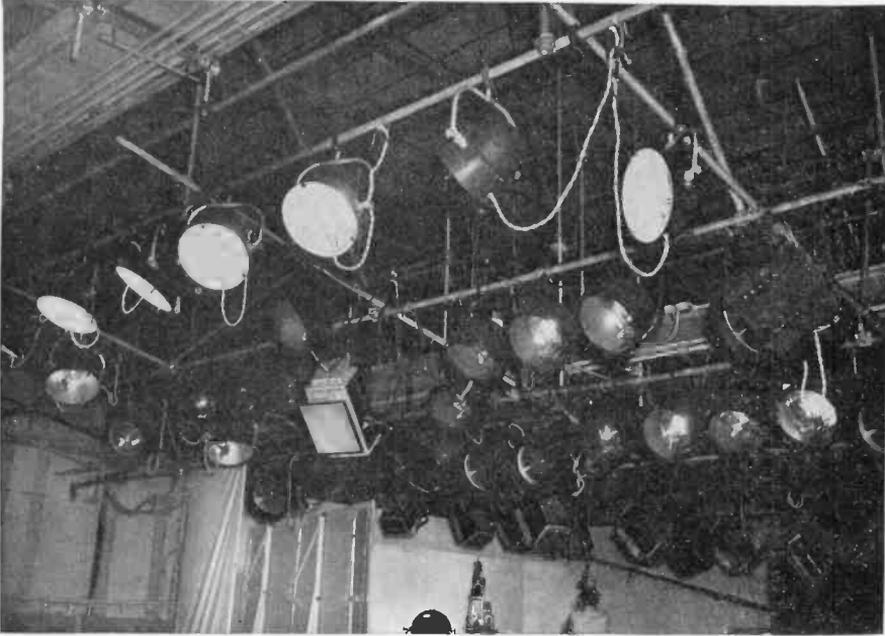


FIG. 14-17. An open horizontal grid of iron pipe is often employed in television studios to provide an overhead support for lighting fixtures. By using standard length pipe and suitably designed pipe clamps, a minimum of assembly work is involved, and the resulting structure can be readily altered at any time.

roughly twice the grid area since the grid on both sides of the catwalk can then be reached. On the other hand, many effects lights are suspended at the rear of sets and close to the studio wall so that a portion of the catwalk should be located in a position to reach these frequently used lighting fixture positions.

A catwalk facilitates the practice that is sometimes followed of running the cables associated with microphones, cameras, and floor-type lighting fixtures up overhead in order to relieve the cable clutter that is characteristic of many television studio floors. Additional advantages of this practice are the reduction in noise that often results from dragging long lengths of cable across the floor and the somewhat easier manipulation of camera cranes and microphone booms that overhead cable suspension affords.

Since catwalks, although desirable, are dispensable, they should not be installed at the expense of a less-than-optimum lighting grid height. In general, this means that where a studio height of at least 20 ft is not available, the likelihood is that a catwalk cannot be installed without sacrificing desirable clearance under the lighting grid.

**Lighting Control Facilities.** The lighting control problem in a television studio is primarily one of energizing the proper lamp circuits when needed and, in some instances, of adjusting the lighting intensity either by turning on more or less lamps or by means of dimmers. Unlike the theater, good television lighting practice does not make use of spots to follow stage action nor are dimming or blackout of the lights necessary to obtain special effects. As a matter of fact, in television practice, the effects obtained by the latter two procedures are achieved more easily and better by video control adjustments than by manipulation of the lighting.

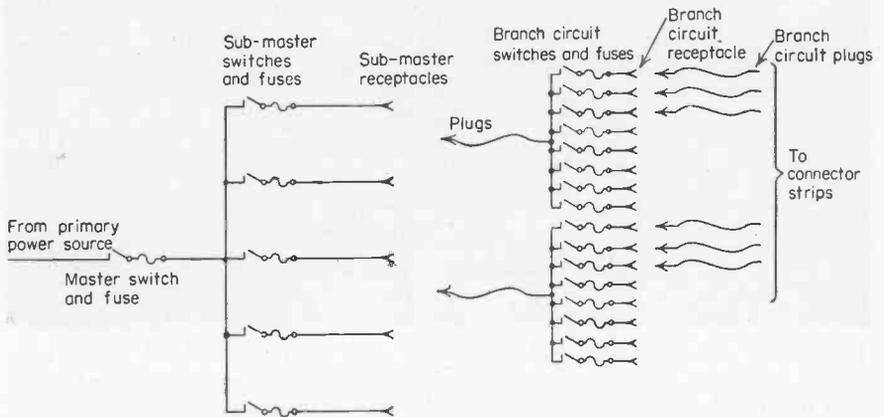


FIG. 14-18. A schematic circuit diagram of a lighting switchboard that provides considerable flexibility by a combination of submaster and branch circuit switches together with associated plugs and receptacles.

On the other hand, it is often desirable to be able to completely darken portions of the studio (*e.g.*, those sets that are not in use) in order to prevent spill light from such areas disturbing sets that are in use. Further, during breaks in rehearsals, it is often desirable to be able to darken an entire studio by means of one main switch thereby leaving undisturbed, and ready for immediate use, the preestablished arrangement of branch lighting circuits.

Television studio lighting control boards, therefore, often include a main or master switch controlling all lighting in the studio except work lights, exit lights, and the like. In addition, submaster switches are often provided to control the lighting to particular portions of the studio; *e.g.*, to a complete set. Within a given working area, however, it is frequently necessary or desirable to have control over several circuits rather than a single one. Accordingly, it is good practice to divide the output from a submaster switch into a number of individually controlled circuits. If the studio is of limited size, it is often practical to provide a separate

switch for every branch circuit. However, if many branch circuits are involved, permanently installed switches on every branch would not only necessitate a very large switchboard but, in addition, would probably not provide the desirable flexibility. An alternate arrangement, that has proved very useful, is illustrated in Fig. 14-18. Here, the master and sub-master switches already mentioned are shown permanently connected to the mains. The branch circuit switches, on the other hand, are separated

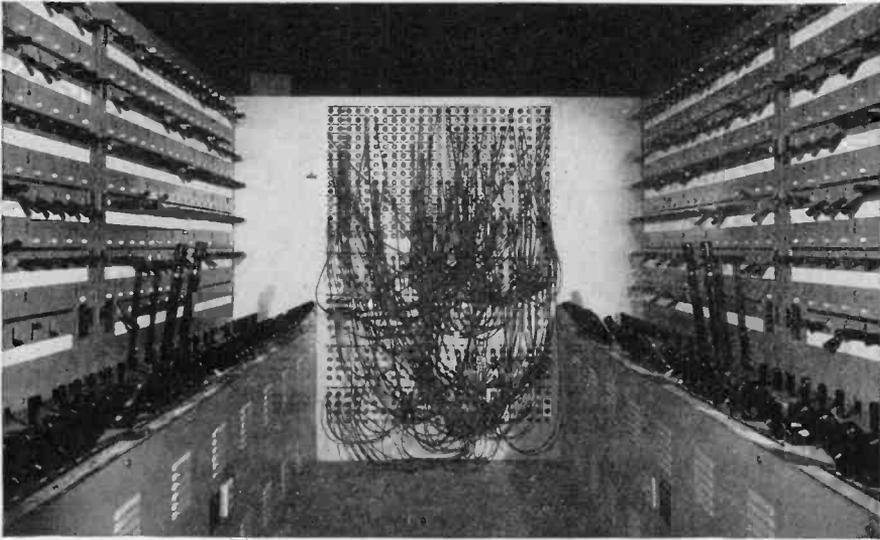


FIG. 14-19. This studio lighting switchboard incorporates switching, transformer-type dimming, and patching facilities. The jacks at the top of the board connect to individual lighting fixtures, those at the bottom to switches (small handles) or to dimmers (large handles on the horizontal portion of the assembly).

into groups of from perhaps 5 to 15 switches with their inputs connected together and thence to an input plug. The output from each branch switch is made available via a receptacle, all branch circuits being equipped with a mating plug. Thus any desired combination of branch circuits may be connected to a given bank of branch circuit switches which, in turn, may be connected to any one of the submaster switches that are provided.

Although a plug and receptacle arrangement provides the maximum amount of flexibility in a lighting switchboard, the patch panel can become a tangled collection of patch cords, as shown in Fig. 14-19. This can be avoided by the use of a number of selector switches but, except in the smallest of installations, this approach is likely to be either limited in its flexibility or exceedingly elaborate in its equipment requirements.

A lighting control board employing rotary selector switches is shown in Fig. 14-20. This particular board is equipped with 72 rotary switches, the arms of which are connected to an equal number of lighting circuits. Each switch is equipped with 12 contacts, the corresponding contacts on all switches being connected in parallel. In the switchboard illustrated,

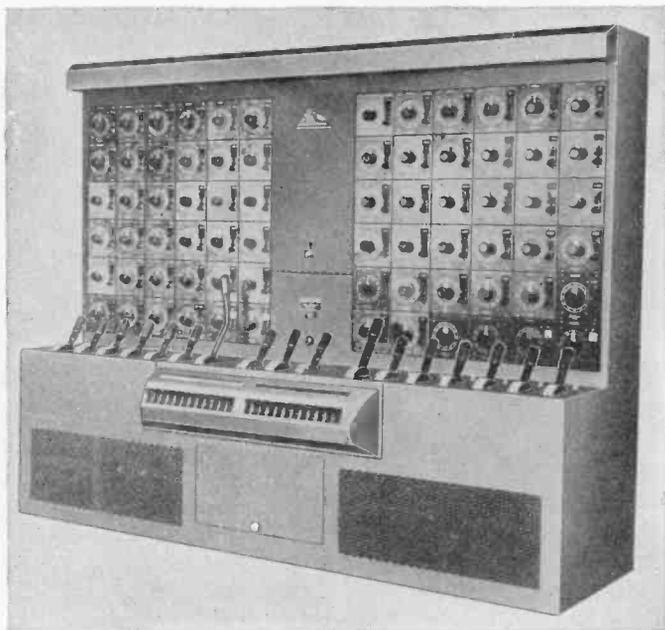


FIG. 14-20. Each dimmer on this studio lighting switchboard (large handles in foreground) has a rotary switch associated with it, thereby providing means for readily connecting each dimmer to any one of a number of load circuits. (Courtesy of Kliegl Bros., Inc.)

10 of these 12 circuits are connected to 4-kw dimmers, as shown in Fig. 14-21, and the remaining two are connected directly to the power mains through suitable circuit breakers. Each of the rotary switches has an associated circuit breaker, rated at 20 amp, which also serves as a silent-acting control switch. With the switchboard shown, any number of the 72 lighting circuits can be connected to any one of the 12 supply circuits (bearing in mind the maximum capacity of the various circuits) by rotation of the correct selector switches. Switchboards employing various combinations of rotary selector switches, dimmers, and circuit breakers can be fabricated, of course, in whatever combination and size a given installation requires.

Regardless of whether or not a patch panel or selector switch is used,

the individual branch circuits themselves can be wired directly to lighting fixtures. This is the usual practice for fixtures that are permanently installed. However, except possibly those used to provide the base light, fixtures are seldom installed on a permanent basis except on those sets that are used, unchanged, day after day. Instead, television studios usually

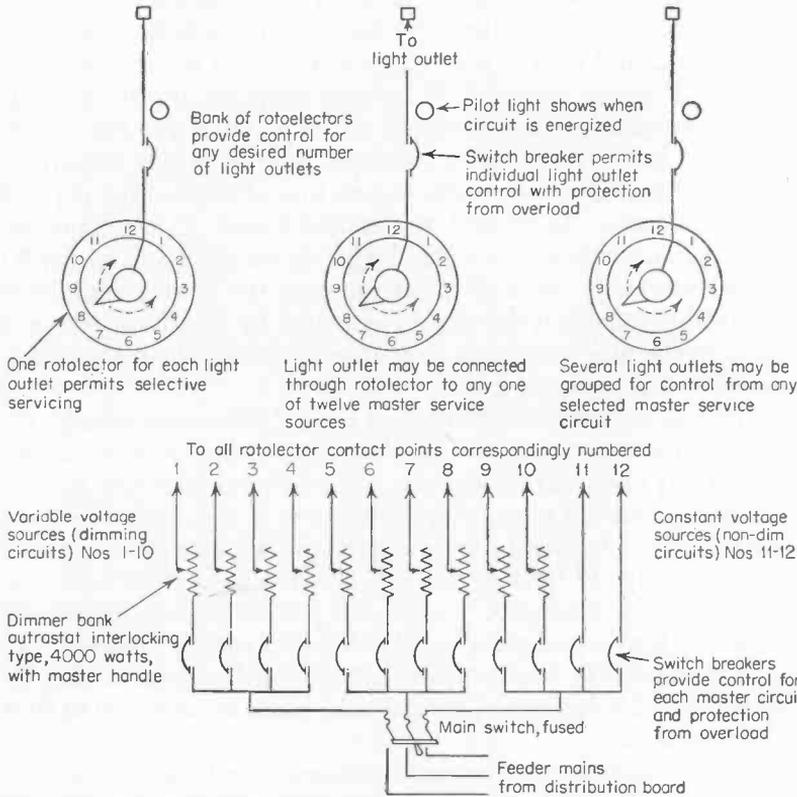


FIG. 14-21. Schematic circuit diagram of a lighting control board employing rotary selector switches. (Courtesy of Kliegl Bros., Inc.)

make a practice of considering most of their fixtures as portable units that are installed on sets in accordance with daily requirements. Under these circumstances, provisions must be made for conveniently located receptacles to which the fixtures may be connected as they are installed. Where an arrangement of this type is employed, a group of the afore-mentioned branch circuits usually terminate in receptacle strips, the majority of which are located on the lighting grid but with some (perhaps, 5 per cent) on the walls of the studio for accommodating floor lights. Each of the strips may contain five or so outlets spaced approximately 2 ft apart,

the power to each outlet being controlled by one of the branch circuit switches.

The number of submaster and branch circuit switches required for a given television studio depends upon a number of factors, including (a) the elaborateness of the productions to be handled, (b) the studio size, (c) the probable maximum number of sets, (d) the number of setups that must be simultaneously handled, (e) the amount of lighting equipment to be controlled, and (f) the percentage of time that the studio is in use. The amount of power required for lighting purposes also depends upon many of the factors just mentioned and others pertaining to the sensitivity of the camera tube. All things considered, lighting power requirements vary from about 15 to 50 watts per square foot of studio area depending upon the studio size. In general, the smaller figure (15 watts per sq ft) applies to the larger studios, and the larger figure (50 watts per sq ft) to the smaller studios.<sup>1</sup> At any given moment the power requirements would probably not equal the total represented by the above figures, but provisions in the way of feeders and branch circuits should be made to accommodate this potential load.

Since branch circuits are often wired for a 2,000-watt capacity, it follows from the above that each branch circuit should be able to handle between 40 and 130 sq ft of floor area. This assumes, however, that every branch circuit is loaded to capacity. Since one of the reasons for providing a flexible branch circuit arrangement is to obtain individual control over several groups of lighting fixtures, it is not likely that each branch circuit will be fully employed. Rather, the pattern of connections will be determined by the desired grouping of fixtures for control purposes. Thus, it is wise to provide at least twice as many branch circuits as the above calculation would indicate, *i.e.*, one branch circuit for every 20 to 60 sq ft of studio floor area.

There are, of course, endless combinations of submaster and branch circuit switches, of outlet strips, and of switchboard arrangements. The particular design adapted for any given studio will depend upon the various factors mentioned above and, in addition, the amount of flexibility that is required. In any event, if the switchboard is located in the studio itself, it is important that only silent-operating switches be used in order to avoid the possibility of air-borne noise being picked up by the microphones that are in use.

**14-6. Studio Control Rooms.** Just as in aural broadcasting practice, it is customary to associate a control room with each television studio. At this point, however, just about all resemblance between aural and television

<sup>1</sup> Gurin, H. M., *Lighting Methods for Television Studios*, *J. SMPTE*, Vol. 55, No. 6, p. 576 (December, 1950).

control rooms ceases. For one thing, a television control room must accommodate more equipment and more people than an aural control room; therefore, it is considerably larger on the average than its aural studio counterpart. Next, the problem of visibility from the control room into the studio, and vice versa, is quite different in the two instances. Further, the lighting in the control room and, to some extent, the acoustics present different problems. Finally, because of the greater amount and kinds of equipment in a television studio control room, there is a corresponding greater number of possible combinations and permutations in the physical layout of the equipment than in aural broadcasting.

**Basic Configurations.** The equipment and personnel immediately associated with the operation of a television studio, but not located on the studio floor, include (a) the camera-control units and those responsible for their operation, (b) the video switching or camera selection controls and the operator thereof (often the technical director or crew chief), (c) the audio console, associated turntables, and the audio control man, (d) the program director, (e) the assistant program director, (f) the intercommunication facilities, and (g) the visitors.

In most instances all the facilities and persons enumerated above are located in the studio control room. However, in a few cases separate rooms have been provided to accommodate one or more of the functions enumerated. For instance, in some installations the audio control console and its associated facilities and personnel have been located in a separate control room. This makes it easier for the audio man to concentrate upon the quality of the sound pickup without competition from the activities of numerous other persons in the control room. On the other hand, this arrangement complicates the intercommunication problem between the director, the video switcher, and the audio man. When all three are in the same control room, they can depend upon direct conversation for communication with each other. When separated, the audio man must employ either a headset or a loudspeaking intercommunication system. Neither arrangement is particularly satisfactory since wearing a headset is not conducive to judging quality from a monitoring loudspeaker nor is an intercommunications loudspeaker a materially better arrangement. On the other hand, the audio man should be in a position to hear the continual flow of instructions that are originated by the program director as he produces the program. In some instances, the audio control console has been located immediately adjacent to the video control room and separated therefrom by means of a sliding glass panel. With an arrangement of this type, the audio and the video control equipment may be separated from each other or not, depending upon the nature of the program being produced and the wishes of those responsible for the operation.

Still another variation from the practice of placing all the audio and video facilities and personnel in one control room is the location of the camera-control units in a separate room while maintaining all other equipment and personnel in a main studio control room. This arrangement is probably more practical than segregating the audio and video control equipment as described above, since the intercommunication problem can be handled by regular means without materially interfering with the

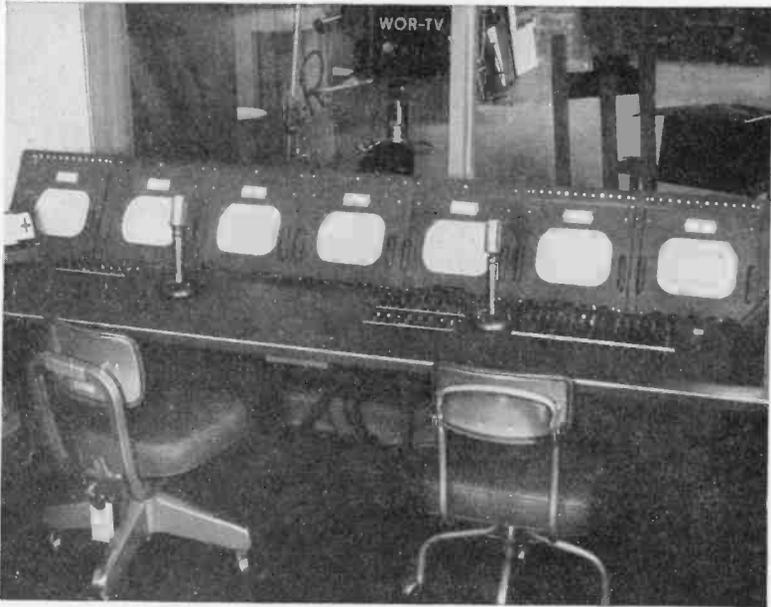


FIG. 14-22. In this television studio control room, one picture monitor is provided at the left for preview purposes, followed by four monitors for an equal number of studio cameras, then an outgoing-line monitor, and finally a second preview monitor at the extreme right end of the array. The program director's position is at the left and the video switcher's at the right. The camera-control units are located in a separate control room. (Courtesy of WOR-TV, New York.)

duties of the personnel responsible for the operation of the camera-control units. On the other hand, this arrangement deprives the occupants of the control room of the opportunity of viewing the output of each camera on the picture and waveform monitors that are invariably associated with camera-control units. Consequently, when the video facilities are segregated in this manner, a larger investment in equipment is necessary in order to repeat in the main control room (see Fig. 14-22) the picture information appearing upon the camera-control units.

Further, whether repeating monitors are used on all camera outputs or a few preview monitors are used in their place, there is always the possibility of a disagreement between the displays on the picture monitor associated with the camera-control unit and the corresponding one in the main control room. Since this can occur without those in either control room being aware of the discrepancy, misunderstandings as to picture quality, composition, geometric distortion, and noise may result.



FIG. 14-23. All the camera-control units for two medium-size studios, two announce studios, and a telecine room are concentrated in this single control room which thus serves the entire studio plant. This arrangement eliminates the need for camera-control units in the individual studio control rooms. (Courtesy of WOR-TV, New York.)

In at least one instance segregation of the camera-control units has been carried to the limit by locating all control units for the entire studio plant in a camera-control center (see Fig. 14-23). This arrangement provides considerable flexibility since any camera-control unit may be associated with any studio (except to the extent that studio and film cameras are of a different type) by means of a camera cable patch panel. Thus, if the needs for a particular program are such as to require the entire complement of available cameras in one studio, it is only necessary to wheel the cameras into the studio, and by means of camera cable tie lines and an associated patch panel, to connect them to the camera-control units. The output of the camera-control units is then made available to the switching system associated with the studio control room involved by means of conventional video jack panels and patch cords.

**Control-room Details.** Television studio productions are usually under the control of a program director who, by means of verbal instructions, cues those responsible for carrying out various phases of the work. Among other things, he usually advises both the audio and video switcher when

to make camera angle and scene changes. When both the audio and the video men are in the same control room with the program director, dependence is placed upon aural instructions, delivered directly. This requires that both the audio and the video men be within hearing distance of the program director. Further, on occasion an assistant director is also present. Thus, there may be four persons in the control room who are closely associated in the production of a television program. Although all four are often located in a single line parallel to the observation window that affords a view into the studio, there is no universal order in which these control-room occupants are seated. There are, however, certain contributory factors which tend to point to a particular sequence that is preferable to others, assuming that there are no existing building layout conditions that prohibit free choice of the equipment arrangement.

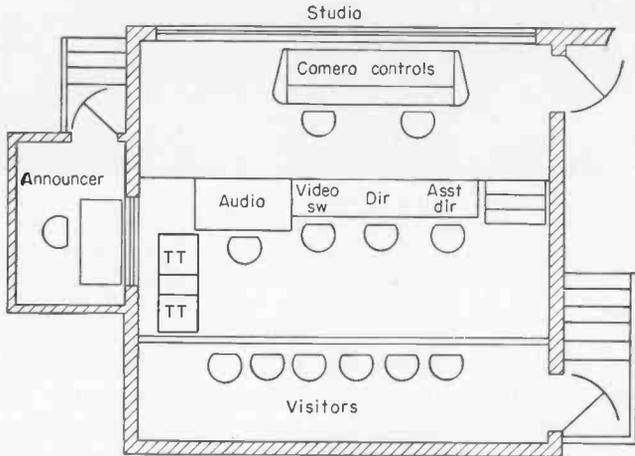


FIG. 14-24. A television studio control-room plan that has proved very successful. The camera-control units are at studio floor level (or slightly above), the video switcher and his associates at a somewhat higher level, and control-room visitors at a still higher level.

Turntables are almost always associated with the audio facilities that are a part of a television studio control room. Most right-handed persons find it easier to operate these turntables when they are located at their left, as shown in Fig. 6-21. Since it is generally undesirable to place the barrier formed by a pair of turntables between the audio man and the remaining occupants of the control room, it follows that the audio console and its associated turntables should be placed at the left end of the row.

As a rule, the assistant program director is seated adjacent to the director in order to be close at hand to carry out the latter's instructions.

This leaves the question as to whether the program director and his assistant should be flanked on one side by the audio man and on the other by the video man, or if both technical men should be on the same side of the program director. Since the directions given by the director usually concern both technical men simultaneously, it is generally believed better to place both of them to the same side of the director so that he may address germane remarks in the general direction of both technical men.

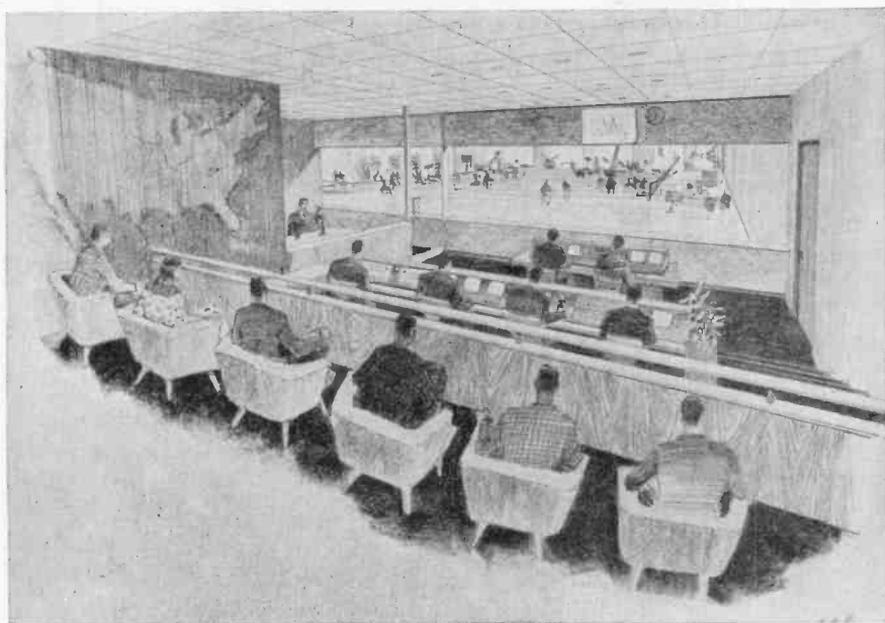


FIG. 14-25. The excellent visibility afforded by the control-room arrangement shown in Fig. 14-24 is evident from this sketch. Each tier is at a successively higher elevation, and all persons are thus afforded a good view of the facilities in front of them.

The factors cited completely define the location of the four persons considered since, to fulfill the conditions outlined, with the audio man at the left end of the row, the video switcher must be adjacent to him, next the program director and finally, on the right end, the assistant program director, as shown in Fig. 14-24. Variations of this basic arrangement are found, of course, since space limitations often require that other configurations be used.

Where the camera-control units are located in the studio control room, they may well be placed in a line in front of the one formed by the audio console, video switcher, and production desk, as shown in Figs. 6-24 and 14-25. In this position, the audio man, video switcher, production director, and his assistant can all see the picture monitors associated with

each camera, *provided* the elevations of the equipment and the control-room floor levels are correctly proportioned, as shown, for example, in Fig. 14-26. This arrangement is economical of picture monitors and avoids the need for picture repeaters at the production desk position.

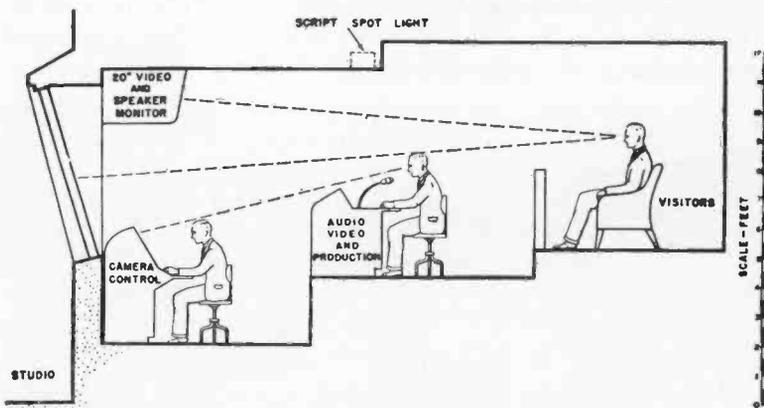


FIG. 14-26. The elevations of the multiple-tiered control room must be carefully determined in order to provide each group of persons with an unobstructed view of the picture monitors and other facilities.

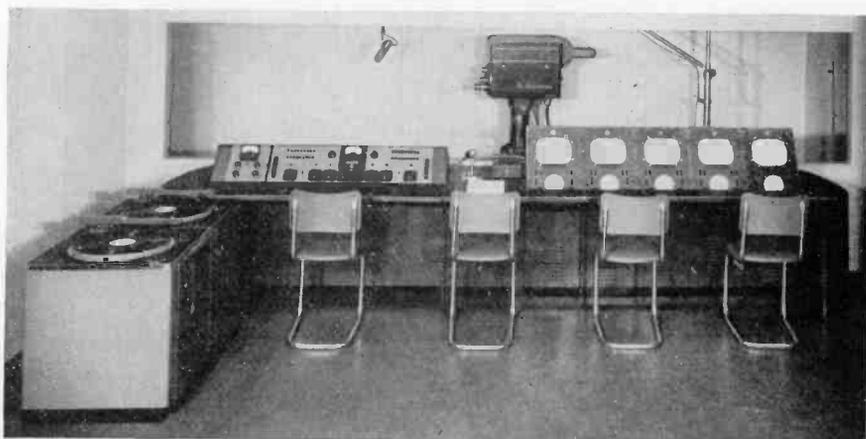


FIG. 14-27. An in-line arrangement of equipment may be used where control-room depth or ceiling height is not available. It does *not* provide all concerned with a good view of the picture and waveform monitors.

On occasion, existing conditions are such that the camera-control units, video switcher, and audio console must all be placed in one long line, as shown in Fig. 14-27. In general, this arrangement has not proved so satisfactory as the double-tier arrangement just described, primarily because

it does not provide a working space for the program director nor a position from which he can readily see the various picture monitors. In addition, the audio man is in a poor position to see the outgoing-line picture monitor and thereby obtain cues for the various operations that he must coordinate with the production in general.

Where space for visitors is provided, it should, of course, be either completely separate from the control room or, if overlooking the control room as suggested in Figs. 14-24 to 14-26, it should be partitioned therefrom by a glass observation window. Adequate aural and visual monitoring facilities should be provided in visitor spaces although, when visitors can overlook the control room, it may be possible to dispense with a separate picture monitor for the visitor area.

**Visibility from Control Rooms.** In aural broadcasting studios it is customary to provide the best possible visibility from the control room into the studio, and vice versa. The need for excellent two-way vision requires complementary design of the studio and the control-room lighting and the choice of control-room window angles that avoid glare and unwanted reflections when viewed from either side.<sup>2</sup>

In a television studio control room, strangely enough, this problem is greatly simplified since, for the most part, there is little need for vision from the studio into the control room unless the production is so simple that it is undertaken without the assistance of a floor manager. As a matter of fact, in monochrome television applications, there is little need, either, to see *from* the control room *into* the studio since, in any event, the program director can make use of only the pictures being produced by the cameras on the floor. Perhaps the most useful purpose served by a control-room window in this instance is to let the occupants of the control room see what is going on in the studio in general and to permit them to visually determine the whereabouts of equipment, properties, sets, and personnel. Thus they may avoid requesting an impossible move of a camera, microphone boom, stage property, or actor. Even so, in practice, sets are quite likely to block the view of those in the control room and, usually, full utility cannot be made of the available studio floor area if sets must be arranged so that vision into all of them is to be had from the control room.

Since vision *from* the studio *into* the control room is not generally a factor, the angle that the control-room observation windows make with the vertical may be selected wholly from the viewpoint of eliminating undesirable specular reflections from the control-room side. Depending upon the layout of the control-room lighting, the arrangement shown in

<sup>2</sup> Chinn, H. A., CBS Studio Control-console and Control-room Design, *Proc. IRE*, Vol. 34, No. 5, p. 287 (May, 1946).

Fig. 14-26 generally proves satisfactory. Other acceptable configurations can also be worked out, of course.

**Control-room Lighting.** As compared to the amount of light employed on a set in the television studio, the lighting in a control room is considerably subdued. As a matter of fact, in order that the control-room occupants may properly judge the picture quality being produced, it is desirable that the amount of light falling upon the face of picture-tube monitors simulate that in the average home situation. On the other hand adequate lighting is required for reading of the script and other program production notes. Fortunately, as explained above, it is usually not necessary to provide, in addition, enough light so that occupants of the studio may see those in the control room.

The desired control of the amount of room light falling upon the face of picture monitors may be obtained in one of two ways. If more or less conventional types of overhead lighting are employed for general illumination, it will generally be necessary to shield the face of the picture tubes with suitable hoods. On the other hand, by installing adjustable script spotlights the amount, direction, and shape of the area that is lighted may be completely controlled. Such fixtures are usually installed on the surface or flush with the ceiling (see Fig. 14-26), and self-contained adjustable framing shutters employed to control the light thrown upon working surfaces.

**Control-room Acoustics.** If evaluation of the quality of the sound pick-up were the only consideration, it might well be argued that the acoustics of a television studio control room should approximate those of the average living room where the program material is ultimately reproduced. As a matter of fact, this criterion is probably not far from the optimum although, if the reverberation time differs materially from that of a living room, the deviation should be toward a slightly lower reverberation time. A trend in this direction is desirable because in the television studio control room, in addition to the monitoring loudspeaker, there is often sound from turntable cueing loudspeakers, from the intercommunication system conversations, and from the instructions being passed directly back and forth between control-room occupants. In practice, depending upon the enthusiasm and the vocal energy that those in the control expend in carrying out their assignments, the environment may or may not become a trifle noisy.

From an acoustical viewpoint, the air-conditioning system in the control room (and, of course, the studio itself) should be designed in accordance with the good engineering practices that have been established for aural broadcasting studios. In particular, it is important to maintain orifice noise at a satisfactorily low level and to take the usual precautions

to prevent sound transmission from one area to another via the air-conditioning ducts.

**14-7. Studio Supporting Areas.** Since it is the intention of this book to cover primarily the technical facilities employed by a broadcasting station, no attempt is made to discuss, in detail, the building space requirements of the many supporting activities that are essential to the operation of a television station. Rather, a check list is presented of some of the numerous areas (other than office space) that must be given consideration in planning a television studio plant (the order of presentation has no special significance).

<i>Area</i>	<i>Remarks</i>
<i>a.</i> Stage properties storage	At least equal to studio floor area
<i>b.</i> Scenery storage	Ceiling heights commensurable with the size of the flats
<i>c.</i> Scenery painting	Preferably located convenient to the studios
<i>d.</i> Carpenter shop	For preparation of flats and stage properties
<i>e.</i> Paint shop	For finishing stage properties
<i>f.</i> Dressing rooms	Preferably immediately adjacent to studios
<i>g.</i> Wardrobe storage	Preferably convenient to dressing rooms
<i>h.</i> Air-conditioning equipment	Sound and vibration isolation of equipment possibly necessary
<i>i.</i> Television-equipment maintenance shop	Preferably convenient to all equipment areas
<i>j.</i> Building-equipment maintenance shop	
<i>k.</i> Garage for mobile unit	
<i>l.</i> Field-equipment storage	Preferably convenient to mobile unit garage or loading ramp
<i>m.</i> Photographic darkroom	If films are to be developed and printed on the premises
<i>n.</i> Rehearsal rooms	To relieve demands for studio facilities
<i>o.</i> Shipping room	For handling shipments of film and supplies
<i>p.</i> Loading ramp	Ample size important if scenery or stage properties are built or stored off the premises

**14-8. Master Control Rooms.** In order to simplify the cable delay problem (see Sec. 2-3, *Horizontal-deflection Circuits*) it is preferable to locate a master control room approximately equidistant from all contributing studios. When located in this manner, the amount of interconnecting cable and associated wireways is often a minimum. Except for this consideration and possibly the matter of easy access to studio control rooms

from master control, there is no limitation on the location of the master control room that is associated with a group of television studios.

The size of a master control room depends upon the number of studios, upon the number of incoming and outgoing program lines that it must serve, and also upon the type of video equipment layout that is employed.



FIG. 14-28. An efficient master control outgoing-line switching console that places essential controls within easy reach of operating personnel. The functions of the various equipments are described in the text.

If each studio control room is set up on a more or less self-contained basis, then a smaller master control will suffice than if only a minimum of equipment is installed in the studio control room and the bulk of it located in the master control area. In any event, in planning a master control room, adequate space should also be provided for supporting services, such as incoming and outgoing audio, video, and telephone circuits, regular and emergency primary power-supply service entrance boxes and change-over switch, and most important of all, for the future expansion of all facilities.

In most master control rooms, the bulk of the audio and video equipment is mounted in standard equipment racks. In the small station, the switching and monitoring facilities, together with the private-line telephone switchboard, are often contained in adjoining racks with a counterlike shelf built out from the racks to serve as the operations desk. This is a very practical arrangement and is economical in space and wiring requirements. Where a somewhat more elaborate arrangement is justifiable,

a separate operating desk may be employed for necessary controls, as shown in Fig. 14-28. In the left foreground of this photograph there is a group of outgoing-line switching sections. Each section consists of a volume indicator at the top, a picture and waveform monitor in the center, and audio, video, and stabilizing amplifier controls in a lower panel that is

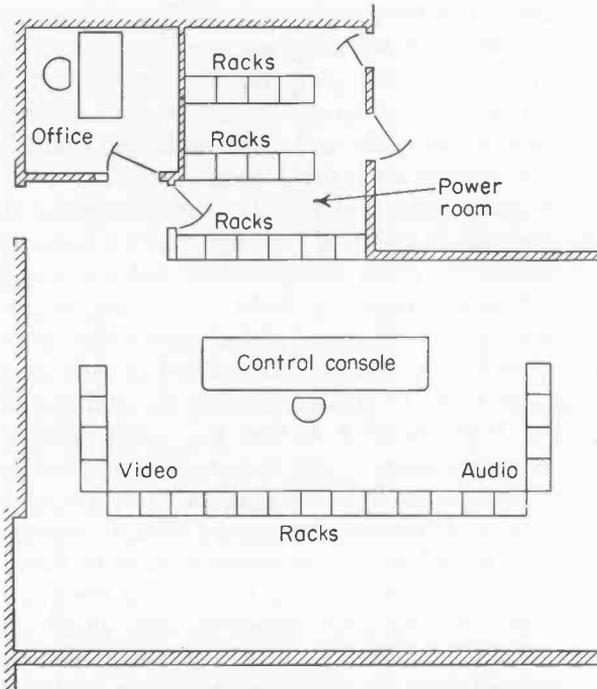


FIG. 14-29. In this master control-room layout the equipment racks are back of the operating personnel seated at the control console. This arrangement makes the racks more accessible to these operators than would be the case if the racks were in front of the console.

sunk below the desk top. Each section serves to monitor the program material being transmitted to the outgoing line associated with the section. The upper panel in each section also contains a rotary preset selector switch that determines the studio or remote program source that is next to feed the outgoing line associated with the section. After the desired program source is preselected, it may be connected to the outgoing line at the proper moment by the operation of a pushbutton. The switch-over from one program source to another may be effected on all lines simultaneously by operation of a master button or on each section individually by operation of buttons associated with the separate sections.

Further, if desired, any given section or sections may be excepted from the group operation by operating a by-pass switch.

To the right of the switching section of this control desk there is located a private-line telephone switchboard, over which there are installed controls for selecting the program source that is sent for cueing purposes to associated studios and remote points. Furthermore, the switching section immediately to the left of the telephone switchboard is actually a testing section rather than one for servicing an outgoing line. Thus, when a telephone call is received from a program originating point, the operator may select the proper cueing signals for the studio or remote point involved and may check the audio and video level and quality on the test selector, all without leaving the control desk.

The equipment racks associated with the control console shown are to the back of the operator at the desk (see Fig. 14-29) rather than in front of him. This location may seem strange at first, but it is actually the most convenient one. There is relatively little to be watched on audio and video racks, assuming that all the essential monitoring instruments are located on the control desk. On the other hand, it may be necessary to go to the equipment racks to change patch-cord arrangements or make other adjustments. If the racks are located in front of the control console, it becomes necessary for those at the desk to walk around it every time an operation is to be performed at the racks. On the other hand, by placing the racks back of those at the control desk, it becomes necessary for the technical personnel merely to swing around in their chairs and, upon standing, they are automatically in front of the equipment racks.

The master control arrangement shown in Fig. 14-29 also shows a method whereby the bulk of the heat-generating equipment (power supplies) may be removed from the master control room proper and thereby reduce the air-conditioning load in this room. A so-called power room is formed in one corner, with a line of racks forming the lower portion of the front wall. Curtain walls (of plaster or equivalent) above the racks complete the closing off of this section from the main master control room. Since the power room is not normally occupied by operating personnel, it need not be air-conditioned as precisely as other areas. As a matter of fact, depending upon the maximum ambient temperature, it may be satisfactory simply to ventilate the power room in a controlled manner, keeping in mind the need for maintaining the operating temperature of electrolytic condensers below their critical value.

## Equipment Installation Practices

PARTIALLY BECAUSE IN SOME RESPECTS the eye is more discerning than the ear when it comes to detecting distortion and partially because a wider band of frequencies is involved, the installation of television facilities is a more exacting engineering undertaking than the installation of equipment for an aural broadcasting station. Furthermore, because of the ever-present possibility of r-f pickup by the audio circuits and of cross talk between video and audio circuits, and vice versa, even the installation of the audio facilities requires more attention than is normally necessary in an aural broadcasting installation. Experience has shown, however, that there are no insurmountable problems and, in most instances, all potential difficulties may be avoided by following good engineering practices.

Program transmission facilities for a television station comprise both audio and video systems. In practically every instance, the installation is custom-designed and custom-built to meet the particular operating needs of the station concerned. As a rule this involves (a) the assembly and wiring of the necessary audio and video equipment into racks, consoles, wall boxes, cabinets, or other suitable housings, and (b) the interconnection of the various equipment assemblies with each other and with incoming and outgoing audio and video circuits. This work entails the selection of suitable types of wire, cable, connectors, jacks, terminal strips, racks, conduits, and associated items. Of equal importance are the methods employed for connecting wires to their terminals, for grounding cable shields, for routing and segregating various kinds of circuits, and for similar practices. Successful methods of undertaking these operations are detailed in following sections.

**15-1. Video Wire Types.** In a television station installation, video frequencies up to 8 or 10 Mc are commonly encountered and, with very few exceptions, are handled by means of coaxial cables such as those shown in Fig. 15-1. Since coaxial conductors normally have their outer sheath grounded, they can accommodate only one-side-grounded circuits. Bal-

anced-to-ground circuits require "twinax" cables (see samples shown in Figs. 12-2c and 15-1) which, although extensively employed in the telephone plant, are seldom found in broadcasting stations. Balanced-to-ground transmission circuits require more complicated equipment facilities and, as a matter of fact, are not provided for in present industry standards covering broadcasting video equipment. Rather, these standards specify that all video equipment shall be constructed so as to accommodate source and load impedances of 75 ohms with one side grounded. On the other hand, balanced-to-ground transmission circuits offer certain transmission advantages, particularly on the longer video circuits. Their use in broadcasting plants will undoubtedly increase with time.

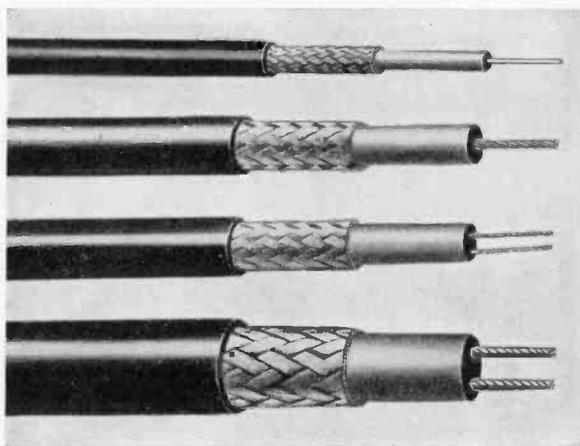


FIG. 15-1. Examples of coaxial and "twinax" cables suitable for video applications. From top to bottom: Types RG-59/U, RG-11/U, RG-22/U, and RG-57/U. (Courtesy of American Phenolic Corp.)

**RG-11/U Cable.** The characteristic impedance of RG-11/U cable is nominally 75 ohms thereby matching the circuit impedance generally employed for broadcasting video facilities. It consists of an inner conductor, composed of seven strands of No. 26 tinned copper wire, which is insulated from a braided copper wire shield by a solid polyethylene dielectric, as shown in Table 15-1. A vinyl outer jacket protects the braided shield from damage and, in addition, prevents it from being grounded in a random and uncontrolled manner.

The attenuation vs. frequency characteristic of RG-11/U cable over the video-frequency range is shown in Fig. 15-2. It is evident from these data that, when the total amount of RG-11/U cable in a video circuit does not exceed a few hundred feet, the attenuation characteristic is not

unduly detrimental. Where several hundred feet of cable are involved, however, resort to equalization may be necessary in order to prevent undesirable degradation of the picture signal.

TABLE 15-1. CHARACTERISTICS OF COAXIAL CABLES

RG-/U No.	Nom. Imp. Ohms	Nom. Cap. Mmf/Ft.	Inner Conductor	Dielectric Nom. O. D.	Inner Shield	Vinyl Jacket	Nom. O. D.	Lbs. Per 100 Ft.	Max. Oper. Volts Rms
								Velocity of propagation 65.9%	
<b>COAXIAL</b>									
11	75	20.5	7-26T	.285	C	Black	.405	10.9	4000
59	73	21	22CW	.146	C	Black	.242	4.4	2300
<b>LOW CAPACITANCE COAXIAL</b>									
62	93	13.5	22CW	.146	C	Black	.242	4.0	750

NOTE: T = tinned; CW = copper weld; C = copper.

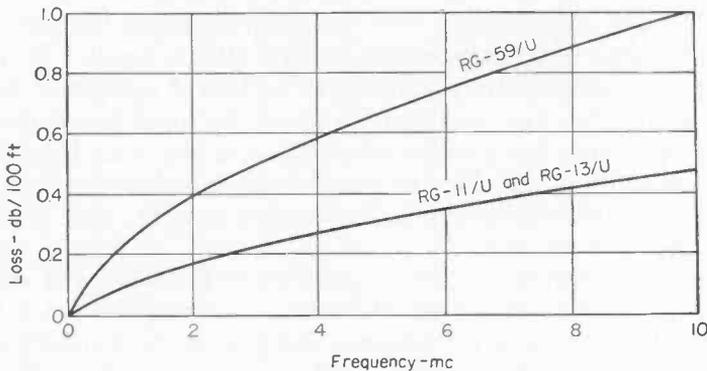


FIG. 15-2. Attenuation characteristics as a function of frequency of representative coaxial cables.

**RG-59/U Cable.** The characteristic impedance of RG-59/U coaxial cable is nominally 73 ohms which is so close to the standard television circuit impedance of 75 ohms that the difference is of no consequence for video applications. The general construction of RG-59/U cable is similar to that of RG-11/U except that a solid No. 22 copper-weld wire (a copper wire with a steel core) is used for the central conductor. Accordingly,

as shown in Table 15-1, the nominal diameters of the two cables are 0.242 and 0.405 in., respectively, and three times as many RG-59/U cables can be placed in a given wireway as RG-11/U cables. Furthermore, the minimum bending radius of cables of this type is usually taken as ten times their outer diameter which, for RG-59/U amounts to 2.4 in. and for RG-11/U comes to 4 in.

The small size of RG-59/U is not without its drawbacks, however. As shown by the appropriate curve in Fig. 15-2, the attenuation of RG-59/U cable is more than twice that of RG-11/U cable. For this reason, the use of the smaller diameter RG-59/U cable is usually restricted (*a*) to short runs, say less than 30 ft, (*b*) for use where a large number of cables terminate within a small area and it is physically impossible or extremely difficult to employ the larger cable, *e.g.*, a video jack field, (*c*) for emergencies where the required number of RG-11/U cables cannot be installed in an existing wireway because of size restrictions, and (*d*) for video patch cords.

**RG-62/U Cable.** The impedance of RG-62/U cable is nominally 93 ohms which is appreciably removed from the standard television video circuit impedance of 75 ohms. However, it has a special characteristic that makes it particularly useful for one particular application in equipment interconnections. The capacitance of RG-62/U cable is only 13.5  $\mu\text{f}$  per foot compared to 20.5 and 21  $\mu\text{f}$  per foot for RG-11/U and RG-59/U cable, respectively. This characteristic makes the cable useful for short bridging runs not exceeding perhaps 10 ft in length. By a bridging connection is meant the paralleling of a piece of equipment having a high input impedance across a through circuit, the input impedance of the bridging equipment being sufficiently high so as not to load the through circuit appreciably. In order to guard against undesirable reflections, such bridging connections must be undertaken so as to avoid branch circuits, as shown in Fig. 6-8.

The manner whereby the lower capacitance is achieved is shown in Table 15-1. Instead of a solid dielectric supporting the inner No. 22 copper-weld conductor, a polyethylene string is wrapped spirally around the conductor and holds it centrally with relation to a polyethylene tube. The usual braided copper shield or outer conductor is supported by this dielectric tube. This combination of dielectrics reduces the total amount of polyethylene between the inner and outer conductors while providing adequate support to hold the inner conductor centrally with respect to the outer. The attenuation characteristics of RG-62/U cable are not shown in Fig. 15-2 since (*a*) it closely parallels that of RG-59/U and (*b*) it is seldom, if ever, used in broadcasting applications for other than bridging connections and then in very short lengths.

**15-2. Camera Cable.** The cables that are used for connecting television cameras to a camera-control or an intermediary unit are especially designed and constructed for this service. They customarily consist of three coaxial conductors and either 21 or 24 single conductors. Each coaxial conductor usually consists of an inner conductor composed of seven strands of No. 28 AWG bare copper wire (equivalent to a No. 20 AWG conductor) which is surrounded by a polyethylene dielectric having an outer diameter of 0.116 in. Over this insulation there is woven a braided shield composed of No. 36 AWG tinned copper wire over which there is a woven color-coded cotton or rayon braid. The surge impedance of such coaxial cable is 50 ohms.

The 21 or 24 individual conductors each consist of seven strands of No. 30 tinned copper wire (equivalent to a No. 22 AWG conductor), rubber-covered, over which there is woven a rayon braid which is lacquered and color-coded. For assembly purposes the single conductors are usually divided into three groups and then, together with the three coaxial conductors, the six groups are assembled around a waterproof jute core. The entire assembly is then taped and covered with a woven shield composed of No. 36 tinned copper wire over which there is placed a woven cotton braid and a neoprene outer jacket. The nominal over-all diameter of the finished cable is 0.82 to 0.84 in. and it weighs approximately 37.5 lb per 100 ft.

The camera cable described is normally terminated on connectors having three coaxial and 21 single contacts. The extra conductors in the camera cables having more than 21 single conductors serve either as spares in the event that a regularly used conductor becomes defective or are paralleled with other conductors to provide a few circuits of lower resistance than is afforded by single conductors. In addition to being used to connect studio and field cameras to their respective control units, camera cable is often used for other video equipment applications. For example, the same type of cable and connectors is sometimes used to connect film cameras to their control units, and microwave transmitters and receivers to their respective control units.

When utilized with studio cameras, the three coaxial circuits are usually employed for transmitting horizontal and vertical driving pulses to the camera and for conveying the video output from the camera to the associated control unit. Of the 21 or more single conductors, 11 are often used for control voltages or currents for the camera tube and associate circuits, including multiplier focus, image focus, orthicon focus, target voltage, beam current, centering current, focus-coil current, and both regulated and unregulated B supplies. Of the remaining 10 single conductors, two are often used for headphone-cue circuits, three for the tech-

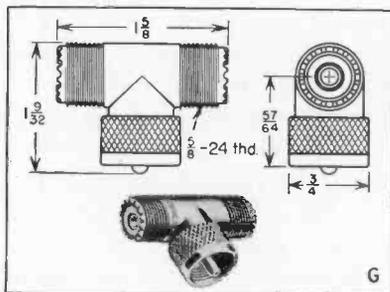
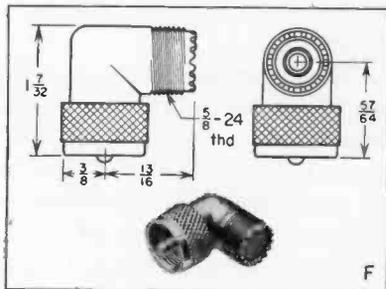
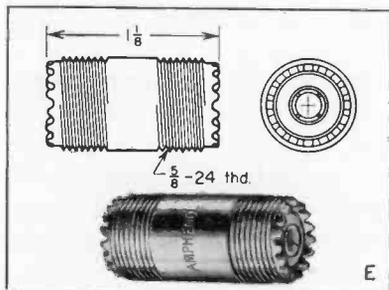
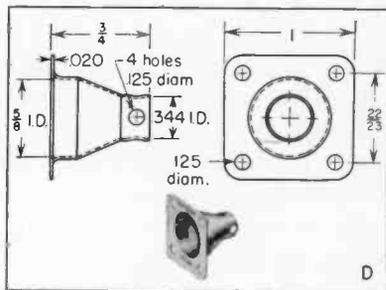
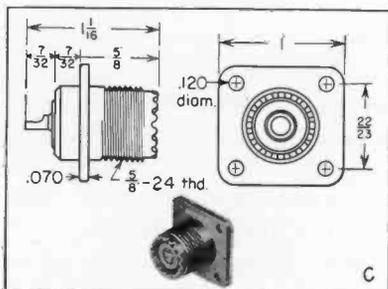
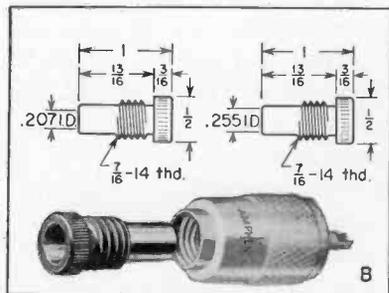
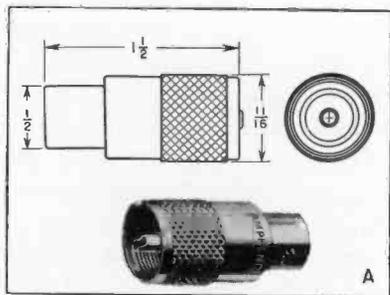


FIG. 15-3. Photographs and dimensional drawings of coaxial cable connectors suitable for video applications. A series of "twinax" connectors using the same size outer shells are also commercially available. (Courtesy of American Phenolic Corp.)

nical and production interphone circuits, four for 115-volt a-c power supply, and one for operation of the on-air tally-light relay. Different manufacturers sometimes utilize the available conductors in the camera cable for slightly different purposes, but the distribution enumerated is typical of that found in many cameras.

**15-3. Coaxial Cable Connectors.** The number of different kinds of cable connectors found in a typical television broadcasting plant is fabulous. A survey made in the field department of one station revealed the use of over 100 different *kinds* of connectors for audio, video, power, and communications circuits. The total number of connectors in use, of all kinds, ran into the thousands. At the studios of the same station, most of the connectors used in the field department were also employed and, in addition, still other types were found in service. Although this situation is not intolerable, it is far from convenient, and as the years go by, it will undoubtedly be simplified. Meanwhile, it is patently impossible to describe other than those types of video connectors that are used most and to omit any detailed description of the better known audio and a-c connectors and those connectors that are used only in small quantities.

**Coaxial Cable Plug.** Perhaps the most elementary video connector is the one that accommodates a single coaxial cable. The type shown in Fig. 15-3A is used extensively for this purpose. This coaxial cable plug is accurately machined from solid brass and heavily silver-plated. A knurled coupling ring carries a thread on its inner surface for locking the male cable plug shown to a female chassis receptacle or other junction. The coupling ring is independent of the body of the plug (but is captive thereon) and, therefore, may be rotated for the purpose of locking two connectors together without twisting the cable or the main body of the plug.

The integral nonrotating center pin contact of the plug illustrated is also silver-plated and insulated from the shell by a molded insert of low-loss dielectric. The plug has the dimensions shown in the accompanying illustration and is used extensively for RG-11/U cable. Where RG-59/U or RG-62/U cable is used, a reducing adapter of the type shown in Fig. 15-3B is required in order to grip these smaller diameter cables firmly.

The function of a coaxial connector is to join together two circuits while introducing the minimum impedance discontinuity into the circuit. For this reason and to ensure reliable operation, it is important to assemble connectors carefully in the intended manner, so that the features built into the connector are fully exploited.

**Coaxial Receptacles.** A coaxial receptacle is a necessary companion piece to the coaxial cable plug described above. The unit shown in Fig.

15-3C is used extensively for this purpose. The die-cast silver-plated zinc outer shell of the receptacles shown contains a serrated edge which mates with a similar edge within the mating plug. This feature locks the plug and the receptacle together, as soon as they are partially mated and prevents one unit from twisting with respect to the other. This greatly assists in the final tightening of the coupling ring and, more important, prevents twisting of the cable while the ring is being loosened.

Connection to the coaxial receptacle described presents no particular problem. The center conductor of the cable is soldered to the lug on the back of the receptacle provided for this purpose, and the shield is soldered to the shell of the receptacle. When the cable for these operations is prepared, the length of the unshielded inner conductor should be kept to a minimum.

In instances where even a small amount of unshielded inner conductor cannot be tolerated, a hood of the type shown in Fig. 15-3D can be applied to the back of the chassis receptacle. To install this hood, it is slipped *over* the pretinned shield and forced *under* the outer vinyl jacket a sufficient distance to permit reaching and soldering the center conductor to its lug. The hood is then pulled from under the vinyl jacket, pushed flush against the back of the receptacle, and soldered to the braid through the holes provided for the purpose.

Cable-type *receptacles* for installation on the end of a coaxial cable to mate with the coaxial *plug* described previously are *not* available as a standard item. Under these circumstances when both ends of a coaxial cable are to be fitted with connectors, it is necessary to use male plugs at both ends. Consequently, when it is desired to connect two lengths of coaxial cable together, use must be made of a junction of the type shown in Fig. 15-3E. In effect, this fitting changes a male plug into a female receptacle.

The right-angle plug adapter shown in Fig. 15-3F is another useful coaxial fitting which assists in situations where a coaxial cable approaches a receptacle from the side. In such circumstances the use of a right-angle plug adapter makes it unnecessary to provide for the relatively large bending radius required by coaxial cables and avoids undue strain on the cables. This strain would tend to pull the cables into a bend of small radius.

The T connector shown in Fig. 15-3G is another useful accessory for coaxial cable connections. It may be employed for making temporary multiple connections to a chassis terminal, *e.g.*, during testing and measuring work. In video applications it is generally not possible to use long branching circuits without detrimental reflections; consequently, a T connector must be used judiciously.

**Terminal Blocks.** In audio installations, it is common practice to make extensive use of terminal blocks at junction points in cable runs, in equipment racks, and elsewhere. Similarly, in video installations, terminal blocks may be used to advantage for parallel applications. In this instance, however, terminal blocks especially designed for video frequencies must be employed rather than those normally used in audio installations.

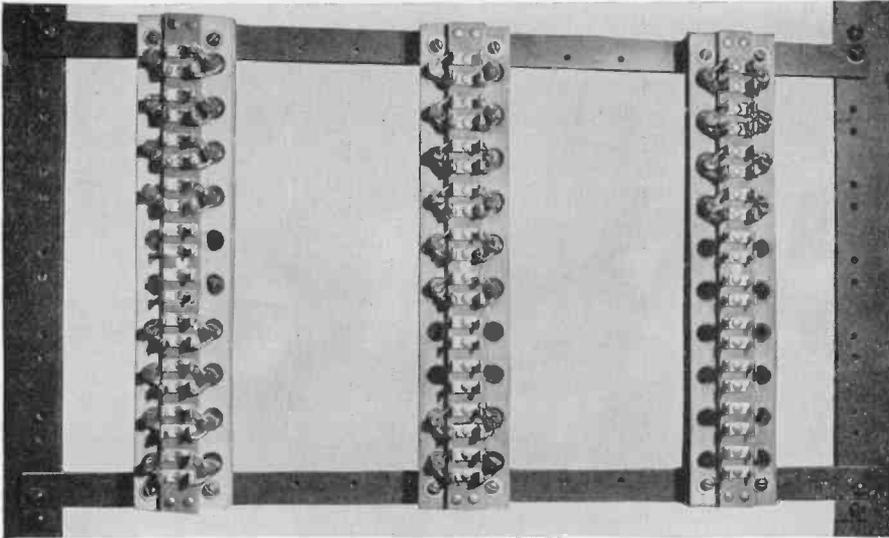


FIG. 15-4. A terminal block suitable for use in video applications at junctions of coaxial cables.

The video terminal blocks shown in Fig. 15-4 have been used extensively in CBS television plants and have proven entirely satisfactory in practice. No measurable cross talk, impedance discontinuity, or pickup of stray fields have been encountered even in circuits containing a multitude of terminal blocks throughout its length.

**15-4. Camera Cable Connectors.** As contrasted to the simple coaxial connectors described in the previous section, television camera cable connectors are relatively complex. Plugs and receptacles each having provisions for three coaxial cables and 21 single conductors are necessary in order to accommodate the conductors in a standard camera cable (see Sec. 15-2). Several types of connectors have been designed and manufactured for this service, but the ones shown in Fig. 15-5 are those in most widespread use.

The connector illustrated has three coaxial fittings and 21 straight pin connectors. Both the pin and the socket contacts are silver-plated and both are of partial floating construction to permit ready alignment of the

large number of contacts involved. The shell of the connector is made of an aluminum alloy in order to keep the weight of the unit to a minimum consistent with the structural strength required in its intended application. A special end-bell and cable clamp gland is incorporated in the cable connector in order to avoid the possibility of strain on the cable being transmitted to the soldered connections. As shown, coupling rings are provided on the mating receptacles to lock the two units together in order to prevent the cable from being accidentally pulled out of the receptacle.



FIG. 15-5. A female camera cable connector is shown at (a) with a corresponding male chassis connector at (b). A male camera cable connector is shown at (c). (Courtesy of Cannon Electric Development Co.)

Right-angle connectors are also available for camera cable in order to cope with situations where the cable leads away from a receptacle at right angles to its axis.

Because of the large number of conductors that are accommodated by camera cable connectors, they are relatively large in size. The units shown are approximately  $2\frac{3}{4}$  in. in diameter and  $3\frac{5}{8}$  in. long.

**15-5. Video Patch Cords and Jacks.** One of the prime requisites for the successful operation of a broadcasting station is continuity of service at all times. This necessity arises from the keen competition between broadcasting stations and the psychological reaction of the average listener to an interruption in program service. A jack field incorporated in an audio or a video system provides a high degree of operational flexibility to cope with the emergency that arises when a piece of equipment

fails. Under these circumstances, by the use of patch cords, defective units that have their input and output circuits available on jacks may be removed from the circuit and replaced by a substitute unit. Furthermore, the availability of a jack field permits rearrangement of the program circuits to cope with special situations or those which do not arise often

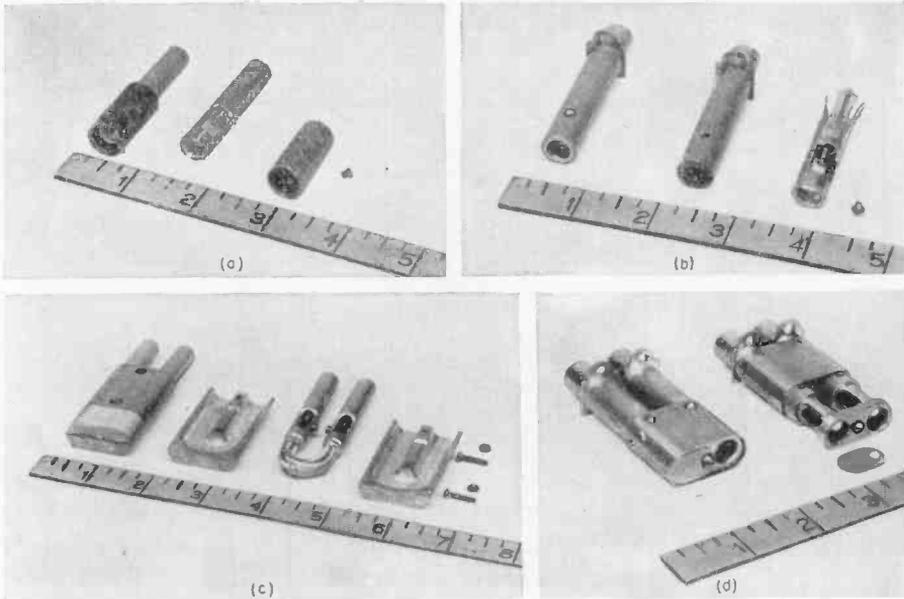


FIG. 15-6. (a) An assembled coaxial patch-cord plug is shown at the left, the unassembled parts at the right. (b) An assembled coaxial jack is shown at the left (rear view), the unassembled parts at the right. (c) A double coaxial plug for "normal" connections. (d) A double coaxial jack assembly. (Courtesy of Bell Telephone Laboratories, Inc.)

enough to warrant the permanent installation of equipment specifically for the requirement. Finally, in addition to the operational conveniences made possible by a jack field, the test and measurement of program facilities are greatly simplified when it is possible to make direct connection to the terminals of the various components in the system.

Unlike the jack employed for audio applications, video jacks and plugs are of a coaxial type and, correspondingly, the patch cord itself is a coaxial cable; e.g., type RG-59/U. Unfortunately there is no more standardization of video jacks and plugs than of video connectors in general and, as a result, there are several types in use. Two widely used types are shown in Figs. 15-6 and 15-8.

The coaxial plug shown in Fig. 15-6*a* consists of two concentric brass shells, the smaller of which is gold-plated and forms the outer conductor of the coaxial circuit. The center conductor of the coaxial plugs is a gold-plated solid brass pin held concentrically within its shell by means of a low-loss dielectric. The ratio of the diameters of the inner conductor and the outer is such as to form a 75-ohm coaxial circuit. The over-all dimensions of the coaxial plug are  $\frac{3}{8}$  by  $2\frac{7}{16}$  in.

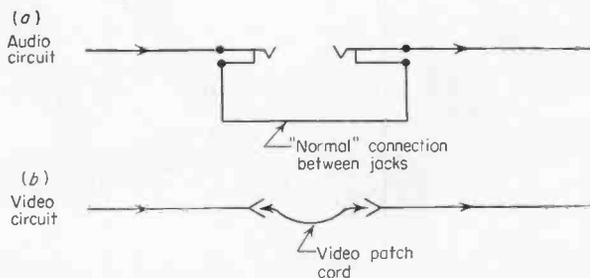


FIG. 15-7. In audio applications circuits may be "normaled" together via side contacts on jacks, as shown at (a). In video circuits, the use of a double plug or a patch cord is necessary, as shown at (b).

A mating coaxial jack, intended for assembly in a jack field mounting strip, is shown in Fig. 15-6*b*. This jack has coaxially arranged gold-plated inner and outer contacts. The former, which is insulated from the latter with a low-loss dielectric, consists of a split tubing that is of correct proportions to make firm contact with the inner conductor of the associated coaxial plug. The outer contacts are formed by series of spring fingers which surround the outer portion of the coaxial plug and form a low-resistance contact thereto. These contacts are mounted in a tubular frame which serves as a shield and which has an outer diameter of  $\frac{1}{2}$  in. at one end and a slightly smaller diameter at the other. The over-all length of the coaxial jack is  $2\frac{3}{4}$  in. and, as shown, it is provided with a tab for holding the jack in a mounting strip.

Unlike audio jacks, coaxial jacks do not lend themselves to construction with auxiliary contact springs that can be used to "normal" together two parts of a circuit, as shown in Fig. 15-7*a*. Under these circumstances wherever a through video circuit is to be provided with jacks, to facilitate breaking into the circuit, one jack must be connected to another by means of a coaxial patch cord, as shown in Fig. 15-7*b*. In practice, video jack fields are usually planned so that coaxial circuits that normally are to be connected to each other terminate on adjacent jacks. Then, to avoid cluttering up the jack field with patch cords, use is made of a double plug

of the type shown in Fig. 15-6c. This assembly consists of a pair of coaxial plugs, mounted flexibly within a metal shell. The twin plug is constructed so as to fit coaxial jacks that are mounted  $\frac{5}{8}$  in. on centers. The over-all length of the twin plug is  $3\frac{3}{16}$  in., the width  $1\frac{3}{16}$  in., and the thickness  $\frac{9}{16}$  in.

Another type of frequently used coaxial plug has the same general appearance as the unit shown in Fig. 15-6a but has a 75-ohm termination built into it. Terminating plugs of this type are very useful in a broadcasting plant for terminating equipment or circuits on a temporary basis.

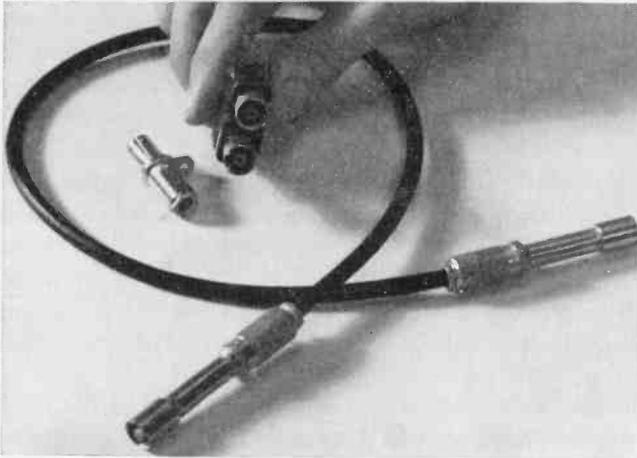


FIG. 15-8. A coaxial patch cord employing another type of plug, together with an associated coaxial jack and double plug. (Courtesy of Cannon Electric Development Co.)

A coaxial plug and jack of somewhat different design from those just described are shown in Fig. 15-8. In this instance the plug consists of a turned brass shell with a knurled finger grip. The inner conductor consists of small-diameter brass tubing, slit at one end to form a pair of fingers that grip the mating central conductor in the associated coaxial jack. The center conductor of the plug is insulated from the shell with Teflon, a low-loss plastic dielectric. The over-all diameter of the plug is  $\frac{1}{2}$  in. and the length  $2\frac{3}{4}$  in.

The companion coaxial jack is also fabricated from brass and has an outer shell that is slotted to form a number of spring fingers that firmly engage the mating surface of the plug just described. A center, solid brass pin, insulated from the outer shell with Teflon, engages the split inner tubing of the associated plug. A mounting ear permits the jack to be firmly fastened in place in a suitable jack strip. All metal parts of both

the plug and the jack are gold-plated to ensure good contact at all times. In addition, the contacts are partially floating to facilitate engaging and disengaging the plugs and jacks.

Additional accessories available for use with the coaxial jacks described include a twin plug (Fig. 15-8) for connecting together two adjacent jacks mounted  $\frac{5}{8}$  in. on centers and a terminating plug containing a 75-ohm internally mounted resistor.

**15-6. Audio Wire Types.** Two basic types of cables are used for most of the wiring of audio facilities in a television plant. One of these is employed for essentially all audio program circuit wiring and the other for use as microphone cable. Because of the importance of well-shielded and properly installed audio circuits in a television station, both cable types are briefly described together with suggested methods of preparing them for installation in order to assist in achieving correct grounding methods.

**Audio Circuit Cable.** The wire used for the interconnection of audio equipment (excluding microphones) usually consists of a twisted insulated pair of No. 20 or No. 22 AWG solid wire over which there is a braided or wrapped copper shield with an insulating jacket overall. Although in some isolated instances a group of cables of the type described are enclosed in a lead sheath, such construction is the exception rather than the rule in broadcasting applications.

For audio installations in a television broadcasting plant, aside from the usual considerations of high insulation resistance, adequate wire size for mechanical strength, convenience in application and in pulling through conduits, the important attributes of an audio cable are adequate shielding and insulation of the shield to avoid chance grounding on metal troughs, conduits, chassis, racks, and other objects. An over-all insulation impervious to moisture is also a valuable asset where the cable is installed in floor troughs (see Sec. 15-9) or situations where high humidity is likely to be encountered.

Careful control of all audio circuit grounds (see Sec. 15-8) is facilitated by adding one extra conductor to the basic audio cable described above. If an uninsulated solid No. 22 AWG tinned copper wire is run parallel to the axis of the wire and immediately under and in contact with the shield, it provides a very convenient means for connecting the shield to a ground terminal.

For situations requiring the use of a flexible audio cable, the solid wire in the cable described above may be replaced by a stranded one; *e.g.*, a pair of insulated conductors, each consisting of 16 strands of No. 34 AWG wire, provides a satisfactory substitute. In this instance the uninsulated grounding conductor is also made of the same stranded construction.

**Butting Audio Cable.** The process of preparing the end or the *butt* of a cable prior to installation of the cable is usually called "butting." The presence of a woven shield in audio cables is the factor that requires special consideration. Depending upon the nature of the insulation over the individual conductors in the cable, there may or may not be a potential danger of the cut loose ends of the shield piercing the insulation and



The outer jacket and cotton wrap are stripped back the required amount.



Grasping the exposed shield, the outer jacket is forced back approximately  $\frac{1}{4}$ ". The cotton wrap is trimmed to the end of the jacket.



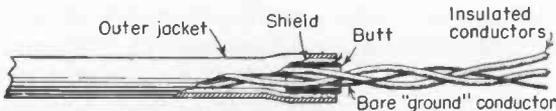
All but  $\frac{1}{4}$ " of the shield is removed and trimmed. A  $\frac{3}{8}$ " long piece of No 8 butting material is stripped on over the conductors.



The butt is slipped up under the shield making certain all the shield wire ends are free.



The outer jacket is pulled out over the exposed shield completely covering the butt end.



Cut-away view of the completed butt.

FIG. 15-9. A recommended method for treating the end or butt of audio cable to ensure against any possibility of the braided shield piercing the insulation and causing a circuit ground.

grounding a conductor. If tests prove that the insulating jacket over the individual conductors is sufficiently tough to resist all possibility of strands of wires from the shield penetrating to the circuit conductor, the butting process may be a very simple one. In this instance, depending upon whether there is a special grounding conductor or not, one or the other of two procedures may be followed.

When a grounding conductor is present, the shield wires may simply be cut off flush with the end of the outer jacket, the shield then being

grounded by soldering the ground wire to a ground terminal. If, on the other hand, the shield is not to be grounded at one end of the cable, the outer jacket may be worked back slightly and the shield and the ground wire cut off flush with the edge of the jacket which should then be worked forward in order to prevent either the shield ends or the grounding conductor from accidentally touching a ground point.

Where there is no grounding conductor included in the cable and the shield is to be grounded, it may be prepared for grounding by the process shown in the first three illustrations of Fig. 15-10.

Where there is any question concerning the ability of the insulation on the individual cable conductors to withstand piercing by loose shield ends, a different procedure for butting the cable should be followed. Many methods for use under these circumstances have been devised but that shown in Fig. 15-9 is believed to be one of the simplest, neatest and most satisfactory, all things considered.

**Microphone Cable.** Microphone cable for broadcasting applications, unlike audio cable, *does* enjoy the status of an industry standard.<sup>1</sup> The cable used for connecting microphones to their wall or portable amplifier receptacles is similar to the cable described above for equipment interconnections except that it is generally of sturdier construction in order to withstand better the portable service in which it is placed. A high degree of flexibility, resistance to breakage of conductors or shield by bending at cable clamps, and substantial resistance to wear of the outer sheath are important requirements.

Standard microphone cable consists of either two or three conductors of stranded, annealed, and tinned copper wire, insulated with synthetic or natural rubber, covered with a cotton wrap and a braided tinned copper shield, and protected with an outer sheath of neoprene. The conductors in two-conductor cable consist of 41 strands of No. 34 AWG wire (equivalent to No. 18) while that in three-conductor cable consists of 26 strands of No. 34 AWG wire (equivalent to No. 20). The outside diameter of either cable is 0.312 in.

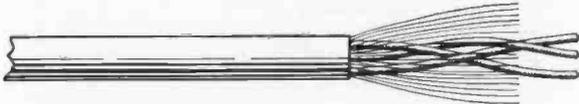
Where a two-wire microphone cable is used, the two conductors carry the program circuit, and reliance is placed upon the shield to carry a ground out to the case of the microphone itself. Since the shield is vulnerable to breakage, particularly at cable clamp positions, this procedure is not considered so reliable as the use of a third conductor specifically for carrying the ground out to the microphone. The added cost of the third conductor is usually considered insignificant compared to the insurance it provides.

<sup>1</sup> RTMA Standards Proposal No. 353, "Basic Requirements for Broadcast Microphone Cables," Radio and Television Manufacturers Association, New York, 1951.

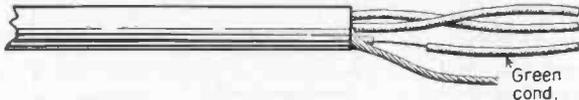
**Butting Microphone Cable.** The proper butting of microphone cable is just as important and presents similar but slightly more complicated problems than does audio cable. Two cases present themselves: one where the shield is to be grounded and another where the shield is to be insulated from grounds at a particular end of the cable (grounding procedures are detailed in Sec. 15-8).



The out jacket and cotton wrap are stripped back the required amount.



The shield is unbraided along its entire exposed length



The shield strands are twisted together to form a single shield conductor. A  $\frac{1}{2}$ " section of insulation is removed from the green conductor.



The shield conductor and the exposed section of the green conductor are twisted together and soldered. A  $\frac{5}{8}$ " length of No 10 butting material is slipped on over the green conductor

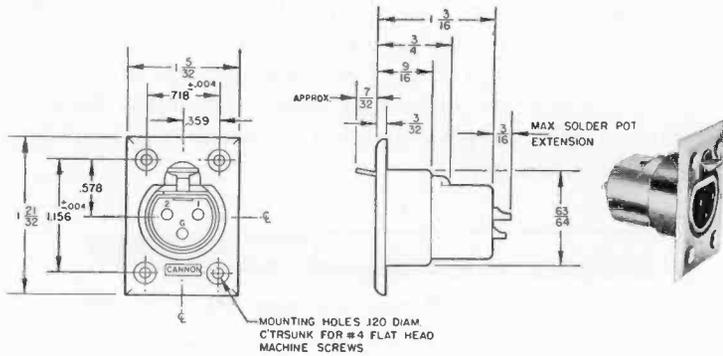


The butting sleeve is slipped up over the shield solder connection

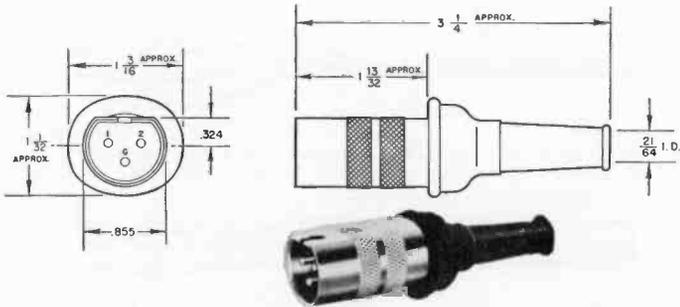
FIG. 15-10. The ends of three-conductor shielded microphone cable may be finished as detailed here.

A recommended procedure for use with three-wire microphone cable when the shield is to be grounded is detailed in Fig. 15-10. A similar process may be followed for two-conductor microphone cables except that the unbraided shield, after being twisted into a flexible lead (first 3 steps in Fig. 15-10), is then connected to the ground terminal of the plug, receptacle, or terminal strip that is involved.

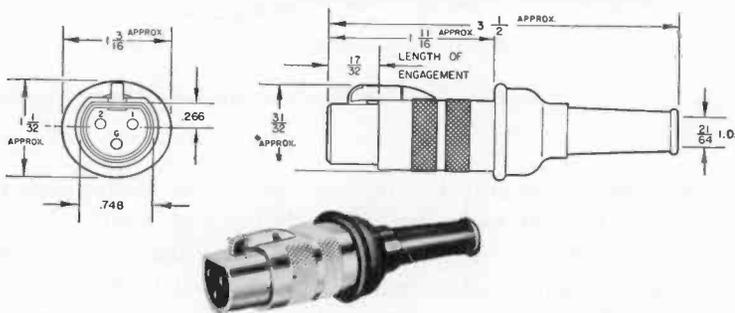
Where the shield is not to be grounded at the particular end of the microphone cable in question, either of the two procedures detailed above for audio cable used in similar situations may be followed; *i.e.*, either the



(a)



(b)



(c)

FIG. 15-11. Photographs and dimensional drawings of the microphone and low-level audio connector standardized by the broadcasting industry. The units shown are (a) female chassis connector, (b) male cable connector, and (c) female cable connector. (Courtesy of Cannon Electric Development Co.)

outer jacket may be worked back, the shield clipped off, and the jacket worked forward into place or, if the nature of the insulation on the conductors requires it, the procedure shown in Fig. 15-9 may be followed.

**15-7. Audio Connectors.** There are almost, but not quite as many different types of audio connectors in broadcasting service as there are video types. Of the audio group only one class enjoys the distinction of being an industry standard; these are the connectors employed for microphone and other low-level audio circuits.

**Microphone Connectors.** The standard microphone connector<sup>2</sup> is a three-contact device whose essential dimensions are standardized in order to permit the connectors of various manufacturers to be used interchangeably. Four basic types of complementary mating and locking connectors are involved, *i.e.*, male and female cable connectors and corresponding types for wall and panel mounting. Two of the three terminals in the connector are employed for the program circuit and the third is the ground contact.

The connectors, samples of which are shown in Fig. 15-11, incorporate many features which reflect years of experience with connectors of all types. These include a cylindrical metallic shell with a flat area parallel to the axis of the cylinder in order to facilitate orientation when mating two units, a lock-in key on one unit and a corresponding lock-in keyway on the other, a cable clamp integral with the body of the connector, and a cable relief gland to prevent sharp bending of the cable, hooded contact pins to prevent damage, contacts designed to avoid the contribution of noise to the audio circuit, and high insulation resistance even under adverse conditions.

TABLE 15-2. MICROPHONE CONNECTOR APPLICATION

<i>Circuit</i>	<i>Type Connector</i>
Microphone or other program source .....	Male
Cables, end toward program source .....	Female
Cables, end toward amplifier or load .....	Male
Amplifier (or load) input circuit .....	Female
Amplifier output circuit .....	Male

The type of connector to be used for a given application is also standardized in order to ensure interchangeability of equipment. Table 15-2 details the standard manner in which the connectors are used with microphone or other program sources and with associated circuits. In addition,

<sup>2</sup> RTMA Standard No. TR-118, "Cable Connectors for Audio Facilities for Radio Broadcasting," Radio and Television Manufacturers Association, New York, December, 1949.

Fig. 15-14 shows a typical application of cord connectors and wall receptacles.

**Audio Plugs and Jacks.** The audio field enjoys an advantage over its video counterpart in that plugs and jacks have become standardized by common usage. The two types found almost exclusively in broadcasting service are the double and the single plugs shown in Fig. 15-12. The double plug is the older of the two in so far as broadcasting service is concerned, it having been adapted from telephone service when broadcasting first started. The single plug, also a telephone item, although adapted only in recent years,<sup>3</sup> is rapidly gaining popularity because of the many advantages it offers over the double plug. These include (a) elimination of the possibility of accidentally reversing the polarity of a circuit by "turning over" a patch cord, (b) almost halving the amount of space required for a given jack field, and (c) a considerable saving in the expense of jacks and associated patch cords. The single plug that is satisfactory for this service has a construction that permits its insertion into the corresponding jack without short-circuiting the program circuit. The common type of tip, ring, and sleeve telephone plug does not accomplish this and is, therefore, unsatisfactory for broadcasting service.



FIG. 15-12. A conventional double audio plug is shown at the left and a space-saving less expensive error-reducing single plug at the right.

**15-8. Grounding Procedures.** The ability to control all circuit grounds completely in a television audio and video installation is an invaluable asset when cross-talk and hum pickup problems arise. The use of audio and video cables which have their shields covered with an insulating jacket, combined with careful installation of these cables to avoid accidental and unknown grounds, goes a long way toward avoiding cross talk and hum pickup. The finding of a chance ground that is responsible for poor system performance can be a most tedious and onerous undertaking. Therefore, every effort should be made to avoid trouble from the beginning.

<sup>3</sup> Chinn, H. A., and R. B. Monroe, Single Jacks for Broadcast Application, *Audio Eng.*, Vol. 31, No. 6, p. 12 (July, 1947).

**Main Ground Point.** Television broadcasting installations should always have a ground connection for the electronic circuits that is independent of the ground bus used for the a-c power system. Unless this practice is followed, there is always the possibility of a large alternating current flowing in the ground lead because of an unbalance in a multiphase power load. This, in turn, may create an appreciable a-c voltage drop in the ground lead which may manifest itself in either the audio or the video program circuits in an undesirable manner.

The point in a television installation where the connection is made to earth is sometimes known as the "main" ground point. It is the usual practice to make this connection to an incoming cold-water supply pipe as near as possible to the point where the pipe enters the building from underground. Where a building is especially constructed for broadcasting purposes, it is often possible to bury a large ground plate in the soil and thereby create a "main" ground point specifically for the electronic equipment. It is preferable that the ground connection for other systems (e.g., the a-c power system) not be made to the "main" ground point for the broadcasting facilities.

**Central Ground Point.** Since it is generally impractical to run separate grounding conductors from each equipment assembly to the "main" ground point, a second grounding point, centrally located with respect to the equipment, is often established as shown in Fig. 15-13. From this "central" ground point, conductors may then be run to each equipment unit as well as to the "main" ground point. The connection to the "main"

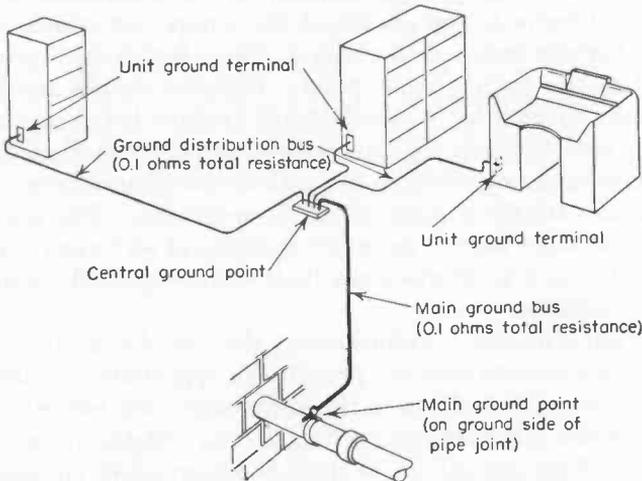


FIG. 15-13. A recommended grounding system involving main, central, and unit ground points connected by insulated ground cables of specified maximum resistance.

ground point should be made with a heavy low-resistance insulated conductor whose size is such that its total resistance is 0.1 ohm or less.

In cases where television studio or transmitter plants are located high up in a building, it may not be practical to run a special bus from the "central" ground point to the "main" ground point because of the excessive length of the run. In these instances an alternate, although less desirable, arrangement is to connect the central ground point both to the water mains and to the steel structure of the building.

**Unit Ground Terminal.** A "unit" ground point is usually established in each rack, console, cabinet, or other equipment unit. To this terminal are connected the ground wires from the various components within the assembly. Where a multiplicity of ground wires is involved, a drilled and tapped copper bus or a terminal block is often employed.

"Unit" ground points should be connected to the central ground point also with an insulated conductor having a total resistance of 0.1 ohm or less. This conductor may be run in the same wireways with audio and video cables. In small installations where there is only one concentrated group of equipment, the central ground point may be eliminated and the conductor from the main ground point brought directly to the unit ground point.

**Equipment Grounds.** As a rule, the ground terminals of individual chassis, frames, and cases are grounded to the "unit" ground terminal. Preferably, individual insulated ground wires should be run from each piece of equipment to the unit ground. Equipment ground wires should be installed even though the ground terminal on the component in question is connected directly to the chassis of the equipment which, in turn, is bolted or otherwise fastened to a rack or frame that is itself connected to the central or the main ground point. Reliance should not be placed upon grounds formed by a nonelectrical contact between chassis and frames since such contacts, together with other purely mechanical connections between frame members in the path to the ground point, may have or may acquire relatively high electrical resistance. The only positive method of assuring a perfect ground connection at all times for individual equipment chassis is to short-circuit these chance ground circuits with a grounding conductor.

**Video Circuit Grounds.** Unfortunately the use of coaxial, or one-side-grounded, video circuits does not provide the opportunity to control video circuit grounds as precisely as in the audio case (see below). Multiple grounds on video cable shields are largely unavoidable since connection to both ends of the coaxial shield used to interconnect equipment units must be made inasmuch as it represents one side of the video circuit. Actually, were it not for the availability of clampers, which are capable

of removing spurious low-frequency disturbances, the use of coaxial circuits for video terminal facilities would be largely impractical.

In arranging video circuit grounds, the important consideration is the avoidance of high-resistance ground busses and of ground leads in which high-amplitude currents may flow. Unless this is done, the voltage drop across the ground lead may introduce unnecessary interference in the video signal.

**Audio Circuit Grounds.** Unless care is taken to control audio circuit grounds in a television installation, cross-talk and hum pickup problems can be anticipated. When it is recalled that government regulations covering the aural portion of a television system parallel the more exacting FM rather than the AM standards, it becomes evident that every reasonable installation precaution should be observed in order to ensure the best possible performance of the audio facilities.

Perhaps the most important practice is the avoidance of multiple grounds on audio circuits, components, and cable shields. Where a ground is required on an audio circuit (see below), the ground connection should be made at one point only and not, for instance, at both ends of a circuit. The same principle holds true for cable shields which should be grounded at one end of the cable run and *not* at both ends. The correct grounding of microphones and of microphone cable shields is of particular importance because their portability makes them especially susceptible to being inadvertently brought close to fluorescent lights, r-f cue transmitter antennas, a-c cables carrying large lighting loads, and other possible sources of audio interference.

Since the correct grounding procedures for microphone cables have sometimes proved somewhat confusing and since they illustrate the basic tenets of the grounding of audio cable shields in general, these principles are detailed in Fig. 15-14. This illustration assumes the use of standard microphone connectors (see Sec. 15-7) and three-conductor microphone cable (see Sec. 15-6). It will be seen that the principles observed consist of (*a*) making a connection to a central or main ground point only at the equipment rack end of the circuit, (*b*) making connections to a cable shield only at the end of the shield toward the main ground point, and (*c*) insulating the shield at the far end of each cable length to avoid chance grounding at this point.

Another important consideration in planning audio circuit grounds is the grounding of unbalanced-to-ground (or one-side-grounded) circuit elements. Although audio transmission circuits from one complete assembly to another should, in general, be of balanced-to-ground configuration, unbalanced-to-ground components are frequently used within a given assembly. For example, in the interests of simplifying their construction,

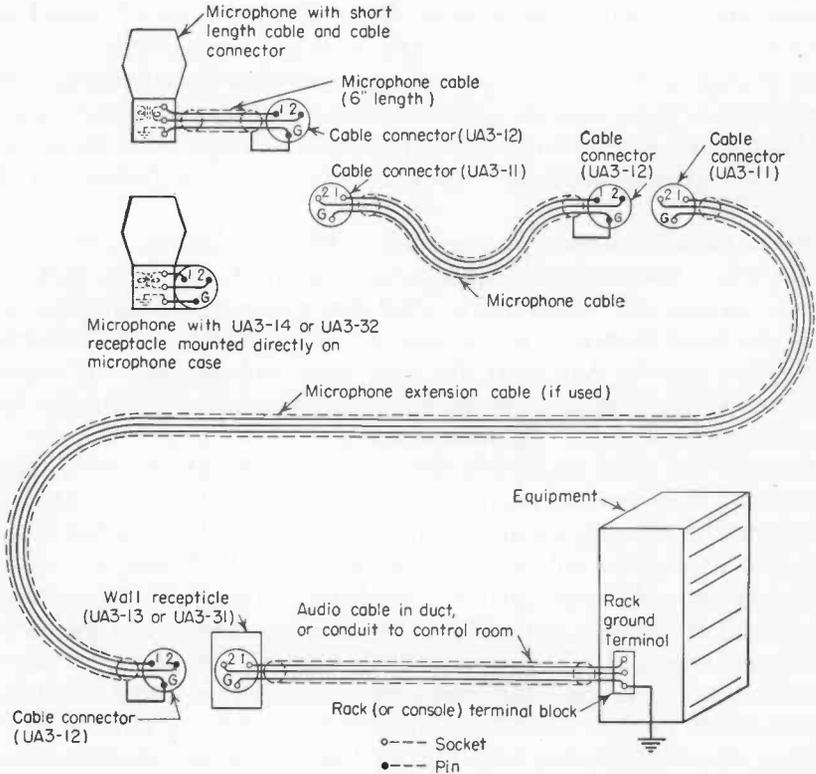


FIG. 15-14. Microphone cable wiring and grounding details using standard microphone connectors.

variable attenuators, filters, and equalizers are often on an unbalanced-to-ground construction. For proper operation, however, these circuit elements should have their common side grounded. It is important that this ground be applied at only *one* point in the circuit. One method of avoiding multiple grounds on circuit elements of this type is to place the ground on the unbalanced-to-ground circuit element itself rather than on the amplifier or other component preceding or following the unbalanced element in question. This procedure also makes it possible to "patch" amplifiers interchangeably to balanced or unbalanced circuits without restricting the use of a particular amplifier to one type of circuit or the other.

**15-9. Wireways.** In order to provide protection for audio, video, communications, control, and a-c cables and to meet governing installation codes, it is customary to install such cables in conduit, raceways, pipe shafts, troughs, ducts, and similar wireways. The various services are sometimes segregated and carried by separate wireways although, unless

some local ordinance requires this segregation, there are only a few instances where it is necessary, provided the wireway is large enough to permit physical grouping of the various services and at least a small separation between them.

The degree of isolation afforded by shielded types of video and audio cables, even when they are in close proximity to each other, is remarkably good, provided the circuits are properly terminated and the cable sheaths correctly grounded. For example, in one test two RG-11/U cables and one shielded audio cable, each 100 ft long, were tightly taped together for their entire length. Both ends of the video cables were terminated in their characteristic impedance of 75 ohms and the audio cable terminated in 150 ohms. At frequencies below 1 Mc, test tone applied to one cable was more than 120 db down in the other cable. At frequencies above 1 Mc, the cross talk was found gradually to increase from -120 db to a value of about -95 db at 10 Mc. However, since proposed industry standard for cross talk is in the vicinity of 45 db, it is evident that a considerable length of adjacent video cable, properly terminated and grounded, can be used without danger of an objectionable amount of cross talk from this source.

In the particular test mentioned, it was found that the audio-frequency cross talk from the video cable to the audio cable was below the thermal agitation noise of the audio cable circuit. As a result of these tests, it would seem entirely feasible to intermix audio and video cables of reasonable lengths in a raceway without any danger of creating cross talk, as long as normal transmission levels and correct grounding procedures are maintained. Nevertheless, it is good engineering practice to segregate cables employed in different services in order to avoid any possibility of cross talk even under abnormal or adverse conditions.

**Rigid Conduit.** Both regular conduit and thin-wall rigid conduit are employed for the installation of cables for all five types of television station circuits enumerated at the beginning of this section. It is not possible, of course, to segregate one set of cables from another when they are installed in rigid conduit, and under these circumstances separate conduit runs are usually made for each type of service. Exceptions may be made where experience or other factors warrant placing more than one service in a given run. For example, the levels employed for audio and communications service may be found to be much alike so that there is little possibility of cross talk, assuming the use of shielded twisted pairs for both services. Again it may be possible to group control circuits with either audio or video circuits although here precautions are in order since, depending upon the nature of the control circuit, detectable key clicks may be introduced in the associated program services.

TABLE 15-3. CONDUIT CAPACITY

Trade size (in.)	Actual I. D. (in.)	Cross-sectional area (sq in.)	40% area (sq in.)	Maximum number of conductors per conduit					
				RG-11/U	RG-59/U	Camera cable	RTMA mic. cable	CBS audio cable	14R, RH, RU, RW, T, TW
1/2	0.622	0.30	0.120	1	2	...	1	3	4
3/4	0.824	0.53	0.212	1	4	...	2	6	6
1	1.049	0.86	0.344	2	7	...	4	9	10
1 1/4	1.380	1.50	0.60	4	13	1	8	16	18
1 1/2	1.610	2.04	0.81	6	17	1	10	22	25
2	2.067	3.36	1.34	10	29	2	17	37	40
2 1/2	2.469	4.79	1.91	15	41	3	25	52	59

The importance of the application will also determine whether more than one service may be placed in a given conduit. If a picture and sound monitor, together with an intercommunication circuit, were to be run to a lighting control gallery or a sound-effects corner of the studio, the use of three separate conduits to accommodate the services named would probably not be warranted. In this instance the picture and sound program material is usually employed only for cueing purposes. Consequently, the possibility of a small amount of occasional cross talk from one service to another would probably be tolerable in the interests of simplifying the installation. These and similar considerations will largely determine the extent to which cables carrying different services may be run in a common conduit.

The "National Electrical Code" <sup>4</sup> (codes of local authorities often concur) specifies that only 40 per cent of the available area in a conduit shall be occupied. On this basis the number of coaxial and camera cables that can be installed in rigid conduit of various sizes is as shown in Table 15-3. Furthermore, bearing in mind the minimum permissible radius for coaxial cable bends and the problem of pulling the cable through conduit, it is recommended that the minimum radius of conduit bends be as shown in Table 15-4.

TABLE 15-4. MINIMUM RADIUS FOR CONDUIT BENDS

<i>Type of Cable</i>	<i>Minimum Radius of Bend (in.)</i>
RG-11/U .....	12
RG-59/U .....	6
Camera cable .....	12

**Flexible Conduit.** Flexible conduit, or "Greenfield," is usually employed in television installations where sound-isolation treatment is installed. It is used to avoid bridging with rigid conduit across the floating construction that is usually a part of the sound-isolation installation. Flexible conduit is also used on alteration work where other types of wireways cannot be placed because of structural conditions.

Care must be exercised in the use of flexible conduit to avoid forming unacceptably short bending radii by pulling the flexible conduit sharply around an obstruction. Furthermore, it is more difficult to pull cables through flexible conduit than through rigid conduit of the same size. For these reasons, the use of flexible conduit should be kept to a minimum.

**Floor Troughs.** Troughs with removable covers are often placed in the floor of television transmitter and studio plants in order to carry the

<sup>4</sup> Abbott, A. L., "National Electrical Code Handbook," 6th ed., McGraw-Hill Book Company, Inc., New York, 1947.

numerous cables between the various equipment units. Troughs provide a versatile wireway since they may be run into wall boxes, under equipment racks, cabinets, and consoles (where covers are usually omitted), made to any dimensions consistent with structural considerations and, when the covers are removed, may often be completely accessible throughout their entire length.

Troughs have one major shortcoming—the contents are subject to damage by any water or other liquid that is accidentally spilled on the floor. This ever-present possibility with trough installations makes it imperative that, wherever possible, only cables with waterproof (or at least water-resistant) outer coverings be installed therein.

**Overhead Troughs.** The overhead installation of troughs largely eliminates the hazard of cable damage from chance liquids. As a matter of fact, the principle of overhead rather than floor wiring may be practiced without troughs at all, by simply using overhead hangers to support the cables as shown in Fig. 12-29.

A combination of both floor and overhead ducts has also proved advantageous, particularly in extensive installations where the size of the ducts that can be placed under equipment racks is insufficient to accommodate all the cables that are required. When an arrangement of this type is employed, advantage should be taken of the opportunity to segregate cables of the various services into two major groups, in addition to subgroups within the major groupings. For example, the overhead trough might well be used to carry all audio, video, and communications cables while the floor trough is used for all a-c power, high- and low-voltage d-c supply, and control cables.

**Pipe Shafts.** Pipe shafts are sometimes available, particularly in large buildings, for running various services (power, water, steam, telephone, and other utilities) vertically from floor to floor in the building. Where a pipe shaft is shared with other services, precautions must be taken to guard against accidental (or malicious) damage to the cables serving the broadcasting station. By its very nature, a pipe shaft must be available to a large number of trades, all of whom may not be indoctrinated in the importance of maintaining continuity of broadcasting service at all times.

The best protection against damage to broadcasting cables that are run in pipe shafts accessible to others is to place the wire in rigid conduit and to use junction boxes with locked covers. Where cables are run in vertical shafts, whether exposed or enclosed in conduit, adequate provisions must be made to support the weight of the cable at regular intervals as, for example, at a pull box at each floor. In addition, precautions must be taken to ensure against the weight of the cable being brought to bear upon an entering bend around an edge of a duct. Any lacing or clamping

employed for supporting the cable should be done with a minimum of pressure on the cable, particularly where coaxial conductors are involved.

**15-10. Rack Mounting of Equipment.** Unlike rack-mounted audio equipment which, for the most part is installed flush with the front surface of the cabinet, video equipment chassis are often recessed back from the front of the rack and enclosed by a door as shown in Figs. 5-13 and 8-13. This type of construction results from the widespread use for video equipment of so-called "bathtub" type of chassis construction which does not afford the luxury of a front panel but does permit ready access to either side of the chassis for maintenance and measurement purposes.

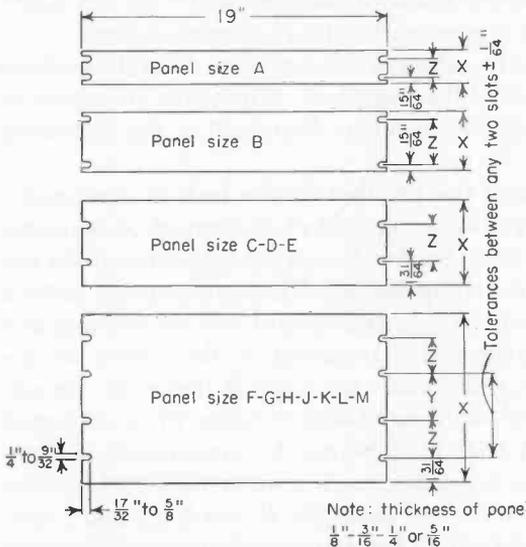


Table of Panel Sizes

Panel size	Dimension X	Dimension Y	Dimension Z
A	12 <sup>3</sup> / <sub>32</sub>		1 <sup>1</sup> / <sub>4</sub>
B	31 <sup>5</sup> / <sub>32</sub>		3
C	5 <sup>7</sup> / <sub>32</sub>		2 <sup>1</sup> / <sub>4</sub>
D	63 <sup>1</sup> / <sub>32</sub>		4
E	82 <sup>3</sup> / <sub>32</sub>		5 <sup>3</sup> / <sub>4</sub>
F	101 <sup>5</sup> / <sub>32</sub>	3	2 <sup>1</sup> / <sub>4</sub>
G	127 <sup>5</sup> / <sub>32</sub>	2 <sup>1</sup> / <sub>4</sub>	3 <sup>1</sup> / <sub>2</sub>
H	133 <sup>1</sup> / <sub>32</sub>	3	4
J	152 <sup>3</sup> / <sub>32</sub>	4 <sup>3</sup> / <sub>4</sub>	4
K	171 <sup>5</sup> / <sub>32</sub>	6 <sup>1</sup> / <sub>2</sub>	4
L	197 <sup>3</sup> / <sub>32</sub>	5 <sup>3</sup> / <sub>4</sub>	5 <sup>1</sup> / <sub>4</sub>
M	203 <sup>1</sup> / <sub>32</sub>	7 <sup>1</sup> / <sub>2</sub>	5 <sup>1</sup> / <sub>4</sub>

FIG. 15-15. Standard relay rack panel sizes. (Copyright, 1949, Radio and Television Manufacturers Association.)

**Rack Standards.** Industry standards<sup>5</sup> define the essential dimensions of equipment racks and of panels that are intended for mounting therein. The standards define the width of panels or chassis intended for rack mounting (*i.e.*, 19 in.), their height (nominally any multiple of 1<sup>3</sup>/<sub>4</sub> in.), the location of the mounting slots, the dimensions, location, drilling, and threading of the mounting rails in the rack together with other pertinent dimensions, as detailed in Fig. 15-15.

The rack size most commonly found in practice has an over-all height of 84 in. and provides 77 in. of useful rack mounting space. Their width

<sup>5</sup> RTMA Standard No. SE-102, "Panel Mounting Racks, Panels, and Associated Equipment," Radio and Television Manufacturers Association, New York, February, 1949

is about 22 in. when not equipped with special side panels or end bells. Where the racks are in the form of cabinets, the depth varies, but 18 in. is a common dimension for the cabinet frame. Along with both front and back doors, the depth, including handles, is often slightly over 24 in. The different manufacturers incorporate various features and accessories in their racks including doors with and without ventilation openings, ventilated tops and tops equipped with blower fans, universal front and rear doors permitting either right- or left-hand hingeing, plain side shields which may be employed or not when a number of racks are placed side by side, end bells for trimming the last rack on each end of a row, program circuit and a-c power wiring ducts running vertically up the inside at the rear, terminal mounting angles, and similar accommodations.

The mounting of equipment in cabinet racks presents several problems all of which can be readily solved if recognized. The more important of these problems and suggested solutions are discussed in the following paragraphs.

**Rack Ventilation.** In planning the ventilation of a rack of equipment, care must be taken that the shelflike projections of equipment components (particularly transformers or large banks of encased condensers) do not form baffles which divert the incoming cool air (that enters at the bottom of the rack) to the side walls where it passes upward and out without any appreciable cooling of the components mounted in the center of the chassis. From a temperature standpoint, the critical items are usually the electrolytic capacitors which often deteriorate rapidly when subjected to a temperature above about 150° F. The rise in temperature of components on a video chassis also manifests itself in other undesirable ways in addition to equipment failure. For example, if the impedance presented by components in critical circuit locations continues to drift for an appreciable length of time, as the temperature gradually rises, a corresponding drift in the performance of the equipment may also be experienced. This may cause temporary poor linearity, poor focus, poor response-frequency characteristics, abnormal synchronizing waveshapes, limited amplitude capabilities, and similar deficiencies that sometimes seem unexplainable.

**Equipment Test Points.** Another problem that must be given consideration where there is a side-by-side assembly of equipment racks is the testing and trouble shooting of the chassis in the rack. When an unbroken line of equipment racks each completely filled with equipment is encountered, special provisions must be made for connecting test equipment to key points in the circuit. This seemingly simple operation is complicated by the fact that the test equipment usually should be located on the front side of the racks where access to the tubes and the controls on the chassis

is to be had, whereas the chassis wiring is accessible only from the back of the racks. This situation is coped with by the installation of feed-through points on the chassis (small pin jacks) that are connected to strategic points of the circuit. Well-designed commercial equipment is usually supplied during manufacture with test points of this kind at all critical points. When they are added in the field, care must be taken that undue capacitance is not added at critical points in the circuit.

**Jack Fields.** A third problem presented by equipment racks with front doors is the disposition of jack fields. If the jack fields are mounted on the same rails that support the equipment chassis, they will be set far enough back to permit closing of the doors with patch cords in place. However, this defeats one of the purposes of a jack field since having to open one or more doors to reach a jack field to make changes in a patch cord arrangement may result in an unnecessary delay in an emergency. Also the jack field may be difficult to reach, particularly if the chassis immediately above it contains components that project forward an appreciable distance from the panel and, in effect, overhangs the jack field. Furthermore, depending upon what equipment is located below the jack field, the patch cords may become entangled with controls or tubes, which may be microphonic or dangerously hot. Finally, if the jack field is located back of a door, it becomes virtually impossible to patch from one rack to another (without jack-terminated tie lines between racks) since the open doors would require unduly long patch cords to reach around them in going from one rack to another.

The solution to this problem is to mount the jack fields flush with the face of the cabinet rack in keeping with long-established audio practice. This procedure, however, entails the use of special split doors. It does, nevertheless, overcome all the problems enumerated above.

**Cable Location.** By long usage it has become standard practice to locate audio and video program circuits on the right side of equipment racks as viewed from the rear of the rack. On occasion, however, the number of circuits involved are so great that some may have to be located on the left side. When this is done, it is customary to place the high-level circuits in this nonstandard position. Control and both d-c and a-c power-supply circuits, on the other hand, are always placed on the left side of the rack as viewed from the rear. The latter (*i.e.*, a-c power circuits) should be run in a metal surface duct provided either with covers and grommeted cable openings or with twist-lock type of a-c receptacles. Cables that are run up the side of cabinet racks (elsewhere, for that matter) should always be supported so that the weight of the cable is not, in any case, taken by the terminals to which it connects.

# Measurements

THE MEASUREMENTS that are undertaken in a television broadcasting plant fall into two broad categories: (a) those which are continuously being made during the monitoring of the audio and video signals and (b) the steady-state or quasi steady-state measurements made for the purpose of determining the operating characteristics of the equipment. Since audio measuring techniques are reasonably well established either by existing standards<sup>1, 2</sup> or by common practice,<sup>3</sup> they are not discussed here. Rather, this chapter is devoted to the video measuring techniques commonly undertaken in a television broadcasting plant.

**16-1. Video Level Measurements.** Measurement of the amplitude of the video frequencies that correspond to a television picture signal is directly analogous to the measurement of audio volume. Unfortunately, however, the state of the art as regards the measurement of video levels is rather primitive. In time, measuring techniques better adapted to television operating conditions than to those of the laboratory will undoubtedly be developed. Meanwhile the oscilloscope or waveform monitor that is in common use serves a useful purpose since, without the aid of this instrument, high-quality video transmission would be virtually impossible.

Although the essential technical details of video waveform monitors were described in Secs. 3-3 and 6-8, a detailed description of the display seen on a waveform monitor and its significance has not been presented. This subject is, therefore, covered in the following paragraphs.

<sup>1</sup> RTMA Standard TR-105B, "Standards for Audio Facilities for Radio Broadcasting Systems," Radio and Television Manufacturers Association, New York, 1950.

<sup>2</sup> Chinn, H. A., Measurement of Audio Volume.

Part I: *Audio Eng.*, Vol. 35, No. 9, p. 26 (September, 1951).

Part II: *Audio Eng.*, Vol. 35, No. 10, p. 24 (October, 1951).

<sup>3</sup> Black, W. L., and H. H. Scott, Audio Frequency Measurements.

Part I: *Audio Eng.*, Vol. 33, No. 10, p. 13 (October, 1949).

Part II: *Audio Eng.*, Vol. 33, No. 11, p. 18 (November, 1949).

**Horizontal-rate Display.** In video waveform monitors it is common practice to employ scanning rates equal to one-half the television horizontal scanning rate. Thus, when adjusted for viewing at the "horizontal" rate, the cathode-ray spot traces across the face of the screen the waveforms corresponding to two horizontal lines of the picture, as shown in Fig. 16-1. However, since the scanning continues at a uniform rate, sub-

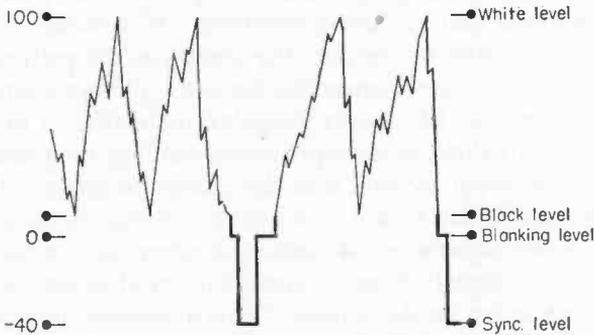


FIG. 16-1. A single sweep across the screen of a waveform monitor at one-half horizontal rate produces the waveforms corresponding to two horizontal scanning lines.

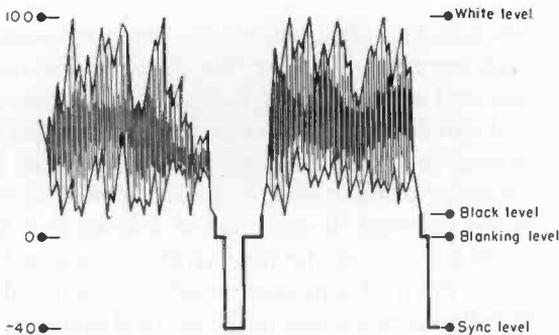


FIG. 16-2. When a waveform monitor is operated continuously at one-half the horizontal sweep rate, the waveforms of many scanning lines are superimposed upon each other.

sequent scanning lines are superimposed upon the first so that, in practice, the display appears more like that shown in Fig. 16-2. At first glance it might be assumed that all the odd lines are on one side of the presentation and all the even ones on the other. Actually this is not the case since the television scanning process is such that all the odd lines are first traced and then all the even ones (or vice versa), over and over again. Thus, for the duration of one field, the waveforms that are presented side by side

are either all odd or all even lines (depending upon the field in question) with the alternate ones subsequently being superimposed upon the first. Thus, each side of the display contains one-half of the odd lines and one-half of the even lines superimposed upon each other.

From this display the maximum and the minimum video levels may be determined, but reference must be made to a picture monitor in order to ascertain what portions of the picture correspond to the particular black or white peak levels that are being observed. In addition, some experience is required in order to correlate the objects in the picture accurately with their waveforms since, depending upon the picture content, the display often appears more like a very irregular modulated r-f envelope than like a series of individual waveshapes corresponding to specific scanning lines. This results from the fact that the change in general shape of the waveforms corresponding to successive scanning lines is usually not very great so that, when superimposed upon each other, each successive waveform deviates only slightly from its immediate predecessor in an upward or downward direction on the screen. Thus a series of lines, all of much the same brightness, are laid down partly adjacent to and partly coincident with their immediate predecessors. Because of the persistence of the phosphor and of the eye, the individual lines more or less merge into a sheet of light.

The display shown in Fig. 16-2 is that of a composite signal consisting of the video signals corresponding to the picture information and the *horizontal* blanking and synchronizing pulses only. Since the waveform monitor trace is not usually blanked out during the *vertical* blanking and synchronizing pulse interval, the display presentation seen in practice is actually somewhat more complicated, as shown in Fig. 16-3.

As compared to the previous illustrations, it is noted that there is now a horizontal line completely across the display at the zero or blanking level (see Sec. 1-12 for a detailed explanation of standard video waveform terminology). This line corresponds to the vertical blanking signal whose duration is between 13 and 21 horizontal scanning lines (see Sec. 1-6). Thus, during the vertical blanking interval, the waveform monitor trace is held at the blanking level (except for those periods where horizontal and equalizing pulses are occurring) for  $6\frac{1}{2}$  to  $10\frac{1}{2}$  successive sweeps across the screen, thereby forming a well-defined horizontal trace at the reference level.

There is also an interrupted horizontal line shown in Fig. 16-3 at the point corresponding to the synchronizing level. This line is formed by the vertical synchronizing pulse whose duration is equal to almost three horizontal scanning lines. Therefore, at the end of each field, this trace sweeps across the waveform monitor screen  $1\frac{1}{2}$  times. The trace is

broken, however, since the vertical synchronizing pulse is serrated, as shown in Fig. 1-4.

In accordance with television synchronizing waveform standards, the leading edge or the beginning of the vertical synchronizing pulse is timed so as to coincide with the leading edge of the horizontal synchronizing pulse as viewed on a waveform monitor of the type under discussion. Therefore, the beginning of the vertical synchronizing pulse is not visible as a separate trace but, depending upon whether an even or an odd field is involved, the leading edge of the pulse begins at  $a$  or  $a'$  in Fig. 16-3. The end or trailing edge of the vertical synchronizing pulse occurs either at  $b$  or  $b'$ , depending upon which point is just short of three horizontal scanning lines from the starting point.

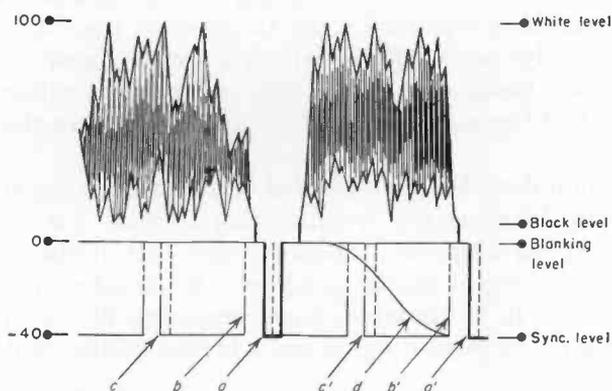


FIG. 16-3. The blanking, equalizing, and synchronizing pulses existing during the vertical blanking interval, which were omitted from Fig. 16-2 for clarity, are added here to produce the complete "horizontal" rate waveform monitor display.

The equalizing pulses that immediately precede and follow the vertical synchronizing pulse are also visible on a waveform monitor although their presence is likely to be overlooked because of the faintness of the trace and the relative narrowness of the pulse. The leading edges of alternate equalizing pulses coincide with the leading edge of a horizontal synchronizing pulse when viewed on the type of waveform monitor under discussion. The width of equalizing pulses, however, is only one-half that of a horizontal synchronizing pulse so that the trailing edges of alternate equalizing pulses split a horizontal synchronizing pulse in half. The leading edge of every other equalizing pulse does not coincide with that of a horizontal synchronizing pulse; rather it is coincident with the serrations in the vertical synchronizing pulse at points  $c$  and  $c'$  in Fig. 16-3. The trailing edge of the narrow equalizing pulse occurs immediately adjacent

to the leading edge where it can usually be faintly seen upon close observation.

Finally, to complicate still further the presentation seen on a video waveform monitor, it is *not* the general practice to blank out the spot during the retrace time of the monitor itself. As a result, the waveshapes that are traced during this period are also displayed, but on an expanded basis (horizontally), because of the fast return time of the oscilloscope trace. If triggering of the horizontal sweep circuit in the waveform monitor is accomplished by the signals under observation, the waveforms are usually positioned on the screen as shown in Fig. 16-3. Under these circumstances the horizontal sweep oscillator is triggered by the leading edge of the synchronizing pulse  $a'$ , and shortly thereafter fast retrace from right to left begins. Thus, the trailing edge of a horizontal synchronizing pulse is present on an expanded scale, as shown by trace  $d$ . If the slope of this trailing edge were infinitely steep, it would appear vertical even on an expanded basis. Since, however, all practical pulses require a finite time to build up and to decay, their appearances are along the lines illustrated.

The waveform described above is that of a composite signal, *i.e.*, a picture signal plus blanking and synchronizing signals. For noncomposite signals (*e.g.*, at the output of a camera-control unit or elsewhere, before the synchronizing signal has been added), the display is considerably less complicated. In this instance, it consists simply of the upper portion corresponding to the picture signal and a horizontal line at the blanking level.

**Vertical-rate Display.** The display seen on a waveform monitor when it is operating at the so-called vertical rate (actually one-half the vertical or field frequency) may appear at first glance to be similar to that seen at the horizontal rate; actually, it is quite different. In this instance, all 525 lines of a television frame are presented just as if they were drawn in their entirety, following the style used in Fig. 1-4, which presents only a few of the lines in detail at particular points of interest. However, as compared to the afore-mentioned illustration, the actual display on the waveform monitor is stretched considerably in a vertical direction and compressed markedly in a horizontal one, as shown in Fig. 16-4. Thus, it is seen that a waveform monitor operating at one-half the vertical scanning rate presents all the even lines in a group on one side of the screen and all the odd lines in another since, during the interval required for the waveform oscilloscope trace to traverse one-half the width of the screen, all the lines in one field will have been transmitted. Thus, the lines corresponding to one field are displayed one alongside the other, rather than one on top of the other as for a horizontal-rate presentation. However,

because of persistence of vision and the decay time of the cathode-ray tube phosphor, several fields may be seen superimposed upon each other.

In Fig. 16-4, the gap between the two groups of waveforms representing the picture signals corresponds to the vertical blanking interval. As shown, in Fig. 1-4, this interval contains not only the vertical blanking pulse but also two groups of equalizing pulses and the serrated vertical synchronizing pulse. These details cannot be seen, however, when the waveform monitor is operating at one-half the field rate.

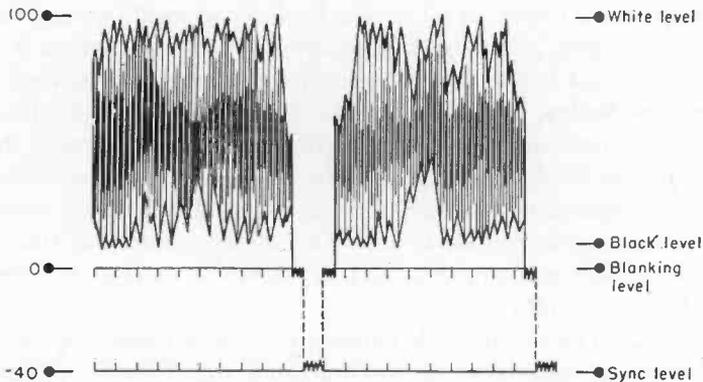


FIG. 16-4. The display seen on a waveform monitor operating at one-half the vertical rate.

A second gap occurs at the end of the second group of pulses, but here part of the display occurs during the flyback time of the oscilloscope spot. As a matter of fact, the horizontal lines in the display traced at both the blanking and the synchronizing levels are created largely during the flyback time of the waveform oscilloscope. During the forward sweep of the oscilloscope spot, only the relatively short front and back porches of the horizontal synchronizing interval contribute to the display at the blanking level and the tips of the synchronizing pulses to the line at the synchronizing level. During flyback time, however, the rate at which the spot is traveling is not only greater, but the length of time that the signal dwells at the level corresponding to the two reference lines named is longer, as is evident from a study of the details of the intervals corresponding to the vertical synchronizing pulse, the following equalizing pulses, and the final portion of the vertical blanking pulse as shown in Fig. 1-4. It is these pulses, except for a portion of the beginning of the vertical synchronizing pulse, that are spread out during the retrace time and trace out well-defined lines at the blanking and the synchronizing levels.

**16-2. Waveform Monitor Standards.** In order to provide a common basis for video signal amplitude measurements, particularly in connection with the transmission of such signals over broadcasting systems, a standard has been adopted<sup>4</sup> covering terminology (see Sec. 1-12), measuring equipment, and the manner of its application. A standard of this type is essential for broadcasting operations since there are many points, beginning with the studio or the field location where the program material originates and including intermediate master control rooms and telephone company terminal and repeater stations and ending at various television transmitter control rooms, at all of which places accurate measurement of the television signal level and a comparison of the results on a unified basis are important to the proper transmission of the information.

**Oscilloscope Scales.** The standard waveform monitor scale is illustrated in Fig. 1-7 together with a signal illustrating the relation between the scale and oscilloscope display. As shown, the position of the presentation on the screen is adjusted in a vertical direction until the blanking level corresponds with the zero on the scale. The upper portion of the scale is graduated in a uniform manner from 0 to 100 and is used to read the value of both black and white peaks.

Below the zero mark, the scale extends to -50 in linear steps and is intended for the measurement of synchronizing signal levels. Thus, these levels are expressed relative to the difference between the reference white and blanking levels rather than as a percentage of the peak-to-peak signal amplitude, as was the early practice. By choosing the blanking level as the reference point, the same scale may be used (*a*) for composite signals, *i.e.*, picture plus blanking and synchronizing signals, (*b*) for picture signals with blanking but without synchronizing signals, or (*c*) for synchronizing signals only.

In practice it has been found advantageous, while retaining the basic features of the afore-mentioned standard scale, to add certain markings that facilitate the measurement of video levels. For example, there is shown in Fig. 16-5*a* a scale that is particularly suited for camera-control units or other monitors that are used only for noncomposite video signals, *i.e.*, picture and blanking signals without synchronizing pulses. In accordance with established practice, the reference black level is placed at 10 on the scale and is suitably labeled. In addition to the scale along the left-hand edge (which is in accordance with the basic standard) there is an added series of horizontal lines, corresponding to the scale divisions, which extend across part of the screen area facilitating measurement of signal peaks wherever they may occur along the time axis. Furthermore,

<sup>4</sup> IRE Standard 50 IRE 23.S1, "Standards on Television," Institute of Radio Engineers, New York, 1950.

the reference white and reference black lines are heavier than most of the others and extend completely across the scale. The blanking level is also shown by a heavy line that is broken in the center (as are the thin lines corresponding to the remaining scale division) to facilitate observation of blanking-pulse waveforms.

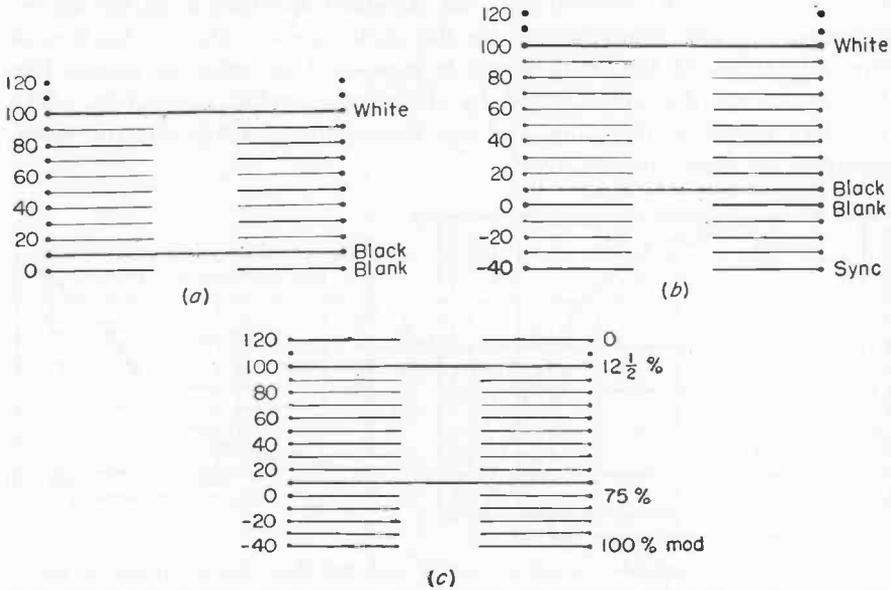


FIG. 16-5. Calibration scales for use on waveform monitors: (a) for camera-control units where only noncomposite (*i.e.*, picture plus blanking) signals are encountered, (b) for line monitors where composite signals are usually handled, (c) for transmitter waveform monitors where the percentage modulation is also of interest.

For use with waveform monitors that display composite signals, the scale described above is supplemented by the addition of markings below the zero or blanking level point, as shown in Fig. 16-5b. A scale of this type is useful for monitors located in master control rooms, on incoming and outgoing lines, and at any other place where a composite signal is handled. On this scale, the synchronizing level that has been standardized by practice is shown at the -40 point and is suitably labeled.

Finally, for use on waveform monitors at transmitters, the scale shown in Fig. 16-5c has proved very useful. Here, the zero or blanking level is shown to correspond to 75 per cent modulation, in accordance with government regulations. Likewise, the synchronizing level is indicated as corresponding to 100 per cent modulation, and the white reference level is indicated as at 12.5 per cent modulation. Regulations specify that the white level shall be 15 per cent or less of the peak carrier amplitude.

**Oscilloscope Characteristics.** The only equipment necessary to make measurements in accordance with present standards is an oscilloscope having certain prescribed characteristics. In addition to a cathode-ray tube with a suitable small spot size, of adequate brightness and associated amplifier and deflection circuits having satisfactory amplitude and deflection linearity, respectively, the standard specifies a particular response-frequency characteristic for the oscilloscope. Standardization of the bandwidth of the oscilloscope is important in order to ensure like indications on the same signal by different waveform monitors. The standard response frequency and rise time characteristics are, therefore, specified as shown in Fig. 16-6.

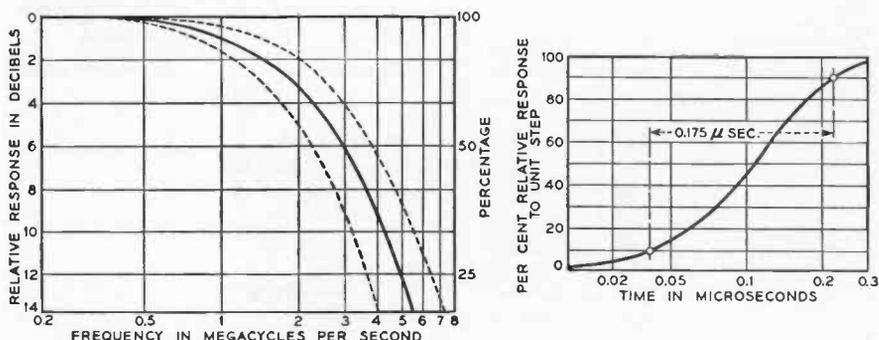


FIG. 16-6. The standard response-frequency and rise time characteristics of waveform monitors used for program transmission measurements. For maintenance and testing work, a waveform monitor with a flat wideband response is essential. (Copy-right, 1949, Institute of Radio Engineers.)

It is evident that the response-frequency characteristic of the oscilloscope is materially attenuated at the high-frequency end of the spectrum as compared to the bandwidth capabilities of television video equipment. This is done partly to eliminate from the display spurious peaks that contribute little to the measurement of levels (from a video transmission standpoint) and partly to restrict the bandwidth of the oscilloscope to the minimum consistent with obtaining satisfactory readings of levels in regular transmission practices.

It is particularly important to note that, for broadcast station test and maintenance purposes and for laboratory measurements made during the course of the design and development of equipment, the use of an oscilloscope having high-frequency rolloff is not generally satisfactory. This is particularly true where it is desirable to detect the presence of spurious peaks or other transmission irregularities since these are often wholly or partly eliminated from the presentation when an oscilloscope employing

a standard rolloff is employed. It is, therefore, good engineering practice in a broadcasting plant to have available waveform monitors, which, when employed for routine transmission measurements during normal operations, may be used with the standard response-frequency characteristic but which, when used for maintenance and test purposes, may be provided with a flat response-frequency characteristic. This choice of characteristics makes it possible for all concerned with the transmission of video program material to make their observations on a common basis while it also provides for the detection of spurious peaks and for the measurements of the various characteristics of the transmission system.

In order to prevent shifts of the display in a vertical direction with changes in the average value of the signal being measured, it is necessary to employ a clamping or d-c restoration circuit in the amplifier associated with the cathode-ray tube. It is desirable that the time constants of such clamping circuits be shorter than the equivalent a-c time constant of the amplifier in order to eliminate momentary shift and bounce of the base line with changes in picture content. On the other hand, it is desirable that the time constants of the restoration circuits be as long as the above limitation permits in order that the true low-frequency content of the signal may be exhibited.

**Oscilloscope Application.** As with any piece of measuring equipment, when an oscilloscope is connected across a video circuit, it is important that it be done in a manner that ensures against any adverse effect upon the signal circuit. Further it is important that the circuit being observed operate with its normal source and load impedances.

At certain points in a video transmission system, the terminations are complex impedances rather than pure (or nearly pure) resistances. Measurements made across such an impedance usually appear severely distorted and, if measurements must be made under these circuit conditions, care must be taken in interpreting the results. One method of making measurements under circumstances such as these is to connect the measuring equipment across a suitably isolated branch circuit, as shown in Fig. 16-7a. Although this arrangement is capable of providing true indications of the outgoing-line level, it requires that the gain and other characteristics of both amplifier stages be identical to accomplish this. Further, should the amplifier feeding the main load fail, there would be no indication of this failure on the waveform monitor unless the cause of the failure were an element common to both amplifier sections, *e.g.*, a common plate or filament supply.

A better solution to the problem of measuring the level across an outgoing video circuit is the employment of a video utility or isolation amplifier having dual output circuits such as the type described in Sec. 6-6. In

this instance there are only passive circuit elements isolating the auxiliary output circuit from the main one and there is, therefore, much less likelihood of a failure in one circuit that would not be reflected in the other. Further, the output level of the auxiliary output circuit relative to that of the main output circuit is determined by stable, passive circuit elements so that indications of a waveform or picture monitor connected to the auxiliary output is not predicated upon the performance of vacuum tubes or other active elements that are not also in the main circuit. The circuit arrangement that may be used with isolation amplifiers having dual outputs is shown in Fig. 16-7b.

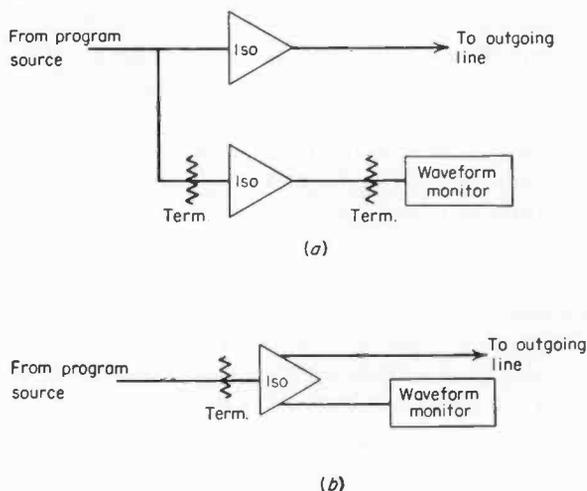


FIG. 16-7. Although a waveform monitor connected as shown in (a) is capable of providing accurate measurements, it does not actually monitor the outgoing line and hence will not warn of a failure of the isolation amplifier feeding the line. The arrangement shown at (b) which contemplates the use of passive circuit elements to provide the necessary circuit isolation overcomes this objection.

**Oscilloscope Calibration.** In order that the deflections of a waveform oscilloscope may be meaningful in terms of some absolute unit, it is necessary to calibrate accurately the gain of the oscilloscope amplifier. Assuming that its remaining operating characteristics are in proper order, calibration of a waveform monitor consists of adjusting the oscilloscope amplifier gain so that a signal of a predetermined voltage level produces a reference deflection of the oscilloscope trace. As noted in Sec. 7-5, *Transmission Levels*, it is common practice in broadcasting video circuits to select 1.0 volt as the standard level for picture signals and -0.4 volt for synchronizing signal levels, both with respect to the blanking level. Thus, on the

scales shown in Fig. 16-5, the 100 mark may correspond to 1.0 volt and the -40 mark to -0.4 volt.

Some waveform monitors incorporate means for self-calibration (see Sec. 6-8), but many depend upon an external source of standard voltage for calibration purposes. In the latter case calibration may be conveniently undertaken by introducing a known calibrating voltage to the input of the oscilloscope in place of the normal input signal. The calibrating signal should be one whose principal frequency components lie within the band of uniform response for the oscilloscope. For a waveform monitor equipped with a standard transmission measuring rolloff characteristic (Fig. 16-6), it is evident that the calibrating signal must be one that has its principal components below 0.5 Mc.

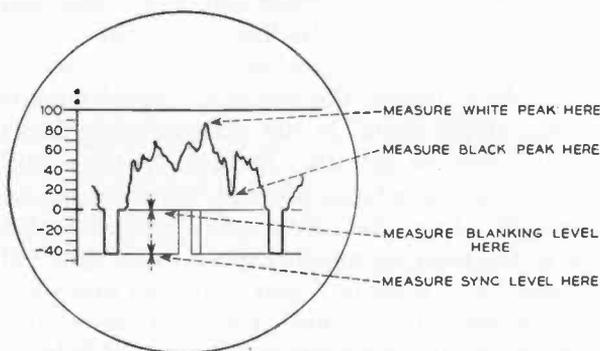


FIG. 16-8. Errors in determining blanking and synchronizing pulse levels may be minimized by observing their values as defined by vertical pulses seen with a waveform monitor operating at horizontal scanning rates.

**Method of Measurement.** Measurements of video signal levels are made with a calibrated waveform monitor by first adjusting the vertical position of the display until the blanking level corresponds with the zero on the scale, as shown in Fig. 16-8. The longer duration of the vertical blanking and synchronizing signals, as compared to the corresponding horizontal signals, makes the former more suitable for measurement purposes than the latter. It is, therefore, common practice to determine the blanking and synchronizing levels, not by observing the bright, but relatively narrow, horizontal pulses but by using the longer, although less brilliant, vertical pulses at the points indicated in Fig. 16-8. Measurements made in this manner minimize errors that may be introduced by distortion of the pulses during transmission.

Measurements of the amplitude of the picture signal are normally made by observing the excursion of important information-bearing signal peaks and, for normal transmission purposes, these are held within the range

from the black reference to the white reference levels. On occasion, certain glint lights and small-area highlights may be permitted to exceed the reference white level where the amounts of energy represented by these signals are insignificant. It is important, of course, where level measurements are being made at two points for comparison purposes, that identical peaks are measured and that agreement is reached as to the procedure to be observed in so far as glint lights are concerned.

The standard terminology that is employed for expressing video level measurements made with a standard oscilloscope equipped with a standard scale is simply to specify the various levels in terms of their scale reading; *e.g.*, a typical reading may be reported thus: white peaks, 90; black peaks, 15; synchronizing level, 40.

**16-3. Amplitude Linearity.** Amplifier and other components in a television transmission system may introduce distortion of the amplitude-transfer characteristics because of overloading or other causes. Thus, if a component is unable to handle the full video signal amplitude, it may cause compression of the signal in the positive-going direction, in the negative-going direction, or in both. In terms of the resulting picture, compression of the video signal may result in "white" compression, "black" compression, or both. From the viewpoint of picture quality, this compression results in the merging together of normally discernible changes in scene brightness (*e.g.*, steps in a gray scale) so that picture detail is lost. White compression, for example, results in loss of detail in highlights; *i.e.*, faces are washed out, folds and textures of light-colored materials become indiscernible, and other light-colored objects lose detail. Black compression results in the loss of detail in the shadows, many dark-colored objects or objects not in strong light simply becoming black picture areas in which little if anything is discernible. In any case, undue nonlinearity of the amplitude-transfer characteristic causes the contrast gradient in the region affected to depart from normal and generally limits the over-all brightness ratio of the reproduced picture.

**Video Signal Peak Factors.** As contrasted to audio harmonic and intermodulation distortion measuring techniques, in video transmission measurements nothing more elegant than input-output amplitude measurements are generally employed for ascertaining the overload point of a given facility. Fortunately, in so far as overloading of a video system affects picture quality, the eye seems to be less critical than the ear is to overloading of an audio system. Consequently, simple input-output amplitude measurements appear ample for video systems in view of the present state of the art.

Depending upon the type of video equipment under observation, the measurement of its input-output amplitude relationship may be simple or

somewhat complex. For utility or isolation amplifiers, the measurement may be made by applying sine waves of known frequency and amplitude to the input and observing the output by means of a calibrated waveform monitor or a suitable vacuum-tube voltmeter. If a stabilizing amplifier or other equipment incorporating clamping circuits is involved, however, the test signal must be applied as a composite video and synchronizing signal in order to provide the type of waveforms necessary for operation of the clamping circuits. If a signal of this type is not available, a measurement of sorts may be made by disabling the clamper circuits and then employing sine-wave test signals. In either instance, in interpreting the results it is necessary to make due allowances for the differences in the peak factor of sine waves as compared to possible video waveshapes.

The significance of the difference between sine-wave and video-frequency peak factors can perhaps be presented best by means of a typical example. In television transmission, the two cases where maximum departure from the a-c axis is encountered are (a) with an all-white horizontal bar in the form of a composite signal and (b) with a narrow white vertical (or nearly vertical) bar on a black background in the form of a noncomposite signal.

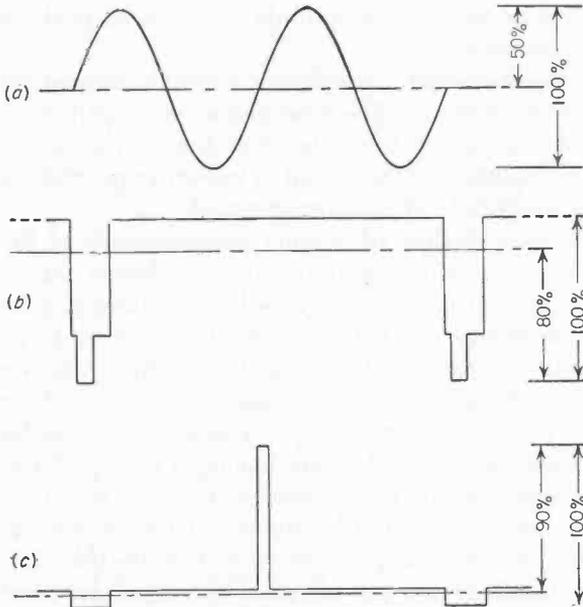


FIG. 16-9. (a) The peak departure from the a-c axis of a sine wave, (b) for an all-white composite signal, and (c) for a noncomposite signal consisting of a narrow white vertical bar on a black background.

The two signals described, together with a sine wave, are shown in Fig. 16-9. The sine wave shown at (a) is assumed to have unit peak-to-peak amplitude and, of course, has its a-c axis at the 50 per cent point. The all-white composite signal shown at (b) is assumed to be constituted in accordance with accepted industry practice (see Sec. 16-2) and also with a peak-to-peak amplitude of unity. An analysis of this waveform, however, shows that the excursion from the a-c axis in the negative direction represents 80 per cent of the peak-to-peak amplitude. The third waveform mentioned, that of a narrow white bar (*e.g.*, 2 per cent of picture width) and a noncomposite signal, is shown at (c). Again, unit peak-to-peak amplitude is shown but, in this instance, the departure from the a-c axis in the positive direction represents 90 per cent of the peak-to-peak amplitude.

From these examples of specific, but by no means improbable, video waveforms, it is evident that equipment intended for the undistorted transmission of video information should be capable of handling, without appreciable compression, a unidirectional pulse of either polarity and of amplitude equal to the full-rated peak-to-peak amplitude of the facility. On the other hand, if tests are made employing sine waves, the equipment should be capable of handling, without compression, sine-wave test frequencies of at least twice the amplitude of the rated peak-to-peak amplitude of the equipment.

**Method of Measurement.** Amplitude linearity measurements may be made in a number of ways. The most elementary method consists simply of applying the test signals to the input of the equipment under test and increasing the amplitude of this signal in known steps while observing and measuring the amplitude of the output signal.

A more elaborate method of making measurements of the type under discussion is with the aid of a step-generator device that automatically and continuously generates test signals having uniformly increasing (or decreasing) amplitudes at a suitable rate of recurrence to permit oscilloscopic observation of the resulting output from the equipment under test. If the amplitude changes of the test signal are made in discrete steps, as shown in Fig. 16-10*a*, the input-output characteristic can be ascertained without the need for an oscilloscope having a sweep characteristic that exactly matches that of the test generator since the resulting display will be a stair-step one wherein the height of each riser is a measure of the amount of compression, if any, as shown in Fig. 16-10*b*. If, on the other hand, the amplitude of the test signal is increased (or decreased) in a continuous manner, then the sweep of the oscilloscope must match that of the test generator exactly in order to avoid inaccurate results.

Still another and more sensitive method of measuring amplitude linear-

ity is to add a high-frequency (approximately 1.5-Mc) sine-wave modulation to the waveform described above. The peak-to-peak amplitude of the modulation may be made equal to the amplitude represented by one riser of the stair-step waveform. If this test waveform is passed through a video facility whose transfer characteristic is not linear then compression or expansion of the sine wave will occur at those amplitude levels where the nonlinearity exists. By recovering the resulting sine waves from the tops of the stair-step waveform while discarding the steps themselves, an oscilloscopic display may be obtained that is more readily interpreted than that shown in Fig. 16-10*b*. By presenting the groups of output sine waves corresponding to each step, side-by-side on a common a-c axis, the expansion or compression of each group with respect to its neighbors becomes readily apparent. Further, the display is more amenable to quantitative analysis than the simple stair-step presentation shown in Fig. 16-10*b*.

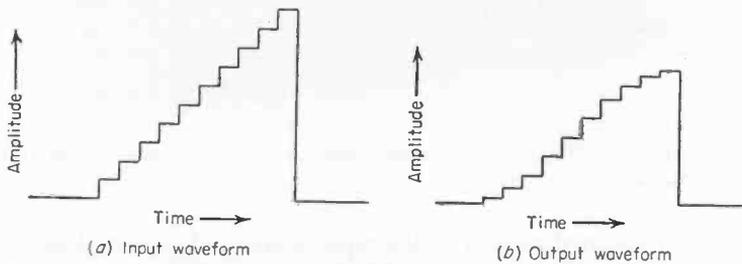


FIG. 16-10. An input testing waveform from a gray-scale step generator is shown at (a). The sample output waveform (b) indicates compression in the device under test at both the white and the black ends of the scale.

**16-4. Response-frequency Characteristics.** The measurement of the response-frequency characteristic of a video facility may be made point by point throughout the frequency spectrum of interest by means of a sine-wave oscillator and a suitable indicating device such as a vacuum-tube voltmeter. This procedure, while possible, is very tedious and slow because of the relatively wide band of frequencies (often extending from 0 to 10 Mc) that is of interest. Rather, it is the general practice to employ a sweep-frequency oscillator, a suitable detector, and an oscilloscope with good *low*-frequency response for measurements in the region above about 100 kc and a square-wave generator or a sine-wave oscillator for frequencies below this point.

**High-frequency Measurements.** A sweep-frequency generator which covers the upper portion of the video-frequency spectrum is shown in Fig. 16-11. This particular unit covers the band from 100 kc to 10 Mc

at a 60-cps sweep rate; *i.e.*, it makes 60 complete excursions of the entire frequency band every second. This repetition rate permits observation of measurements made with the aid of this sweep generator on a regular cathode-ray oscilloscope which may be associated with the sweep generator, the equipment under test, and a suitable detector in the manner indicated in the block schematic diagram Fig. 16-12. The use of a detector may be dispensed with, provided the oscilloscope used has a band-



FIG. 16-11. A sweep-frequency generator that covers the spectrum from 100 kc to 10 Mc at a 60-cps rate. (Courtesy of Radio Corporation of America.)

width at least as great as that of the equipment under test. Under these circumstances, the frequency-modulated output will be seen directly on the cathode-ray tube with an appearance along the lines shown in Fig. 16-13a. On the other hand, by employing a suitable detector, the envelope of the frequency-modulated signal (which has a recurrence rate of 60 cps) may be observed on any oscilloscope having good low-frequency response, with the appearance shown in Fig. 16-13b.

Suitable detector circuits for this application are shown in Fig. 16-14. The first circuit shown is a conventional half-wave rectifier with the usual low-pass filter circuit between the detector and the output terminals. The second circuit shown employs two rectifiers in a voltage-doubler arrangement. Either crystal or vacuum-tube diodes may be used for the rectifiers in these circuits although the former are usually preferred because of their convenience.

When a sweep-frequency oscillator is used as a source of test signals, it is necessary to provide some means for determining the frequency represented by any particular portion of the trace that is of especial interest. This is usually done by introducing a calibrating marker of one kind or another. In the sweep oscillator illustrated, a separate continuously vari-

able calibrated sine-wave oscillator, covering the band of frequencies from 100 kc to 10 Mc, is provided for this purpose. A signal of suitable intensity (relatively small) from this oscillator is mixed with the frequency-modulated oscillator output, and the resulting beat frequency appears on the oscilloscopic display as a marker pip, as shown in Fig. 16-13c. A second type of calibrating marker (employed in other equipment) consists of a calibrated tunable absorption wavemeter which produces a small notch in the resulting display, as shown in Figs. 16-13a and 16-13b.

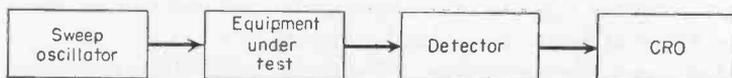


FIG. 16-12. Block diagram showing an equipment arrangement for making sweep-frequency measurements.

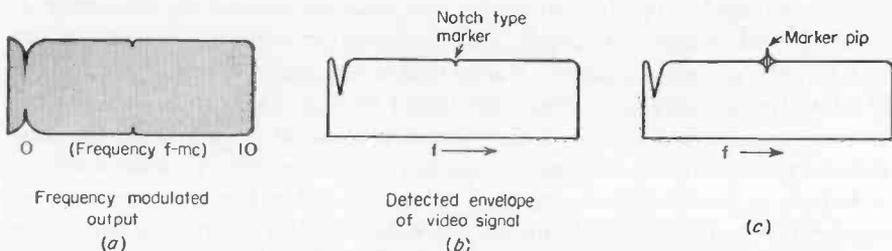


FIG. 16-13. (a) The appearance of the frequency-modulated output of a sweep-frequency generator when applied directly to an oscilloscope. (b) The envelope of the same signal produced by a suitable detector. A notch-type marker pip is also shown. (c) The appearance of a beat-frequency type of marker pip.

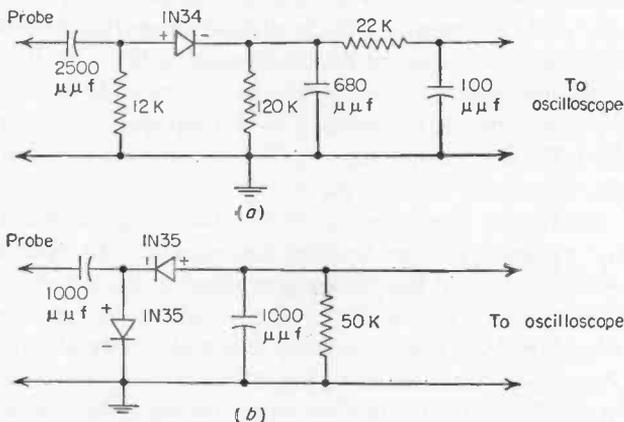


FIG. 16-14. (a) Half-wave and (b) full-wave detector circuits suitable for sweep-frequency measurements.

Most of the video amplifier components employed for broadcasting purposes are designed for operation into low-impedance (usually 75-ohm) circuits. Thus the output of these equipments provides a convenient point to connect the indicating oscilloscope and its associated detector (if one is used). Under these circumstances, in testing a multistage video amplifier, it is customary first to apply the test signal to the grid of the last stage, determine its characteristics, make such corrections or adjustments as are indicated, and then to apply the test signal progressively to preceding stages until the input terminals of the device are reached. In this manner, stage after stage is added to the chain under test and the deficiencies (if any) contributed by each may be determined.

**Low-frequency Measurements.** The response of video amplifiers at the low-frequency end of the spectrum is usually determined either by point-by-point sine-wave or by square-wave measurements. The techniques for employing sine waves for response measurements are straightforward and consist, essentially, of applying known frequencies to the input of the amplifier stage or stages under test and measuring the output level with a suitable indicating instrument such as a vacuum tube or other suitable type of voltmeter. This process is capable of providing detailed information as to the response-frequency characteristic of video facilities although it has certain limitations when used for the measurement of equipment that employs clamping. In this case, low-frequency sine-wave measurements can usually be made only after the clamping circuits have been disabled, in which case true results are not necessarily obtained particularly where reliance is placed upon the clamping action to obtain good low-frequency response. Furthermore, it is not generally possible to mix low-frequency sine-wave signals with blanking pulses in order to make measurements with clampers in their normal operating condition. Another disadvantage of sine-wave measurements is the fact that response-frequency measurements do not, in themselves, provide information concerning the phase-shift characteristics of the equipment under test. On the other hand, for some applications, there is no complete substitute for point-by-point sine-wave measurement.

To some extent, the shortcomings of sine-wave measurements may be overcome by square-wave measuring techniques. In this instance, a square wave of the desired frequency is applied to the input of the amplifier or amplifiers under test and the output observed on a cathode-ray oscilloscope having good low-frequency response. For aligning the low-frequency phase response of an amplifier, it is customary to employ a square wave with a fundamental frequency equal to the field frequency of the television system. With a test signal of this frequency, low-frequency phase adjustments can be made in order to obtain a minimum tilt and flat top of

the amplified square wave. Square-wave tests at other frequencies may be made, of course, by varying the frequency of the input test signal. As a rule it will be found that in a properly designed video amplifier there is very little, if any, deviation from uniform response throughout the region up to and even beyond the point where the high-frequency measuring techniques described above are employed. However, should the amplitude or the phase response be faulty, it will be manifested by tilted, convex, concave, or other shape tops of the output waveform.

Square waves may be mixed with blanking signals with some degree of success for measuring the performance of equipment employing clamping. In this instance, in order to obtain a meaningful display, it is generally necessary to employ filters to eliminate the spurious frequencies that are generated.

**16-5. Resolution Measurements.** The measurement of the resolving power of a television system is related closely, of course, to the measurement of the response-frequency characteristics as discussed above. As a matter of fact, the ability of a television system to resolve detail is a function (among other things) of the response-frequency characteristics of the system. Resolution measurements are, therefore, a measure of the bandwidth of the transmission system and are often used for such determinations where facilities for making more detailed analyses are not available. On the other hand, the performance of the camera pickup tubes and of the picture tubes cannot be determined by response-frequency measurements of the type described in the preceding section.

The standard method of making resolution measurements is to televise a test chart of specified design (Fig. 16-15) by means of the equipment whose capabilities are of interest. A measure of the resolving power of the system is then obtained by observing the point at which the individual lines of the graduated wedges are no longer distinguishable as separately defined images. The calibration adjacent to these wedges then indicates the resolving power of the system in terms of the number of black *and* white lines of the width adjacent to the calibration that would occupy a dimension equivalent to the picture height. This convention assumes that the resolution throughout the picture height is equal to that at the particular point where the wedge is being observed. Although such an assumption is not always valid in actual practice, it does provide a useful and workable custom.

In common with most optical devices, television systems do not usually enjoy equal resolution at all points throughout the picture area. Further, as is well known, in television the resolution is not necessarily the same in both the horizontal and the vertical direction. A satisfactory test pattern which is intended for serious and detailed measurements, therefore, makes

provisions for resolution determinations in both directions and in the corners as well as in the central portion of a picture. Horizontal wedges are employed for the measurement of vertical resolution and vertical wedges for the determination of horizontal resolution.



FIG. 16-15. A camera being trained on a standard test chart for resolution measurements and camera alignment purposes.

**16-6. Test Charts.** A properly designed test chart may be used to provide a great deal more information in addition to the resolution determinations described in the preceding section. With this in mind, standard test charts<sup>5</sup> (available in the form of 18- by 24-in. paper charts and on 16- and 35-mm film) have been devised incorporating features that permit determination of (a) horizontal and vertical resolution, (b) geometric distortion, (c) aspect ratio, (d) uniformity of shading, (e) streaking, (f) gray-scale rendition, (g) effectiveness of interlacing, (h) presence of r-f or other interference, (i) irregularities in response-frequency characteristic, and (j) picture monitor brightness adjustments.

<sup>5</sup> IRE Standard 50 IRE 23.S1, "Standards on Television," Institute of Radio Engineers, New York, 1950.

It should not be inferred from the above that a test chart is necessarily the best or the only means for making the various measurements listed. As a matter of fact, it is useful primarily as a periodic maintenance and as a quick preservice checking device which, for the most part, provides qualitative rather than quantitative information.

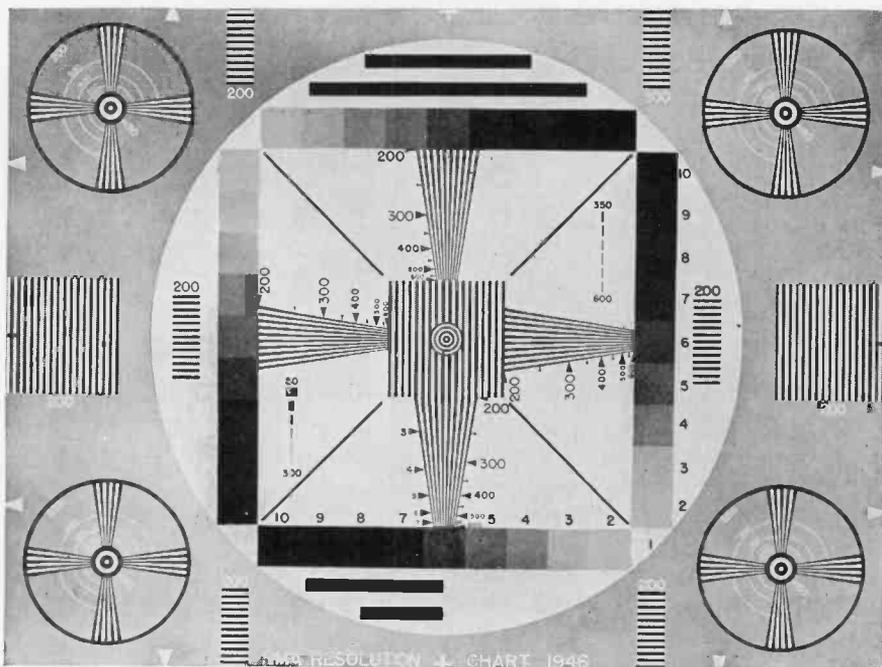


FIG. 16-16. The standard test chart employed for the adjustment and evaluation of television equipment and systems. (Copyright, 1946, Radio and Television Manufacturers Association.)

**Geometric Distortion.** The extent of the geometric distortion present in a picture display may be determined by observing individually the vertical and the horizontal sweep linearity. The standard test chart shown in Fig. 16-16 incorporates two groups of short horizontal black and white bars at the top of the chart, two similar groups in the central area, and two more groups at the bottom. These bars are labeled "200" indicating that their thickness is such that a total of 200 black and white bars (100 of each) would be required to fill the picture height. These groups of horizontal bars may be compared with each other in order to check the vertical sweep linearity at the top, center, and bottom of the picture. The over-all height of each group of bars will be the same when the vertical sweep is linear.

The horizontal sweep linearity may be checked by comparing the spacing of the three groups of vertical bars, also labeled "200," which are located at the right- and left-hand borders and also in the center of the test chart. The trueness of the large circle in the center of the test chart and of the small ones in the four corners also affords a good check on the linearity of the vertical and horizontal scanning.

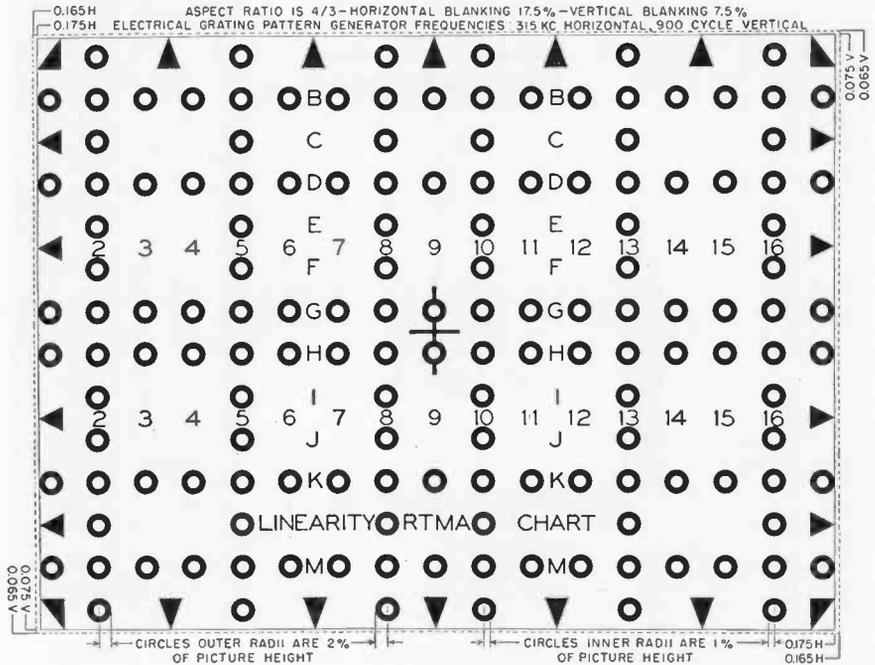
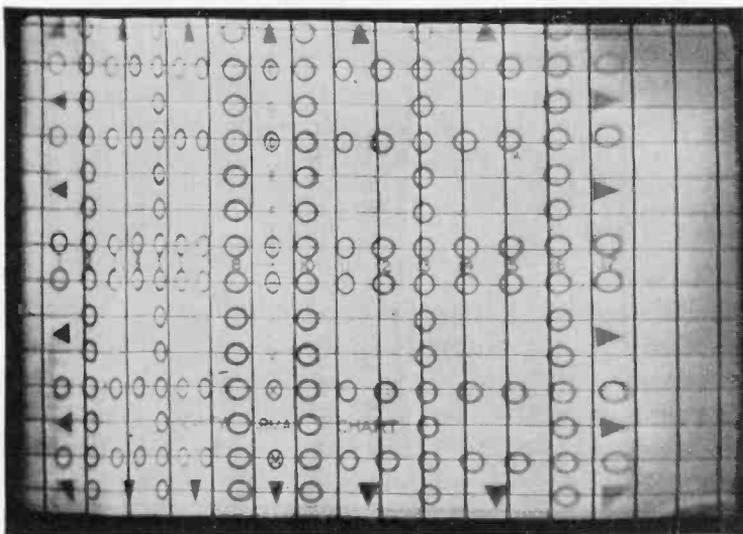


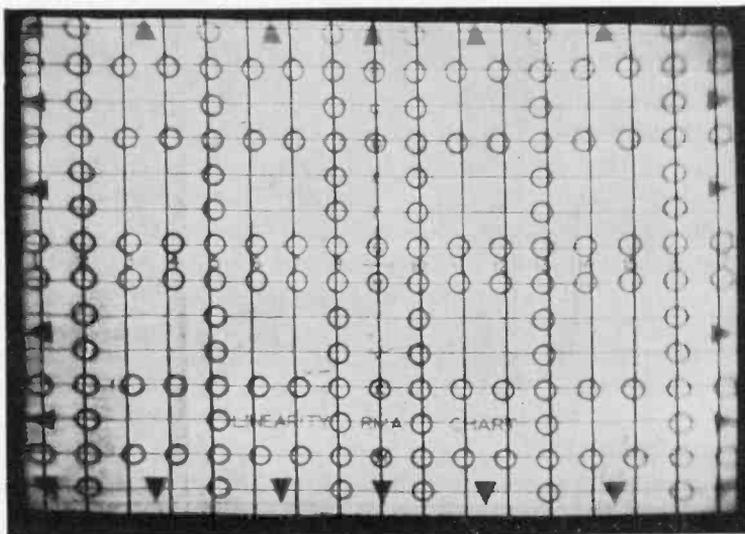
FIG. 16-17. A test chart which, when used in conjunction with a suitable grating generator, permits accurate determinations of geometric distortion. (Courtesy of Radio and Television Manufacturers Association.)

Linearity measurements employing the procedure just described result in an over-all determination that does not readily permit separation of the geometric distortion contributed by the pickup device from that of the picture monitor. One method of alleviating this difficulty is first to adjust the picture monitor for as perfect linearity as possible, with the aid of a grating generator (see Sec. 16-7, below) and then noting any additional distortion produced when the test chart is scanned by a camera pickup unit.

A more critical determination of the magnitude of the geometric distortion present in a television pickup device may be made with a grating generator and a linearity chart of the type shown in Fig. 16-17. Further-



(a)



(b)

FIG. 16-18. The appearance of a linearity test chart with the output of a bar generator superimposed on the display. (a) Excessive geometric distortion. (b) The geometric distortion in this instance is well below 2 per cent. (Courtesy of Allen B. Du Mont Laboratories, Inc.)

more, by employing this combination of testing aids, the scanning linearity of the camera pickup unit itself may be accurately determined, regardless of the scanning linearity of the picture monitor. This is accomplished by scanning the linearity chart with the camera pickup device under observation and then mixing with this video signal the output of a grating generator that is electronically producing a signal that corresponds to accurately spaced horizontal and vertical bars.

By proper choice of the grating generator output frequencies, the horizontal and vertical bars may be made to coincide exactly with the rows and columns of circles on the linearity chart when no geometric distortion is present. On the other hand, displacement of the circles from their ideal location immediately indicates the nonlinearity of scanning in the pickup device (see Fig. 16-18a). The size of the circles on the linearity chart illustrated are such that, if the grating lines remain within the boundaries of the circles, the geometric distortion is less than 2 per cent (Fig. 16-18b).

**Aspect Ratio.** The gray scales located within the center circle of the test chart shown in Fig. 16-16 are proportioned so that, when the horizontal and vertical scanning is linear, the four step-wedges form a square if the aspect ratio is correct. The over-all dimensions of the chart itself are also in the correct 3 by 4 aspect ratio and can be used for determining this characteristic. The location of exact edges of the gray field of the chart may be determined by observation of the small white arrowheads, two of which appear at each of the four borders of the chart. As shown, the head of each arrow is exactly at the border of the chart and thereby provides means for locating these boundaries precisely.

**Shading.** The standard chart provides two methods of checking uniformity of shading in those cameras which employ shading techniques. One method is to simply observe the display on a picture monitor and to visually determine the evenness of the gray background that forms a large part of the chart. A second method is to observe the average picture signal axis on a waveform monitor, which axis should be parallel to the reference black line when observed at both line and field frequencies.

The four gray-step scales may also be used as an additional aid in determining the uniformity of shading. When the shading is uniform, the same steps will be distinguishable on all four gray scales.

**Streaking.** Streaking may occur in a television transmission system because of a variety of reasons, *e.g.*, poor low-frequency phase characteristic or poor clamping action. The standard test chart incorporates four relatively long horizontal bars, two at the top and two at the bottom, in order to provide a check on streaking which usually manifests itself most prominently at the lower frequencies.

A test chart, specifically designed for streaking measurements, is shown in Fig. 16-19. This chart permits the amount of streaking to be expressed in a numerical manner thereby making it possible for different observers to compare streaking determinations on a quantitative basis. This procedure is useful, for example, in cataloguing the amount of streaking produced by different camera tubes, by different circuitry, or for comparing the streaking at different points along a television transmission system. In using a chart of this type it is important to align the bars so that they are exactly parallel with the scanning lines in the pickup device. If the bars are tilted as much as 10 degrees or so, all streaking will probably disappear, as explained in Sec. 7-3, *Horizontal Structures*.

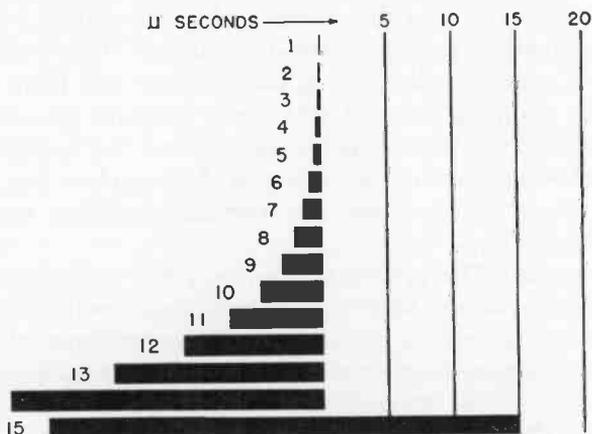


FIG. 16-19. A test chart that provides a basis for quantitative determinations of streaking.

In passing, it may be noted that, where streaking measurements on other than camera equipment are of interest, use may be made of a special square-wave-type generator<sup>6</sup> that electronically produces the waveforms corresponding to the bars (one at a time) shown in Fig. 16-19. With equipment of this type, it is possible to undertake streaking measurements without the need for having to employ an entire camera chain and associated valuable equipment.

**Gray-scale Rendition.** The specifications covering the standard test chart shown in Fig. 16-16 stipulate that the four gray scales shown shall each be composed of 10 steps varying in an approximately logarithmic manner over a 30-to-1 range. Unfortunately, as noted in Sec. 7-7, the

<sup>6</sup> Seigle, R. K., Television Streaking Test Set, *Electronics*, Vol. 24, No. 11, p. 96 (November, 1951).

charts that are available commercially often leave a great deal to be desired in the accuracy of the gray-scale graduations. Accurate gray scales require special reproducing processes; witness the fact that in the illustration shown here all 10 steps of the scale are by no means distinguishable. In any event, by checking all the camera tubes that are of interest on a given gray scale, their brightness transfer characteristics may be determined, at least on a relative basis. Where more precise gray-scale measurements are of interest, resort must be made to custom-created gray scales which may be assembled from commercially available sheets of material having accurately determined reflectance values.

**Interlacing.** The four diagonal lines within the large circle of the test pattern may be employed to obtain a qualitative indication of the accuracy of the interlacing of the system under observation. A ragged or zigzag line indicates a poor interlacing condition. This test is not effective, however, where the interlacing fails entirely and there is complete pairing of the scanning lines. Under these extreme circumstances, the diagonal lines will not have a jagged appearance, but a glance at one of the horizontal wedges should forewarn of the complete loss of interlace since under these circumstances the vertical resolution cannot exceed approximately 250 lines.

**R-f Interference.** The presence of r-f or other high-frequency interference in the video *amplifier* circuits manifests itself by the familiar moiré pattern of the picture as a whole. In some types of commercial equipment, r-f high-voltage power supplies are employed and interference from this source is sometimes introduced into the horizontal *scanning* circuits. This type of r-f interference may be detected by observation of a vertical line in the test pattern such as one of the vertical lines in the large 200-line squares or one edge of the vertical gray scales. When r-f interference is present in the horizontal sweep circuits, vertical lines in the test pattern become modulated and take on the appearance of a wriggling worm, the intensity of the "wriggling" being a function, of course, of the extent of the r-f interference.

**Response Irregularities.** A spurious peak or a sharp cutoff in the response-frequency characteristic of a television transmission system often discloses itself in the resulting picture display as discrete, closely spaced, positive or negative, horizontally displaced, delayed or advanced repetitions of the original signal. This manifestation of "ringing" of the video circuits can be detected by observation of vertical lines in the picture whose dimension in the horizontal direction is such as to create a signal having a frequency in the immediate vicinity of the response-frequency irregularity. The vertical wedges in the standard test pattern produce signals of various frequencies, of course. The relation between the num-

ber of lines,  $N$ , and the fundamental frequency,  $f$ , of the corresponding signal is

$$f \text{ (in megacycles)} = \frac{N}{80} \quad \text{or} \quad N = 80f \text{ (megacycles)}$$

The lower of the two vertical wedges of Fig. 16-16 shows this relationship by the calibrations on the left side of the wedge of the frequency in megacycles corresponding to the number of lines shown by the numbers on the right side of the wedge.

For the detection of "ringing," however, the multiple lines in the wedges often prove disconcerting. Therefore, individual vertical lines are provided for the purpose. These range in widths corresponding to 50-line resolution at one extreme and to 600-line resolution at the other, and are arranged in two groups. The group in the lower left-hand quadrant corresponds to 50, 100, 150, 200, 250, and 300 lines. The group in the upper right quadrant represents 350, 400, 450, 500, 550, and 600 lines. Determination of the individual line (or lines) which produces "ringing" permits a qualitative determination of the frequency (or frequencies) where a transmission irregularity exists.

**Picture Brightness.** The standard test chart shown in Fig. 16-16 has been carefully designed in order to provide a balance between the white, gray, and black areas so that the brightness of a display on a picture monitor or receiver may be adjusted with the aid of the chart and subsequently prove satisfactory for reproduction of an average scene. This is an important consideration to be kept in mind in the design of any test patterns or special charts that are prepared for television application.

**16-7. Grating Generators.** A grating generator is an electronic device that is capable of producing a display on a picture monitor consisting of a series of horizontal and vertical lines which have the appearance of a grating. The horizontal lines or bars serve to check vertical scanning linearity, and the vertical bars serve for horizontal linearity checks. The bars are created by electronically generating accurately timed pulses in the proper sequence to produce the desired horizontal and vertical markers. The desired degree of accuracy is often achieved by driving the grating generator with standard synchronizing generator pulses.

With these carefully timed signals as a standard, the scanning linearity of picture monitors may be determined by observing the uniformity of the spacing of the vertical and of the horizontal bars. Equal spacing between bars indicates perfect scanning linearity, while nonuniform spacing discloses the presence of geometric distortion. Curvature of the grating reveals the presence of interfering magnetic fields or the presence of spurious modulation in the scanning generator waveforms. In any event, with

the grating as a guide the scanning linearity of the picture monitor under test may be adjusted until the best possible performance is obtained.

A block diagram of the circuits employed in one commercially available grating generator is shown in Fig. 16-20. This unit produces a pattern consisting of 14 horizontal bars and 17 vertical bars in conformance with the requirements imposed by the linearity test chart shown in Fig. 16-17. As shown in Fig. 16-20 and in the schematic circuit diagram of Fig. 16-21, a standard synchronizing signal, consisting of both vertical and horizontal synchronizing pulses, is applied to an amplifier and a blocking oscillator

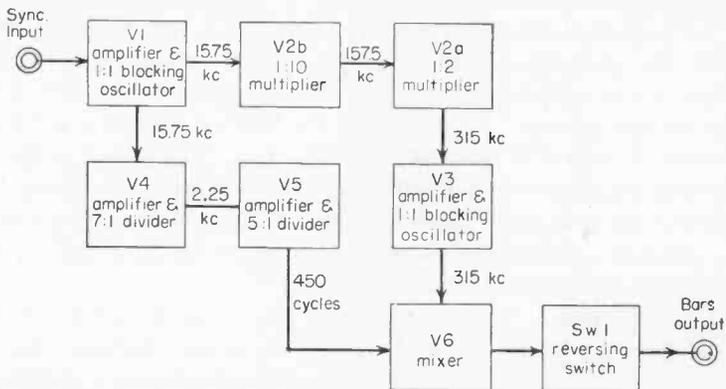


FIG. 16-20. Schematic block diagram of a linearity bar generator.

tube V1. A portion of the output of this tube is applied to a frequency multiplier stage V2b. This tube increases the 15.75-kc original synchronizing signal to 157.5 kc, a multiplication of ten times. A second multiplier, V2a, then doubles this frequency thereby producing a 315-kc signal which drives an amplifier and blocking oscillator tube V3. The output of this stage, which in the final signal produces the vertical bars, is applied to one of the inputs of a mixer stage V6.

The signal for producing the horizontal bars, which is applied to the other input of the mixer tube V6, is also derived from a portion of the output of the first amplifier and blocking oscillator V1. In this instance the 15.75-kc synchronizing waveform is applied to an amplifier and divider stage V4 which effects a 7-to-1 division. The 2.25-kc output from this tube is applied to a second amplifier and divider stage V5 where a 5-to-1 division takes place, producing a 450-cps signal. This is the signal which generates the horizontal bars and which is mixed with the 315-kc vertical bar signal in the mixer tube V6. A switch permits selection of a positive polarity output signal from the cathode circuit of the mixer tube V6 or one of negative polarity from its plate circuit.



The grating generator described produces a single grating pattern that is especially designed to meet the needs of most television broadcasting applications. Other types of grating generators are available for specialized laboratory use, which permit independent selection of the number of vertical and horizontal bars produced as well as adjustment of their width. One such unit, for example, produces from 12 to 36 horizontal bars and from 10 to 64 vertical bars, with the width of the bars adjustable from zero to a width equal to 10 per cent of the bar spacing.

**16-8. Pulse Cross Display.** One of the most important, if not *the* most important, series of measurements made in a television broadcasting station is that undertaken for the purpose of ascertaining whether the synchronizing generator is producing output waveforms that are in accordance with governmental and with industry standards. In general, two basic types of measurements are made of the output waveforms from a synchronizing generator. One type is the routine operational check measurements that are performed on incoming signals from remote points and on a routine basis, on the output of local synchronizing waveform generators. The other type is the detailed measurements that are made when testing and adjusting synchronizing waveform generators for operation in accordance with prevailing standards. The first kind of measurement calls for a device which is relatively simple to operate and which is able to quickly provide reasonably accurate information concerning the synchronizing signal under observation. The second type of measurement may usually be undertaken in a more leisurely manner but with as great an accuracy as possible, *i.e.*, with laboratory type of equipment (see Sec. 16-9).

**Fundamental Principles.** In order to fill the need for operational type of measurements, the so-called "pulse cross" type of display was developed.<sup>7</sup> One of the features of the pulse cross method of observing synchronizing waveforms is the fact that it makes use of a modified picture monitor and thereby extends the usefulness of a piece of video equipment available in every television control room. The method consists, essentially, of expanding both the vertical and the horizontal scanning of the picture monitor so that the individual scanning lines may be observed in some detail. Since synchronizing (and other) waveforms manifest themselves on a picture tube as changes in brightness (rather than as amplitude differences), these brightness changes may be translated by the observer into their equivalent amplitudes in order to obtain an indication of the shape of the prevailing waveforms. This procedure does not permit so detailed a determination of the shape of the waveforms as with a

<sup>7</sup> Monfort, R. A., and F. J. Somers, Measurement of Television Synchronizing Impulses, *RCA Rev.*, Vol. 5, No. 3, p. 370 (January, 1942).

conventional oscilloscope, but adequate information is generally obtainable for operational checks.

In a normal picture display, the horizontal and vertical synchronizing pulses occur at the end of each line and each field, respectively, and in most equipment at least a portion of both types of synchronizing pulses occurs during the flyback time. Furthermore, the front porch occurs at a position corresponding to the right edge of the picture and in a location that is usually under a picture-tube mask. Similarly, the back porch is generally hidden under the left edge of the picture mask. In a corresponding manner, the synchronizing waveforms existing during the *vertical* blanking and synchronizing interval either occur during the normal vertical flyback interval or are hidden from view by the top and bottom of the picture-tube mask. In addition, of course, the signal amplitude and polarity normally applied to the control element in the picture tube are such as to blank out the trace during both the horizontal and the vertical synchronizing intervals. Thus, more is required than simply expanding the picture-tube sweeps in order to make visible the synchronizing and blanking signals that are of interest.

First, it is necessary to introduce a shift in the timing of the sweep triggering circuits in order to bring that portion of the display that is of particular interest onto the picture-tube raster. This need is implicit in the act of expanding the scanning waveforms since, under these circumstances, only a portion of the entire display can be presented at any one time on the face of the picture tube. The normal display is, therefore, shifted in phase by intervals corresponding to approximately one-half of a field and one-half of a line in order to present, in the center of the raster, the synchronizing and blanking waveforms that are outside the visible limits of the regular display. In addition, the polarity of the video signal is usually reversed so that the normally negative-going blanking and synchronizing pulses on the grid of the picture tube become positive-going signals that produce white rather than blanked-out traces.

**Details of Display.** The appearance of the resulting display is shown in Fig. 16-22, from which the origin of the name "pulse cross" becomes evident. The pattern formed by the synchronizing and blanking pulses, when displayed so as to appear in the center of the raster, has the general appearance of a cross with a horizontal axis of approximate symmetry. In order to assist in identifying the various parts of the pulse cross display, Fig. 16-22 has been prepared with the scanning lines associated with the *A* field shown as solid lines and those associated with the *B* field as dotted lines. As a further aid, the synchronizing pulses that correspond to those shown in the pulse cross display are shown in a conventional amplitude vs. time diagram for the two fields in question. Finally, the individual lines

of the raster are numbered with the line coinciding with the start of the vertical synchronizing pulse in field A arbitrarily called line No. 1.

Examination of the upper portion of the pulse cross display shown in Fig. 16-22 will reveal that the appearance of lines 506 to 518 are all alike. The dark left end of these lines represents the residual ends of horizontal scanning lines, the bulk of the scanning lines being outside the confines of the visible raster because of the expanded horizontal sweep. Next there is a narrow region, corresponding to the front porch, where the trace is an intermediate gray. Reference to the synchronizing waveform diagrams (remember that the signal polarity has been reversed so that black is now in an upward direction) shows that the front-porch amplitude is part way between the zero signal and the synchronizing pulse level, hence an intermediate shade of gray in the reproduction. Next, there is a wider, whiter region which corresponds to the synchronizing pulse itself; then a second intermediate gray region created by the back porch and about as wide as that corresponding to the synchronizing pulse. Finally, there is a dark region extending the remainder of the way to the right edge of the display which corresponds to the beginning of the regular horizontal scanning lines in a normal raster.

From the pattern just described, the relative lengths of the front and back porches and of the horizontal synchronizing pulse may be determined. Furthermore, by adding a marker in the form of accurately timed pips, the absolute time duration of these portions of the synchronizing and blanking signals can be readily ascertained. Thus the pulse cross pattern may be employed for checking the timing of the horizontal synchronizing and blanking pulses

Referring again to Fig. 16-22, it may be seen that lines 520 to 524 are alike in appearance but entirely different from those just described. Reference to the waveform diagrams will show that these lines are within the vertical blanking interval. In the pulse cross display, the intermediate gray region at the left corresponds to the vertical blanking level, the lighter region which follows (and which has a width of approximately one-half that of the horizontal synchronizing pulses described above) corresponds to the first group of equalizing pulses. The next intermediate gray region corresponds to the signal at blanking level that separates the equalizing pulses. The second lighter region corresponds to the second of the two equalizing pulses that occur within each field interval; finally, from this point to the end of the display, there is seen the intermediate gray corresponding to blanking level signals.

The display just described permits the observer to ascertain the relative widths of the equalizing pulses (which are normally one-half the duration



of horizontal synchronizing pulses) and to count the number of equalizing pulses that are present.

Next, it may be observed that the pulse cross displays of lines 1 to 6 are all alike. These lines correspond to the interval occupied by the vertical synchronizing pulse and are entirely of a light shade except for two intermediate gray regions that correspond to the serrations in the vertical synchronizing pulse. Here, with the aid of marker pips, the duration of the serrations may be accurately determined as well as their number.

The pulse cross pattern is approximately symmetrical about the horizontal center line represented by the vertical synchronizing pulse display so that the lower half may be interpreted in an analogous manner to that detailed above.

**16-9. Video Waveform Analyzer.** For a detailed scrutiny of synchronizing generator and other video waveforms, resort is usually made to a cathode-ray oscilloscope. A specialized type of oscilloscope is required for these observations, however, since the average oscilloscope does not incorporate the refinements that are required for such examinations. For example, it is often desirable to be able to examine the waveforms corresponding to a few lines of a television picture raster or of one particular line or even of a portion of a single line. This requires means for selecting and locking the oscilloscope to the particular field and line that is of interest and for expanding the resulting display to the degree necessary to show the detail that is desired, *e.g.*, observation of the slope of the leading or trailing edges of specific pulses. Further, an accurate method for measuring small time intervals is required in order that the degree of conformance of the pulses under observation to applicable standards may be ascertained. The accuracy required of such measurements is evidenced by examination of Fig. 1-4, which shows the standard synchronizing waveforms and which shows that measurement intervals as small as  $0.003H$  (where  $H$  is the horizontal scanning period) or 0.19 microsecond are required.

The cathode-ray oscilloscope shown in Fig. 16-23 is especially designed to fulfill the requirements outlined above. The unit incorporates a wide-band (10-Mc) deflection amplifier, a driven-type sweep circuit, a special type of synchronizing system which includes a calibrated synchronizer delay circuit, a precision sweep calibrator, and a high-voltage cathode-ray tube. As shown by the block diagram given in Fig. 16-24, the unit consists of two basic parts. The cathode-ray tube and its supporting circuits constitute the indicator part and are shown in the upper portion of the diagram. The synchronizer circuits are shown in the lower portion.

The synchronizer is designed to operate either from a synchronizing signal derived from a composite television signal applied to the indicator

unit or from a separate external source of synchronizing pulses. After passing through a phase inverter and amplifier unit, either the synchronizing signal is applied to a field and line selector unit or this unit may be by-passed completely when it is desired to operate the oscilloscope in a conventional manner. In any event, the resulting signal is employed to operate a trigger generator whose output may be applied to a trigger amplifier (in the indicator portion of the unit) directly or via a calibrated delay circuit. The delay circuit, when used, provides means for continuously varying the delay of the trigger pulses from 4 to 1,000 microseconds. This delay circuit, combined with the line and field selector, permits selection of any particular line of a television picture signal and any portion of that line for observation on the cathode-ray oscilloscope.

As shown in the lower part of the block diagram, the synchronizer portion of the oscilloscope also provides a trigger output, with or without a delay of approximately 30 microseconds, for initiating the action of an external test signal generator or other device. In addition, a test pulse generator is included to produce a signal, synchronized with the oscilloscope sweep, that is useful for checking the transient response of video equipment. The test pulse duration is 1 microsecond and the rise and fall time is 0.02 microsecond. Finally, the synchronizing section incorporates a sweep-rate calibrator which is capable of applying timing markers to the oscilloscope trace at intervals of 0.2, 1, or 10 microseconds.

The indicator portion of the oscilloscope illustrated contains a sweep-trigger amplifier (driven from the synchronizing section circuits just described) and a sweep generator whose rate may be continuously adjusted for sweep durations of from 1 to 15,000 microseconds (1 Mc to 67 cps). As shown by the block diagram, this sweep generator may be triggered either by the synchronizer output or by an external triggering source.

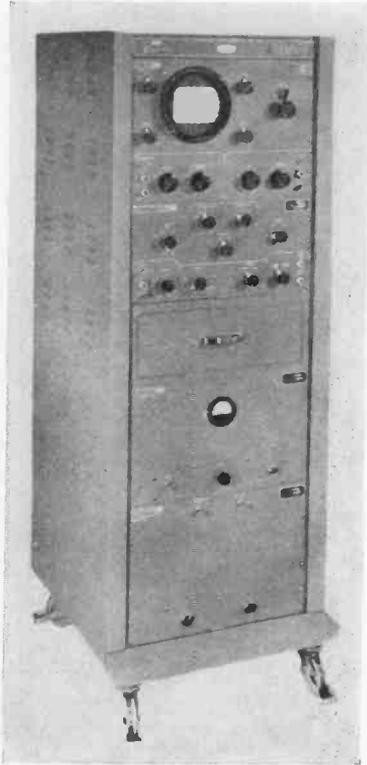
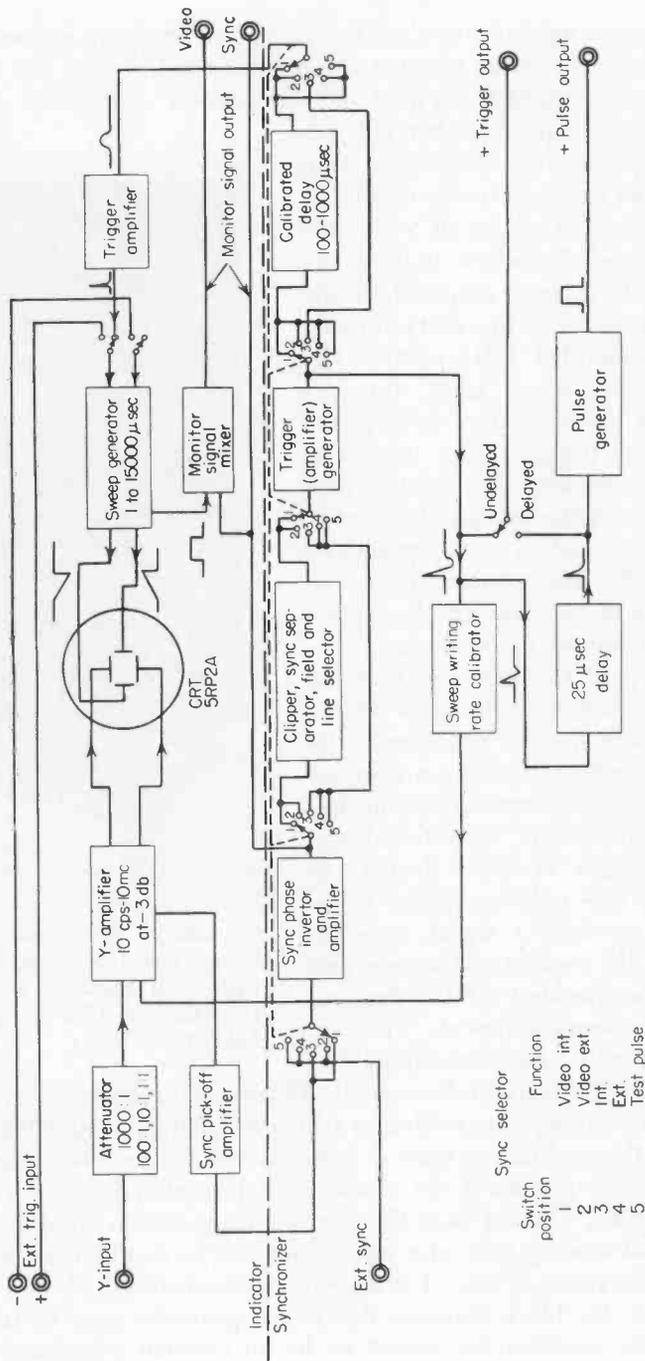


FIG. 16-23. A cathode-ray oscilloscope especially designed for the analysis of television waveforms. (Courtesy of Allen B. Du Mont Laboratories, Inc.)



Switch position	Function
1	Video int.
2	Video ext.
3	Int.
4	Ext.
5	Test pulse

Fig. 16-24. Schematic block diagram of the television oscilloscope shown in Fig. 16-23.

The sweep generator also provides a marker signal which is mixed with a portion of the video signal under observation and the combination made available for driving a video monitor. The marker then serves to identify the line or group of lines that has been selected by the field and line selector for observation on the cathode-ray oscilloscope.

The input circuit of the vertical deflection amplifier includes a three-step, compensated, high-impedance attenuator followed by a 10-cps to 10-Mc amplifier with sufficient gain to obtain a 2-in. deflection on a cathode-ray tube having a 12-kv accelerating potential. The over-all sensitivity of the amplifier is 0.1 volt rms, per inch of deflection for a 10-Mc bandwidth.

## Color-television Broadcasting Equipment

THERE IS NO DOUBT but that color-television transmissions will completely replace monochrome transmissions even though the type of color-television system<sup>1</sup> that finally proves to be the "ultimate" in quality, in conservation of bandwidth, in simplicity, and in economy may not be decided for some time to come (if ever). Strangely enough, the rate at which the transition to color occurs may be determined by factors other than technical ones.

Some are prone to compare color television to color motion pictures and to draw attention to the relatively small number of picture productions being released in color even though commercial color film processes have been available for the past generation. Actually, the factors primarily responsible for the relatively slow progress toward more extensive use of color film are not the controlling ones in the color-television field. In motion-picture work, the relatively great cost of finished color film as compared to black-and-white film, coupled with the lack of sufficient processing capacity to meet all needs expeditiously, and certain other factors peculiar to color film applications, has greatly impeded the wide use of color film.

In color television, on the other hand, the added cost for both broadcasting and receiving equipment can be quite nominal compared to the total investment, the added cost of operation can be small, and the additional bandwidth requirements can be zero. Furthermore, the preference of people for a colorful world, rather than a monochrome one, is evident all around us. Thus, from the viewpoints of initial cost, operating expenses, channel availability, and the preferences of viewers, there are no major impediments in the way of universal adoption of color-television transmissions.

In keeping with the character of the remainder of this volume, the

<sup>1</sup> Fink, D. G., *Alternative Approaches to Color Television*, *Proc. IRE*, Vol. 39, No. 10, p. 1124 (October, 1951).

material in this chapter is concerned primarily with the equipment and techniques that are available for commercial use as contrasted to those still in the experimental or developmental state. With these factors in mind, there is presented in the following sections (*a*) a brief review of the basic principles of color-television systems, (*b*) an explanation of the terminology peculiar to color transmissions, (*c*) a description of the color transmission system adopted as standard by government regulation on Nov. 20, 1950, and (*d*) examples of commercial monochrome television broadcasting equipment modified for color transmission.

**17-1. Basic Principles.** In both monochrome and color-television systems the picture area is scanned in a systematic manner and suitable pulses are generated to provide means for synchronizing the scanning beam of the picture monitor or receiver with that of the pickup tube. In monochrome transmission, aside from synchronizing pulses, it is necessary only to transmit a signal that corresponds to the brightness variations in the original scene. In color television, on the other hand, it is necessary also to transmit information as to the hue and saturation of the colors in the scene. Hue may be described as the main quality factor in color, *i.e.*, the element that distinguishes a color as red, or blue, or green, or some other color. Saturation, on the other hand, may be defined as the amount of hue in a given color, *i.e.*, the purity of the color or the degree of dilution of the color by mixture with white. Therefore, in color television, it is necessary to transmit information as to the brightness, hue, and saturation of the colors in the original scene.

Fortunately, by creating mixtures in various proportions of three correctly chosen primary colors, it is possible to produce almost all the colors of the visible spectrum. Furthermore, in an additive color system, by correctly proportioning the three primary colors, white light can be produced. In this manner, saturated colors may be diluted and various degrees of saturation obtained. Thus, a color-television system may be established by devising means for transmitting and receiving signals corresponding to the brightness of three primary colors (such as red, blue, and green) in the original scene.

The universal approach to color television, therefore, is to separate the light from the original scene into three primary colors and to develop video signals corresponding to these three components. This is usually accomplished with the aid of monochrome camera tubes and either conventional light filters or dichroic mirrors. The three video signals thus created have the same general characteristics as those produced by a monochrome camera chain except that one set of components corresponds to the reds in the original scene, a second set to the blues, and a third set to the greens.

FIELD SEQUENTIAL  
COLOR TELEVISION SCANNING

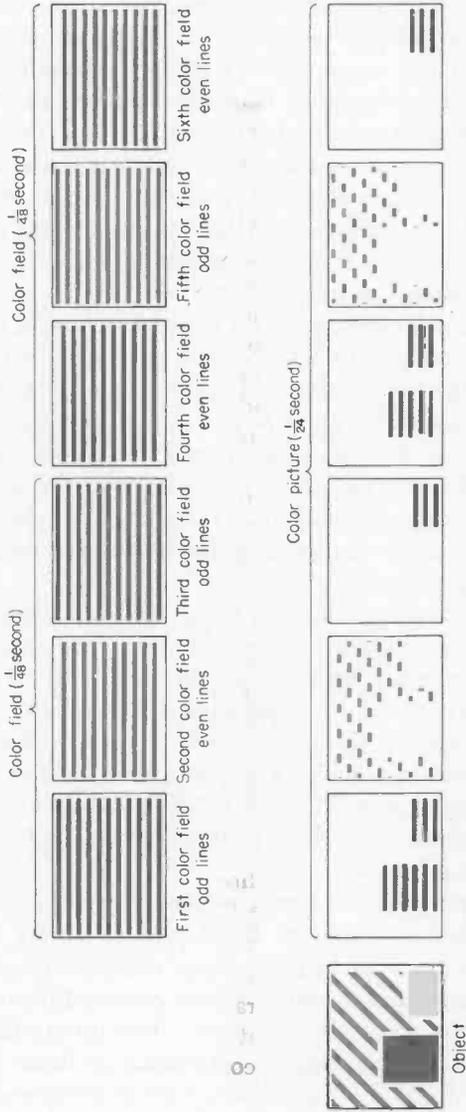


Fig. 17-1. The composition of successive fields in a field sequential system is shown in the upper illustration. The lower one shows the manner whereby the colors in a specific object would be separated out, transmitted, and recombined (in the viewer's eye).

**Simultaneous Color System.** The three video components corresponding to the three primary colors can be simultaneously conveyed to the picture monitor by means of three transmission channels and, by suitable means, converted back into light of corresponding colors, and then recombined to form the original colors.

Although feasible, a simultaneous color transmission system requires three times the bandwidth of a monochrome system employing similar scanning frequencies and associated standards. Fortunately, because of the retentivity of the eye, a time multiplex or sequential system may be employed for the transmission of the signals corresponding to the three colors and a single channel employed for their transmission. Field, line, and dot sequential systems together with variations of these basic systems, have all been demonstrated although, as of the time of writing, only the field sequential system has been adopted by government regulation as a standard color-television system.

**Field Sequential System.** In the field sequential color-television system scanning of the picture area is undertaken in the same manner, although not necessarily at the same rate, as in the standard monochrome system. Color rendition is accomplished by having the video information transmitted during the first field correspond to the red colors in the original scene, that during the second field to the blue, and that during the third field to the green of the original scene. The color sequence is then repeated in the same order. Since a 2-to-1 line-interlaced system is employed for color, just as in monochrome transmissions, the successive fields, as shown in the upper portion of Fig. 17-1, represent the following information:

<i>Field</i>	<i>Composition</i>
1st	Odd red lines
2d	Even blue lines
3d	Odd green lines
4th	Even red lines
5th	Odd blue lines
6th	Even green lines
7th	Odd red lines
Etc.	Etc.

From the above it is evident that it requires the passage of six fields to produce one complete color picture. Further, the colors are different for each succeeding field, hence the name: field sequential system.

The application of this scanning arrangement to a specific case is detailed in the lower portion of Fig. 17-1. At lower left is shown a sample color scene or object. The following illustrations show how the information in the original scene is broken down into its primary colors and into

odd and even lines. Upon the passage of six fields, the image shown at the right end of the line is produced. The example shown employs only 21 scanning lines; consequently, the reproduced image is only a rough approximation of the original. It illustrates, however, the manner in which the original color scene is analyzed for transmission purposes and then recombined to form the final picture.

**Line Sequential System.** In a line sequential system, the color is changed for each line. With a 2-to-1 line-interlaced system the first field would contain only odd lines, hence the first line may be red, the third blue, the fifth green, the seventh red, etc. The second field may be scanned in the same manner so that, at the end of two fields, all lines are scanned but each has been scanned in only one of the three primary colors. In order to scan all lines in all three colors, the order of scanning must be changed for subsequent fields so that after the passage of six fields, all lines have been scanned in all three primary colors. In one system that has been demonstrated, the field rate was maintained at the monochrome standard of 60 per second, so that, in this instance, only 10 complete color frames were presented per second.

Depending upon the line repetition rate, line sequential systems seem to be prone to produce line crawl or jitter. Where the shift in line colors follows a uniform pattern, there is a tendency for the eye to follow lines of a given color as they progress vertically through the picture area. Various nonuniform shift sequences and double or interlaced shifts have been tried which have somewhat reduced the effect, but it still remains as a problem in line sequential systems operating at conventional line repetition rates and at picture brightnesses that are considered essential for good reception.

**Dot Sequential System.** In monochrome television systems, it is common practice to employ line-interlaced techniques in order to enhance the quality of the picture obtainable with a given transmission bandwidth (see Sec. 1-3). Of course, interlacing of horizontal scanning lines is actually done along the vertical dimension and, in view of the advantages it offers, the possibility of interlace in a horizontal direction is also attractive. Horizontal interlace implies dividing each horizontal line into segments and transmitting the information contained in only a portion of the segments during any given field. As in line-interlacing practice, the segments transmitted during a given field may be uniformly distributed over the picture area, and by systematically rotating the selection of segments the information in the entire picture area may be transmitted after the passage of a predetermined number of fields. If the segments are short in length, they have the appearance of dots and the technique described is, therefore, often called a dot interlace system.

The basic principle described has been applied to color-television transmission by scanning each line in a series of dots rather than continuously and with successive dots corresponding to the different primary colors arranged in an orderly sequence. Thus the system may be termed a dot sequential color-television system.

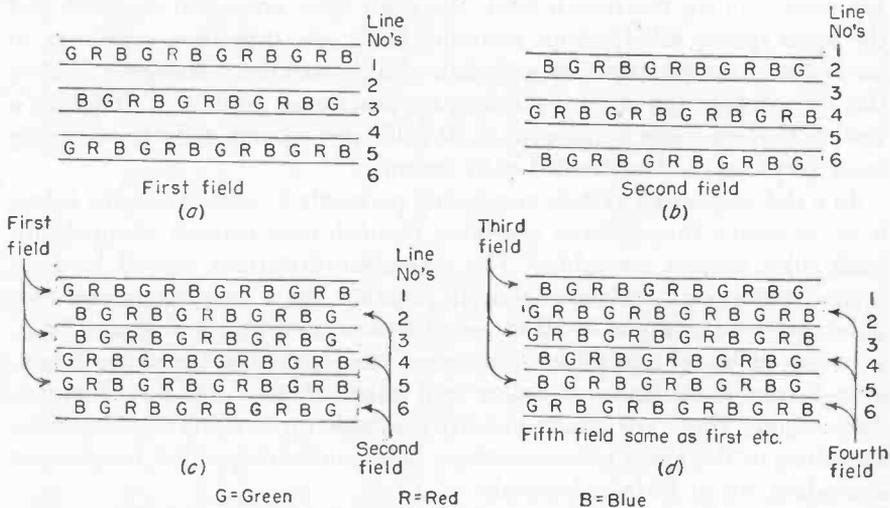


FIG. 17-2. The composition of the first and second fields in a dot sequential system (in its most elementary form) is shown at (a) and (b), respectively. The result of combining the first and second fields is shown at (c); similarly for the third and fourth fields at (d).

In one application of the dot sequential color-television system the distribution of primary colors among the dots is as shown in Fig. 17-2. During the first field, the odd lines are scanned in the conventional manner but are divided into segments or dots corresponding to the primary colors, as indicated in Fig. 17-2a. Examination of the illustration shows that in successive lines the dots are not only displaced horizontally (e.g., those in the third line are not directly under those in the first line) but, in addition, a given color is also shifted horizontally, although the dots are always presented in the same color sequence. (A system employing an oscillating color sequence has also been proposed.) This arrangement is employed in order to avoid the possibility of creating a regular pattern in any given color or colors.

During the second field, the even lines are scanned in a similar fashion, as shown in Fig. 17-2b. With the two fields combined, the resulting scanning pattern is as shown in Fig. 17-2c. The third and fourth fields are scanned in a similar manner, but the position of the dots in a given line is again shifted, as is the color of the dots, with the result shown in Fig.

17-2*d*. Thus during the first field the odd lines are scanned, but dots of a given primary color are separated by spaces. During the second field, the even lines are scanned, again with spaces between dots of a given color. The odd lines are again scanned during the third field, and the dots of a given color displaced so as to fill the spaces left during the first field. Likewise, during the fourth field, the even lines are again scanned and the open spaces filled. Four scanning fields are, therefore, necessary to cover the entire picture area with dots of a given color. However, during this time dots of the other two colors are also being presented. Thus, in a system that operates at the rate of 60 fields per second, only 15 complete color pictures are transmitted each second.

In a dot sequential system employing presently available camera tubes, it is necessary to use three complete monochrome camera channels for *each* color camera assembly. The geometric distortion caused by both optical and electrical deficiencies (in practice, never completely unavoidable) must be identical in all three cameras since by optical means (*e.g.*, a system of lenses and dichroic mirrors) the light from the scene is separated into three primary colors and directed into separate cameras. Accordingly, there are simultaneously available three video signals, corresponding to the three primary colors, each containing video frequencies extending out to 4 Mc or beyond.

In order to fit these three signals within a 4-Mc transmission band, it is necessary to employ further expedients. A number of methods of doing this have been proposed<sup>2</sup> all of them on the basis that only gross detail need be transmitted in color while the fine detail may be transmitted in monochrome.<sup>3</sup> As of the time of writing, no standard method of doing this has been agreed upon, so the reader must be left to a pursuit of the contemporary literature for the latest developments in this field. In view of these circumstances, as already indicated, the remainder of the chapter is devoted to a discussion of the color-television system that is standard in the United States and to a description of equipment suitable for professional applications adhering to these standards.

**17-2. Color-television Terminology.** For the most part the same terminology is employed in both monochrome and color television although the latter has introduced a few new terms and an expansion of the definition of several of the terms applied previously only to monochrome transmission. Color-television terminology is given in the following paragraphs.

<sup>2</sup> Loughren, A. V., and C. J. Hirsch, Comparative Analysis of Color TV Systems, *Electronics*, Vol. 24, No. 2, p. 93 (February, 1951).

<sup>3</sup> Bedford, A. V., Mixed Highs in Color Television, *Proc. IRE*, Vol. 38, No. 9, p. 1003 (September, 1950).

**Field.** In monochrome transmission, the term "field" signifies a single scanning of the picture area in accordance with a prescribed scanning pattern. In a 2-to-1 interlaced system this involves the scanning of the alternate lines of the raster. In a field sequential color-television system, the term "field" has the same significance, but in scanning through the picture area just once the alternate lines corresponding to only *one* color are scanned. Thus for a complete scanning of the picture area in all three primary colors a total of six fields are required.

**Frame.** In monochrome transmission the term "frame" signifies one complete scanning of the picture area. In a field sequential color system, the term signifies the complete scanning of the picture once in a *single* color. Thus, in both cases a frame is comprised of two fields and consists of both the odd and the even lines. In a monochrome system, however, the two fields follow one another whereas in a color system the two fields of a given frame are separated from each other by two intervening fields of different colors.

**Color Field.** The term "color field" signifies scanning of the picture area just once in each of the three primary colors; *i.e.*, it consists of three fields that follow each other, one for each of the primary colors. In a 2-to-1 interlaced scanning system, a color field is comprised, therefore, of alternate lines of the picture area in each of the primary colors.

**Color Frame.** A "color frame" consists of the scanning of *all* (both odd and even) lines of the picture area once in each of the three primary colors. In a 2-to-1 interlaced scanning system a color frame consists of two color fields or six successive fields.

**Color Synchronizing Pulse.** The term "color synchronizing pulse" (sometimes called the "color pulse") is applied to the one pulse that is added to the monochrome synchronizing waveform in order to create the standard color-television synchronizing waveform. This pulse, which is detailed in Sec. 17-4, immediately precedes each red field and may be used to synchronize the color phase of the pickup device with that of the receiver or picture monitor.

**Color Phase.** The term "color phase" is usually employed to signify whether the various cameras, projectors, monitors, and receivers of a given system are or are not in phase with each other in so far as the color of the field being scanned or displayed at a given instant is concerned.

**17-3. Standard Color System Characteristics.** In order to fit any type of color-television system within the confines of the bandwidth allocated for monochrome television transmissions, it is necessary to make changes of one kind or another in the basic characteristics of the system as compared to a monochrome system. If, for example, a field sequential system

having 525 lines and 30 color frames per second were to be employed, a transmission bandwidth approximately three times that of a similar monochrome system would be required. This results from the fact that a color frame contains three times as many fields as does a monochrome frame.

One method of fitting a field sequential color-television system within the confines of a standard television channel is to reduce the number of scanning lines and the frame frequency. To the theorist who chooses to ignore the subjective effects of color as compared to monochrome pictures, this procedure seems to imply an unacceptable degradation in the overall picture quality. Actually, as has been pointed out elsewhere,<sup>4</sup> color so enhances the ability to distinguish objects in a scene that the effective resolution is materially increased by the addition of color. Changes in color greatly facilitate delineation of the edges of objects, thereby producing a subjective resolution noticeably greater than that of the same image viewed in monochrome. Thus, the number of scanning lines in a color-television system can be reduced (within reason, of course) from the number in a monochrome system without degradation in performance. In practice it has been found that the reduction in the number of scanning lines necessary to fit the field sequential color-television system, within the confines of the standard television channel, is not only indistinguishable to the average viewer but is far outweighed by the presentation of a picture in full color.

TABLE 17-1. UNITED STATES TELEVISION STANDARDS \*

	<i>Color</i>	<i>Monochrome</i>
Scanning lines per frame . . . . .	405	525
Frame frequency . . . . .	72 per second	30 per second
Field frequency . . . . .	144 per second	60 per second
Horizontal line frequency . . . . .	29,160 cps	15,750 cps
Color frame frequency . . . . .	24 per second	None
Color field frequency . . . . .	48 per second	None
Color sequence . . . . .	Red, blue, green	None

\* See Table I-1 for standards common to color and monochrome transmissions.

The manner in which the transmission characteristics of the standard field sequential color-television system differ from the more familiar monochrome system is summarized in Table 17-1.

<sup>4</sup> Fink, D. G., Color Fundamentals for TV Engineers, *Electronics*, Vol. 23, No. 12, p. 88 (December, 1950).

- NOTES: 1. H = Time from start of one line to start of next  
 2. V = Time from start of one field to start of next  
 3. Leading and trailing edges of vertical blanking should be complete in less than 0.1H  
 4. Leading and trailing slopes of horizontal blanking must be steep enough to preserve minimum and maximum values of (x+y) and (z) under all conditions of picture content  
 5. Dimensions marked with asterisk indicate that tolerations are permitted only for long time variations and not for successive cycles  
 6. Equalizing pulse area shall be between 0.45 and 0.5 of area of a horizontal sync pulse  
 7. Color pulse area shall be between 0.45 and 0.5 of the area of horizontal sync pulse

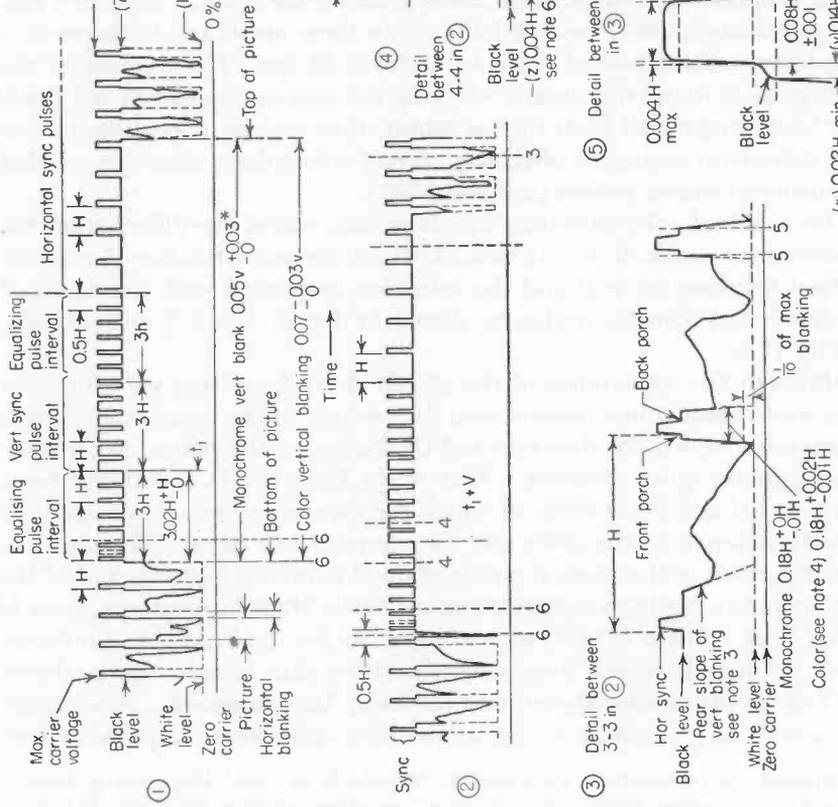


Fig. 17-3. Monochrome and color-television synchronizing waveforms as specified by government regulation.

**17-4. Standard Color Synchronizing Waveforms.** Basically, the synchronizing waveform adopted as a standard for color television<sup>5</sup> is identical with that employed for monochrome transmissions except for the addition of a color pulse. However, as is evident from Table 17-1, both the horizontal and the vertical repetition rates are different in the two systems. Since it has been the practice to specify the timing intervals of the standard synchronizing waveform in terms of the horizontal ( $H$ ) and the vertical ( $V$ ) intervals, the same synchronizing waveform diagram is applicable to both methods of transmission, as shown in Fig. 17-3.

The general appearance of the standard color synchronizing waveform differs from that for monochrome transmissions only by the inclusion of a color synchronizing pulse in the vertical blanking interval preceding each red field. As shown in detail 1 of Fig. 17-3, the color pulse is located midway between the first two equalizing pulses of the group preceding the vertical synchronizing pulse that initiates a red field. Further, as shown by detail 6, the size and shape of the color pulse are the same as those of a regular equalizing pulse (see detail 4). Since there are 48 red fields per second, the repetition rate of the color pulse is 48 cps. The purpose of the color pulse is to provide means whereby the commencement of red fields may be distinguished from that of others, thus making it possible to employ automatic means for obtaining correct color phase wherever needed in a color-television system (see Sec. 17-9).

The standard color-television synchronizing waveform differs from the monochrome standard in only two additional respects: the duration of the vertical blanking interval and the tolerance associated with the width of the horizontal blanking pulse, as shown in details 1 and 3, respectively, of Fig. 17-3.

Although the appearance of the standard synchronizing waveform for color and monochrome transmission differs only in the three small details enumerated above, the duration and the timing of the pulses on an absolute basis are quite different. This stems from the fact that the basic intervals ( $H$  and  $V$ ) in terms of which the various pulses are specified are entirely different in the color and the monochrome cases. The absolute time durations of the vertical and horizontal scanning intervals and of the various pulses for both monochrome and color transmissions are given in Table 17-2. These figures, as contrasted to the monochrome tabulation given in Chap. 1, pertain to government rather than to industry standards.

**17-5. Synchronizing Generators for Color Transmissions.** Synchronizing waveform generators for color-television applications capable of sup-

<sup>5</sup> Federal Communications Commission, "Standards of Good Engineering Practice concerning Television Broadcasting Stations," as amended Nov. 20, 1950, U.S. Government Printing Office, Washington, D.C.

TABLE 17-2. COLOR AND MONOCHROME SYNCHRONIZING PULSE DURATIONS—GOVERNMENT (FCC) STANDARDS

	<i>Time Duration (microseconds)</i>			
	<i>Color</i>		<i>Monochrome</i>	
	<i>Min</i>	<i>Max</i>	<i>Min</i>	<i>Max</i>
Vertical scanning period . . . . .	6,950		16,667	
Horizontal scanning period . . . . .	34.3		63.5	
	<i>Min</i>	<i>Max</i>	<i>Min</i>	<i>Max</i>
Vertical blanking . . . . .	485	695	833	1,330
Horizontal blanking ° . . . . .	5.8	6.9	10.8	11.4
Horizontal synchronizing pulse ° . . . . .	2.4	3.1	4.4	5.7
Front porch . . . . .	0.7	...	1.3	...
Equalizing pulse ° . . . . .	...	1.4 °	...	2.5 †
Color synchronizing pulse ° . . . . .	...	1.4 °	...	...
Vertical synchronizing pulse ° serration . . . . .	2.1	2.7	3.8	5.1
Pulse rise time . . . . .	...	0.14	...	0.25

° At the "base" of the pulse, i.e., 10 per cent of the amplitude point.

† Area to be 0.45 to 0.5 of the area of the horizontal synchronizing pulse.

TABLE 17-3. ORIGINAL AND MODIFIED COUNTER SCHEDULE

<i>Circuit in relative proximity to oscillator</i>	<i>Original (monochrome) frequency output</i>		<i>Modified (color) frequency output</i>	
	<i>Division</i>	<i>Pulse rate (cps)</i>	<i>Division</i>	<i>Pulse rate (cps)</i>
1a	7	4,500	9	6,480
2a	5	900	9	720
3a	5	180	5	144 ‡
4a	3	60 °	3	48 §
1b	2	15,750 †	2	29,160

° Vertical monochrome drive rate.

† Horizontal monochrome drive rate.

‡ Vertical color drive rate.

§ Color field rate

|| Horizontal color drive rate.

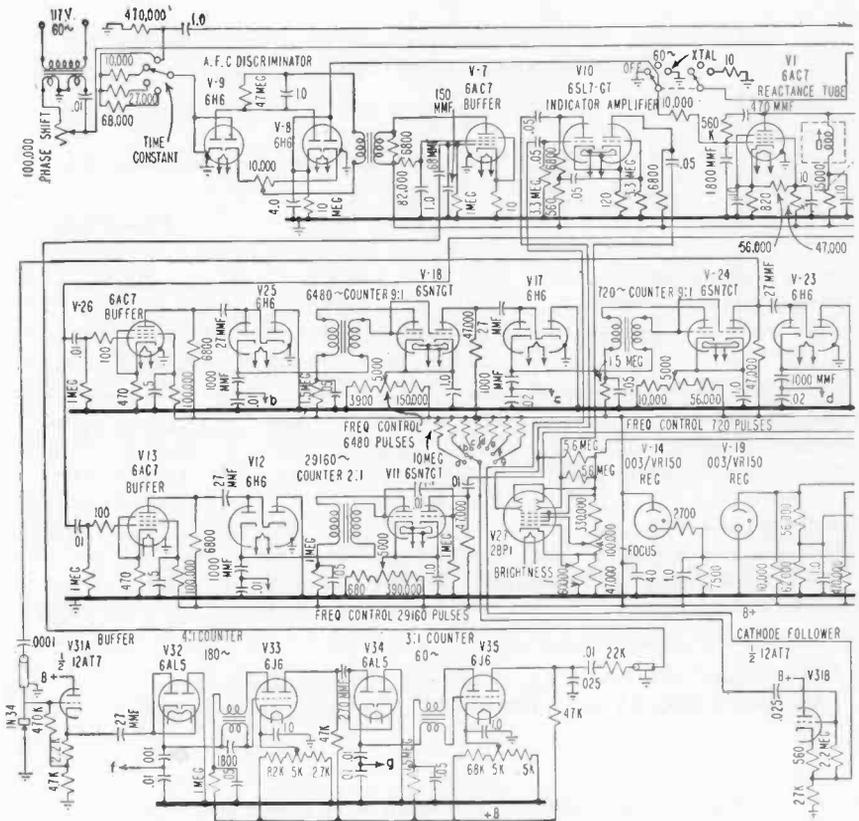
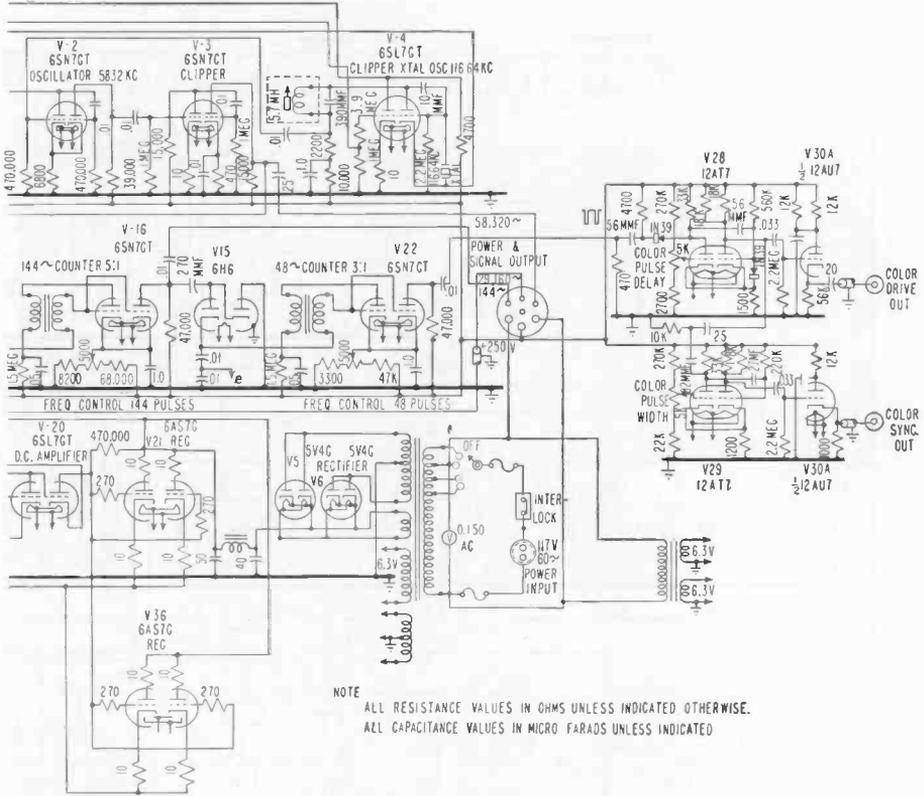


FIG. 17-4. Circuit diagram of the pulse-former portion of a monochrome synchro-

plying vertical and horizontal driving signals, vertical and horizontal blanking signals, color synchronizing and drive pulses, and composite synchronizing signals can be designed along the same lines as detailed for monochrome synchronizing generators in Chap. 5. In addition, as outlined below for the equipment of one particular manufacturer, monochrome-type synchronizing generators may be readily modified for color standards.

The monochrome synchronizing waveform generator shown in Fig. 3-2 consists of two units: a pulse former and a pulse shaper. Its conversion for use in the standard color-television system consists of (a) modifications altering the basic oscillator frequency and the frequency dividers to comply with color standards, (b) modifications to improve circuit performance at the new signal frequencies, (c) the addition of circuits to generate color synchronizing and drive pulses, and (d) the addition of



nizing generator that has been modified for color-television applications.

frequency dividers to provide means for locking the master oscillator to a 60-cps power source.

**Pulse-former Circuits.** The circuit of the pulse-former portion of a portable synchronizing waveform generator that has been modified for operation in accordance with color-television standards is shown in Fig. 17-4. The modifications include changes in the master oscillator (V2) circuit to permit operation at 58.32 kc rather than at the original frequency of 31.5 kc. This change is effected by utilizing only one-half of the original oscillator coil, T3, and adjusting it to resonate at the new frequency. The frequency division schedule of the counters in the original equipment is also changed in accordance with the tabulation given in Table 17-3. The change to new counting rates is accomplished by modification of the resistive and capacitive component values associated with counter tubes V11, V16, V18, V22, and V24 as shown in Fig. 17-4.

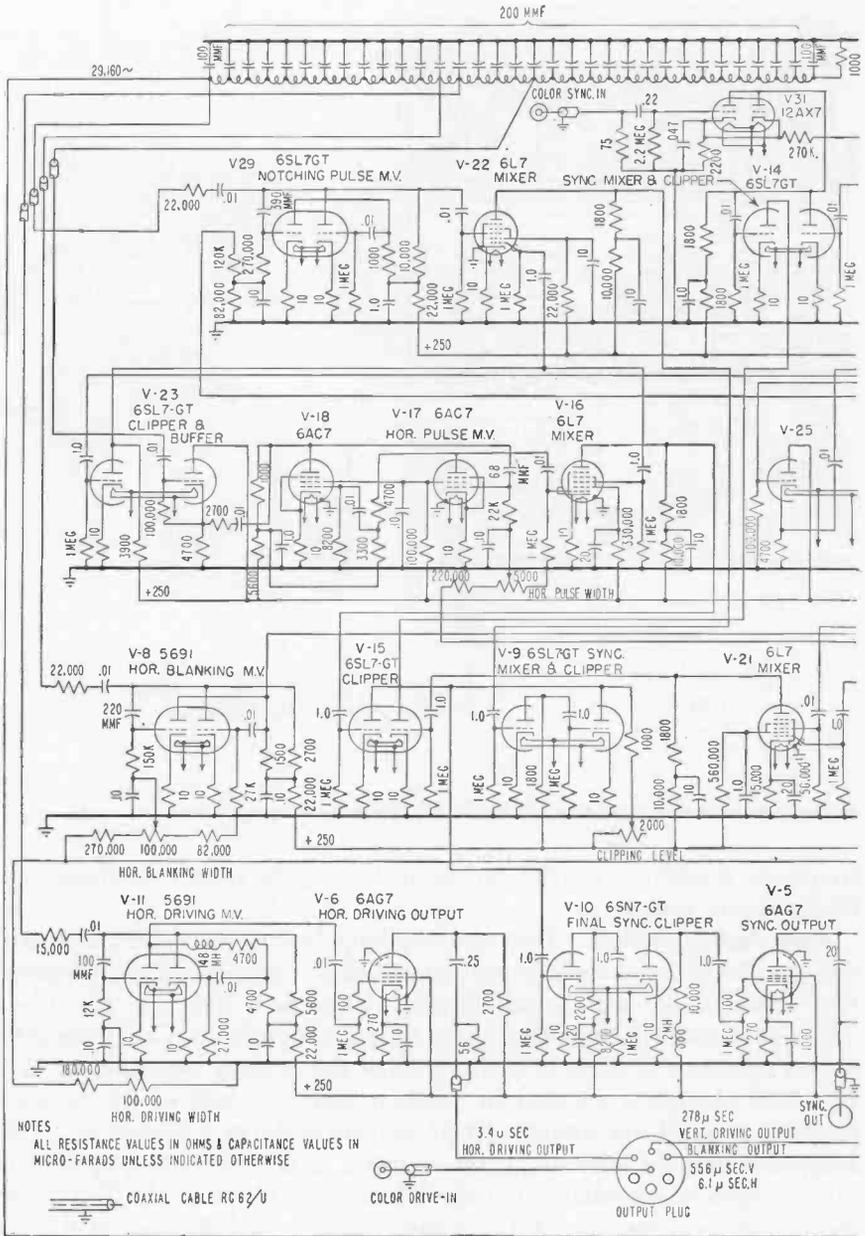


Fig. 17-5. Circuit diagram of a pulse shaper



New counter circuits, shown at the lower left of the figure, are also required to obtain a 60-cps output for comparison with the a-c power-line frequency when the master oscillator of the synchronizing waveform generator is locked to the 60-cps power source. The new counters, V32 through V35, receive a 720-cps signal from the second 9-to-1 counter, V24 via buffer V31A, and divide down in successive steps of 4 to 1 and 3 to 1 in order to obtain 60 cps.

Finally two monostable multivibrators V28 and V29, together with associated cathode followers V30A and V30B, are added to form color driving (8 microseconds in width) and color synchronizing (1.4 microseconds in width) pulses, respectively. The output of the 48-cps counter V22 is used to drive the first multivibrator V28, which, upon cycling, actuates the second multivibrator V29. By this arrangement the duration of the color pulse is determined by the circuit constants of the second multivibrator, but its time of occurrence is determined by those of the first multivibrator. In addition, a portion of the output of the first multivibrator, whose duration of operation is one-quarter of a horizontal line, may be employed as a color driving pulse.

**Pulse-shaper Circuits.** A circuit diagram of the modified pulse shaper is given in Fig. 17-5. In addition to showing the new circuit values, this diagram details the manner in which the color synchronizing pulse is amplified by a new tube V31, and then combined in a common plate load resistor with the output of the equalizing pulse amplifier V14. From this point on, the function of the modified pulse shaper is identical with that of the original unit except, of course, for the difference in pulse rates.

The procedures outlined above are not, by any means, the only ones that can be employed to convert a monochrome synchronizing waveform generator for color-transmission standards. Nor do they necessarily represent the best possible way of effecting a conversion. However, the modifications described do represent one means which has been employed in practice and which is capable of producing standard color-television synchronizing signals.

**17-6. Image Orthicon Camera Conversion.** The conversion of a monochrome image orthicon camera to produce video signals conforming to FCC color-television standards is exceedingly simple when use is made of a rotating color filter disk, but it is fantastically difficult if undertaken on an all-electronic basis. The former modification involves only the addition of a rotating color filter disk in front of the camera tube and modification of the camera deflection circuits to function at the higher scanning frequencies. The latter modification, employing currently available image orthicon tubes, involves the addition of a color separation optical system, two additional image orthicon tubes in each camera, together with their

supporting circuits and components, and an electronic switching system to select sequentially the outputs of the three complete camera channels that an all-electronic system entails. Implicit in the requirements of an all-electronic system is perfect geometric registration of the output of the three image orthicon tubes required for each camera channel. As is well known, it is not always easy in practice to obtain acceptably low geometric distortion from a single image orthicon chain not to mention the difficulty of achieving and maintaining universes of three identical camera channels as are presently required for an all-electronic color camera system. The procedures involved in modifying the monochrome-type camera chains shown in Fig. 3-2 for color-television operation are outlined in the following paragraphs.



FIG. 17-6. The color filter disk assembly which is added to a monochrome camera to convert it for field sequential color-television operation.

**Color Disk and Drive System.** The extent of the color disk and drive installation is shown in Fig. 17-6 for a camera of one particular manufacture. In order to produce 144 fields per second with the 12-segment disk shown, it is necessary to rotate it at a speed of  $(144/12) \times 60$  or 720 rpm. Furthermore, since the image produced on the photocathode of the image orthicon by the associated optical system is inverted, the direction of rotation of the filter disk must be clockwise in order for the color-

segment boundary or spoke to progress across the face of the camera tube in the same direction as does the scanning beam.

For direct or live pickup applications, not only must the movement of the spoke of the filter disk be in the same direction as the scanning beam, but in addition the camera disk spoke must be opaque and so shaped and phased that the horizontal line being scanned at any particular instant is optically shadowed by the spoke. By maintaining this relationship, color contamination is avoided since, just before the scanning beam reaches a given part of the raster, the spoke moves into place and cuts off further exposure of the photocathode area involved to the color in question. The scanning beam then discharges the target and, as the spoke moves on, the photocathode is exposed to the next color in the sequence.

For live pickup applications using incandescent illumination, the following types of color filters have been used:

Red: Wratten No. 25 or EK TV filter No. 250

Blue: Wratten No. 47, one-half density or EK TV filter No. 474

Green: Wratten No. 58 or EK TV filter No. 580

As contrasted to live pickup applications, a different shaped filter disk segment is required for the pickup of projected film when conventional intermittent projectors are employed. With projectors of this type, it is the usual practice to project the film image onto the face of the camera tube only during the vertical blanking interval, for the reasons given in Sec. 9-6, *Pull-down and Projection Cycles*. Accordingly, for film projection applications, a given color filter must cover the entire photocathode area during the short interval while the film image is being projected. On the other hand, a color filter disk for film applications need not produce any careful shadow registration during the subsequent scanning interval since the film image is not being projected upon the camera tube during this time. A nine-segment disk designed for film projection applications for use with the image orthicon camera is shown in Fig. 17-7. The geometry involved in this application necessitates large filter segments and, assuming that the same over-all size of disk is maintained, there must necessarily be fewer segments than in the live pickup design. In order to obtain the required 144 color fields per second with the nine-segment disk illustrated, it must be rotated at a speed of  $(144/9) \times 60$ , or 960 rpm. The two disks described, one for direct pickup and the other for film use, are made mechanically interchangeable, and provisions also are made to drive the disk shaft at either 720 or 960 rpm.

The motor employed in the equipment illustrated is a 1/100-hp 1,440-rpm 48-cps 115-volt synchronous motor and is driven from a source of

a-c power that is precisely phased with the output of the synchronizing waveform generator. The 48-cps sine-wave power used to operate the filter-disk drive motor is derived from the color drive pulse output from the synchronizing generator.

In applications where the synchronizing waveform generator is locked to the 60-cps primary power source, it is feasible to make use of a 60-cps synchronous motor, operating from the same power source and properly geared down, to drive the camera color filter disk. In this instance also, suitable means must be provided to permit the phase of the driving power to be continuously varied in order that the position of the color filter disk may be readily adjusted for correct color phase.

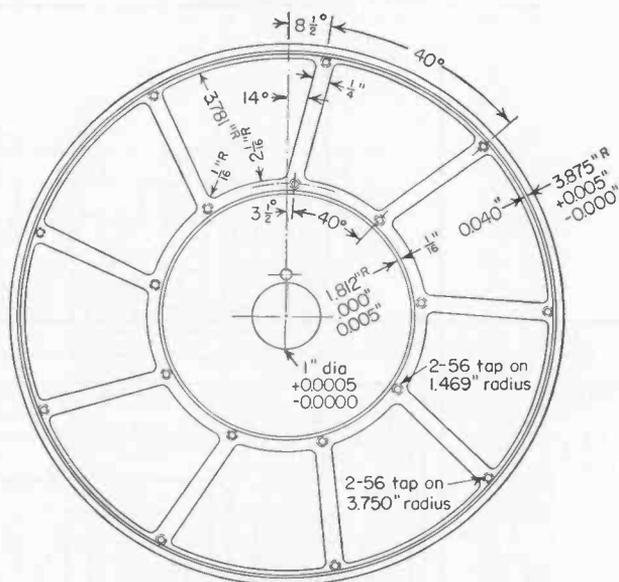
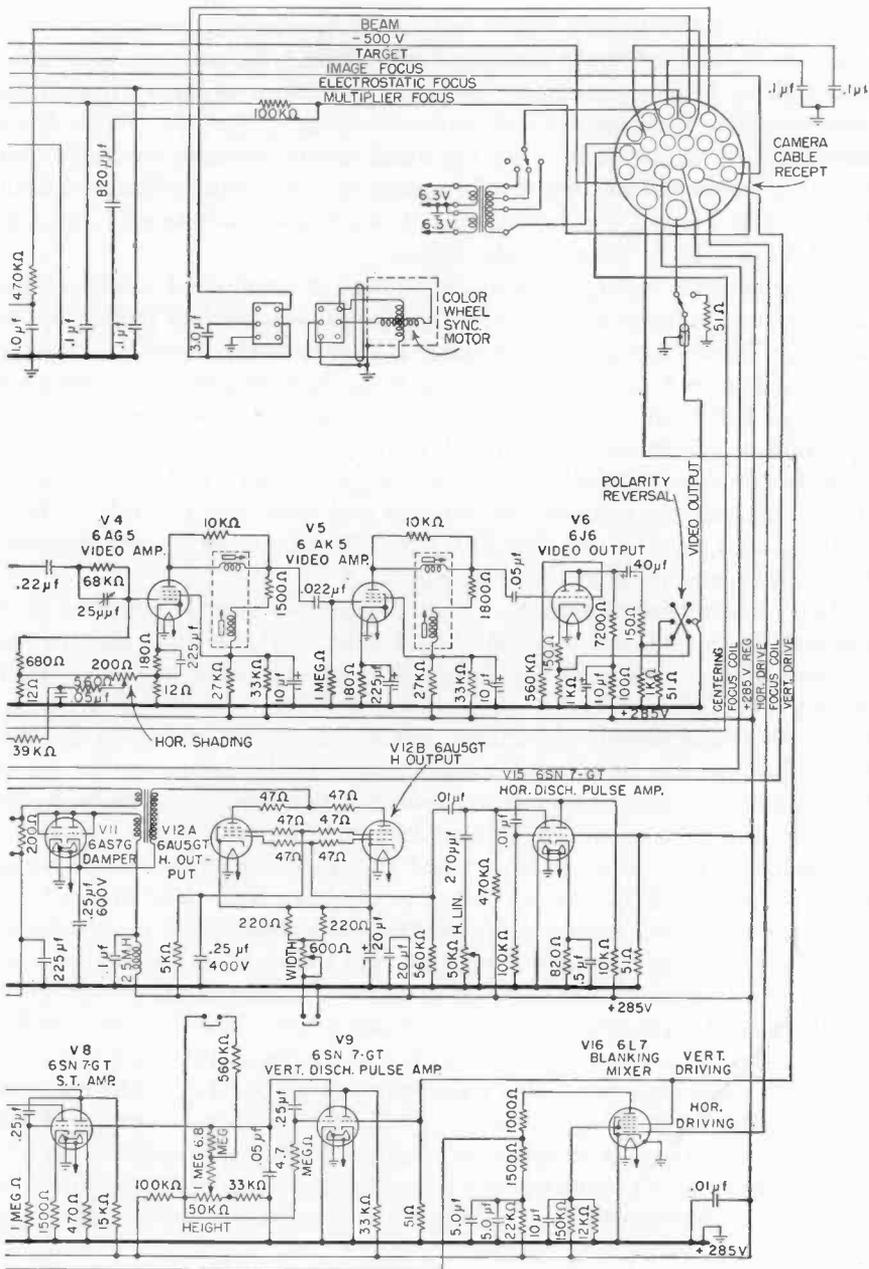


FIG. 17-7. For color motion-picture film transmission a color filter disk of this size and shape may be used on an image orthicon camera.

**Camera Circuits.** The changes in circuit components undertaken in the camera portion of the modified camera chain are primarily those necessary for accommodation of the higher horizontal and vertical sweep frequencies employed for standard color-television transmissions. A schematic wiring diagram of the modified image orthicon camera is shown in Fig. 17-8. The changes incorporated include alteration of the time constants of the generators for both horizontal and vertical sweep circuits and the production of greater scanning power to provide the required deflection at the higher scanning frequencies.





adapted for field sequential color-television applications.

The required additional power output for the vertical scanning circuits is obtained by the simple expedient of reducing the amount of inverse feedback by inserting a resistor between the output of the vertical feedback amplifier V10 and the vertical saw-tooth amplifier V8. In the horizontal-deflection circuit, on the other hand, modifications to secure greater scanning power output include the installation of a more efficient output transformer, T4, and the employment of two beam power tubes V12A and V12B, in parallel as shown in the figure.

The schematic wiring diagram also shows a number of modifications that are incorporated in order to adapt the camera for film pickup applications. These changes are the same as those employed when an image orthicon camera is used for film transmission in monochrome service (see also Sec. 8-10) and include provisions for independently reversing the direction of horizontal and vertical scanning, reversal of picture signal polarity (to cope with either positive or negative film), and provisions for the connection of remotely located size and centering controls. These modifications involve switches S10, S11, S12, connector J9, and resistors R103, R114, and R115 as shown in Fig. 17-8.

**17-7. Camera-control Units.** Camera-control units for use in a field sequential color-television system do not differ markedly from their monochrome counterparts (see Sec. 2-5). In fact, the latter may be readily modified for color-television applications by making provisions for operation with an associated color mixer (see Sec. 17-8) by modifying the picture-tube assembly to provide a display in color, by arranging the waveform monitor circuits to operate at color-television scanning rates (actually at submultiples thereof), and by corollary circuit modifications.

The appearance of a camera-control unit, modified for color operation, is shown in Fig. 17-9. As contrasted to the color filter disk employed in the camera, the one in the camera-control unit rotates in a counterclockwise fashion since its center of rotation is to the right of the picture tube and the color segments must progress across the face of the picture tube in the same direction as does the scanning beam. The disk is provided with a total of six filter segments, and on the basis of 144 color fields per second it must be rotated at a speed of  $(144/6) \times 60$  or 1,440 rpm. A 1/50-hp 1,440-rpm 60-cps 115-volt synchronous motor is employed for this application and is mounted in a manner that permits rotation of the entire motor frame (by means of a convenient knob) for phasing the color filter disk with respect to the output of the synchronizing waveform generator.

The shapes of the individual color filters are such that, when rotating at synchronous speed and when properly phased, a filter of a given color sweeps across the face of the picture tube at the same rate and in the

same direction as does the scanning beam. Further, during a given field, the entire length of the horizontal line being actively scanned is covered by only one of the color filters; as a matter of fact, it is this criterion that determines the shape of the individual filter segments.<sup>6</sup>

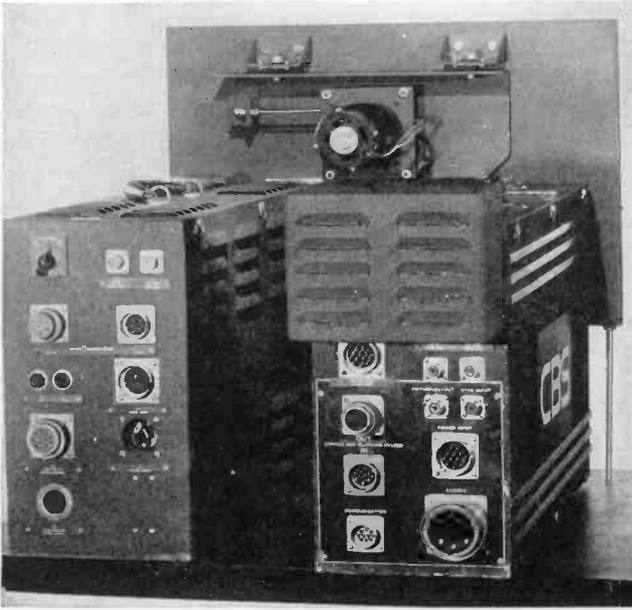


FIG. 17-9. Rear view of a portable color mixer (left) and of a portable monochrome camera-control unit (right) modified for color-television applications. The color filter disk for the picture tube in the latter unit is contained within a rectangular housing which also carries the disk driving motor.

The time constants of both the horizontal and the vertical sweep generators require modification in order to accommodate color-television standards. In addition, a high-efficiency yoke for the picture tube and a horizontal scanning output transformer designed for the frequencies in hand are used. These modifications ensure adequate deflection and fast retrace time at the higher scanning rates. The original vertical scanning output transformer is entirely satisfactory for operation at the 144-cps scanning rate, however.

It is customary for the waveform monitor that is a part of a color camera-control unit to operate at one-third of the vertical scanning rate or at 48 cps. Operation at this rate provides a display wherein the wave-

<sup>6</sup> Goldmark, P. C., J. N. Dyer, E. R. Piore, and J. M. Hollywood, *Color Television—Part I*, *Proc. IRE*, Vol. 30, No. 4, p. 162 (April, 1942).

forms corresponding to the three primary colors are presented in three separate groups, as shown in Fig. 17-10. It is desirable that the display always be presented in the same color sequence so that the three fields displayed may be readily associated with their respective colors. This may be accomplished by synchronizing the vertical sweep generator with the 48-cps color driving pulse that is available from the synchronizing waveform generator. Thus when the "vertical" sweep rate is employed, the video levels shown by the first group of waveforms are those corresponding to the red fields, the second group to the video levels of the blue fields, and the third group to the video levels of the green fields.

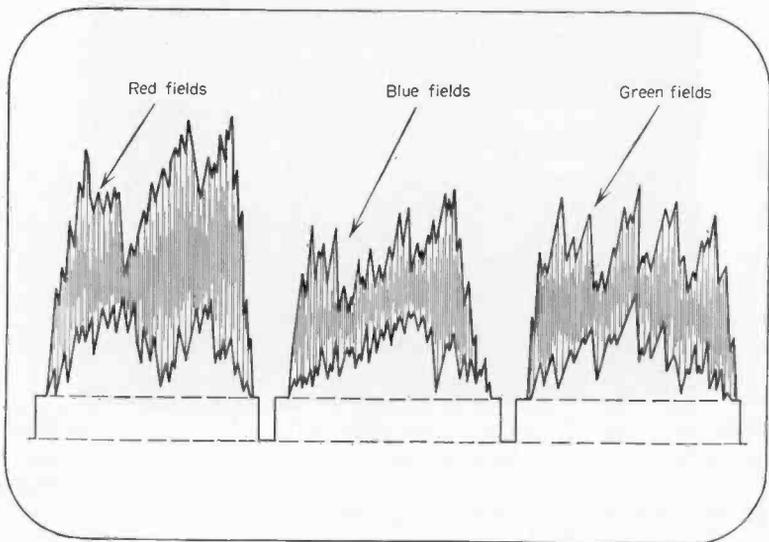


FIG. 17-10. Simplified sketch of the display on a color-television waveform monitor.

**17-8. Color Mixer.** One unit not found in a monochrome camera chain but required for a color-television system is the color mixer. As the name implies, its purpose is simply to mix together, in the desired proportions, the video signals corresponding to the three primary colors. This may be accomplished by separating out the red, the blue, and the green signals and passing them through separate video channels where their amplitude and other characteristics may be individually adjusted.

A side view of a color mixer whose design has proved in practice to be very satisfactory is shown in Fig. 17-11 while a schematic block diagram of the unit is shown in Fig. 17-12. The functions and operation of the device are described in the following paragraphs.

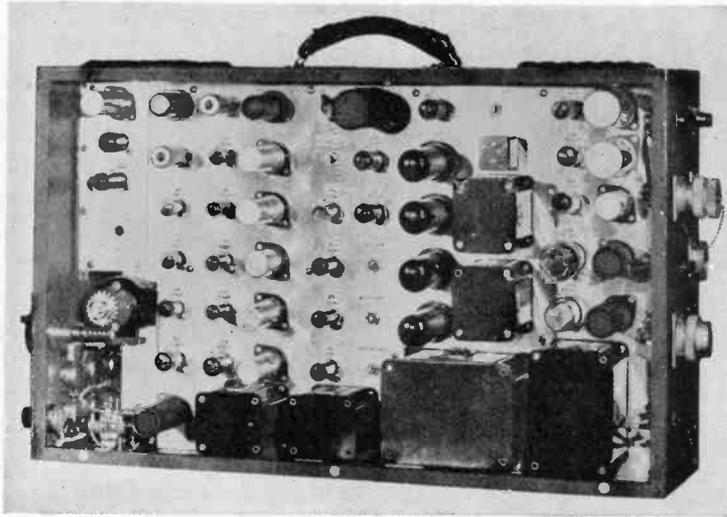


FIG. 17-11. Side view of a portable color mixer.

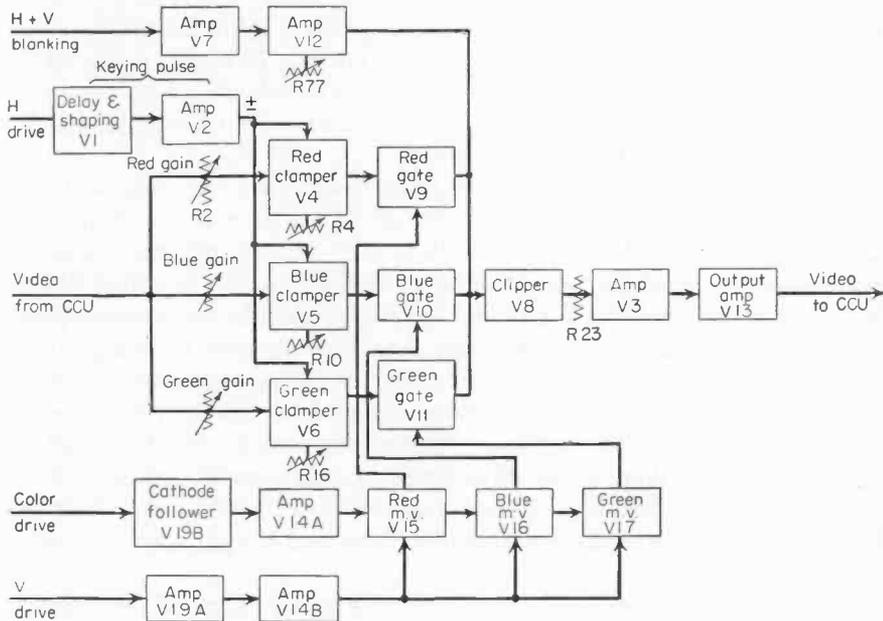


FIG. 17-12. Schematic block diagram of a color mixer.

**Video and Blanking Circuits.** The color mixer is inserted between two stages of the video amplifier which is a part of the camera-control unit. A noncomposite signal, *i.e.*, picture signal plus blanking only, is obtained from the camera-control unit and applied to the color mixer. Here, it is applied simultaneously to three video gain controls, associated with red, blue, and green video signal channels, respectively. By adjustment of these gain controls, picture signals of the desired amplitude are applied to clampers V4, V5, and V6 which are similarly associated with the red, blue, and green channels. Keying pulses from clamper keying tube V2, which is driven by a horizontal pulse amplifier V1, are applied to the red, blue, and green clampers during the horizontal blanking interval and provide separate d-c insertion for the three video channels.

After clamping, the three signals are applied to the input of three gating tubes V9, V10, and V11, associated with the three separate color channels. The red, blue, and green gate tubes are normally biased beyond cutoff by a high negative potential on their respective suppressor grids and are turned on, in sequence, for the duration of one color field, under the control of the gating pulse circuits described hereafter. Thus, the output of each of the three channels is selected in rotation and on a synchronous basis so that the signal that is transmitted by a given channel is always that associated with a particular color field. This action thereby provides a means for individually adjusting the amplitudes of the video signals corresponding to the three primary colors. In addition, the background levels of the three fields are individually adjustable by means of potentiometers R4, R10, and R16 which, respectively, determine the d-c operating bias of the three gating tubes.

The outputs of the red, blue, and green gate tubes are combined and applied to a common plate load resistor R23, through a series clipper V8. Combined horizontal and vertical blanking pulses, obtained from a synchronizing waveform generator, are amplified by the cascaded blanking-pulse amplifiers V7 and V12 and are also applied to the common plate load resistor via the same path. The amplitude of these blanking pulses is controlled by adjustment of R77 while the series clipper tube V8 removes any blanking-pulse modulation or switching transients generated in the gating tubes. The resulting video signal, which consists of picture signals corresponding to the three primary colors combined with horizontal and vertical blanking, is then amplified by tubes V3 and V13 before being reinserted into the video amplifier chain that is a part of the camera-control unit.

**Gating-pulse Generation.** As shown in Fig. 17-12, positive-going 48-cps color drive pulses are applied to the grid of cathode-follower V19B, then further amplified and inverted by V14A for use as starting triggers

for the bistable red-gate multivibrator V15. Meanwhile, negative 144-cps vertical drive pulses are amplified by V19A and V14B and employed as stopping triggers for the three gate multivibrators V15, V16, and V17.

The red, blue, and green gating-pulse multivibrators V15, V16, and V17, respectively, are all of the symmetrical, bistable type; *i.e.*, either section of the multivibrator may be made conducting and the opposite section cut off by the proper application of triggering pulses. Furthermore, the plate circuit of the red multivibrator V15A is coupled to the grid circuit of blue multivibrator V16A, whose plate circuit, in turn, is coupled to the grid circuit of green multivibrator V17A. This circuit arrangement results in a chain reaction when a triggering pulse is applied, such that the reversal of any one multivibrator also results in the reversal of the next multivibrator in the chain, as explained below.

When a given multivibrator section becomes conducting, the plate acquires a negative potential of sufficient magnitude to cut off the associated gating tubes. If the action is assumed to start with V15A conducting, the red gate tube will be turned off until the arrival of a negative 48-cps color drive pulse (via tubes V19 and V14) turns the V15A section of the multivibrator off. This action causes the plate of V15A and, consequently, the suppressor of the red gate tube V9 to assume ground potential thus permitting the red gate V9 to become conducting. This condition prevails for only one field, however, since 144-cps vertical drive pulses from amplifiers V19A and V14B are applied to the grid of multivibrator V15B and cause the multivibrator action to reverse  $\frac{1}{144}$  second later. This again results in the application of a potential to the suppressor of red gate tube V9, that is sufficiently negative to cause the tube to become inoperative. Thus, the red gate tube operates for only the one field immediately after the application of the color drive pulse. Since the color drive pulse always precedes the red field, the signal passed by the gate tube V9 is that corresponding to the associated red field. Furthermore, multivibrator V15A remains conducting and, consequently, red gate V9 inoperative, until the arrival of the next color drive pulse,  $\frac{1}{48}$  second later.

Because of the chain circuit linking the multivibrators together, reversal of the red multivibrator at the end of the red field results in operation of the next unit in line, namely, multivibrator V16. Thus, simultaneously with V15A becoming conducting, V16A is turned off and, paralleling the preceding action in V15A, this results in the gate tube V10 becoming conducting for the duration of the blue field which follows the red field. In a similar manner, the third gating tube V11 becomes conducting at the correct moment to permit passage of the signal corresponding to the green field.

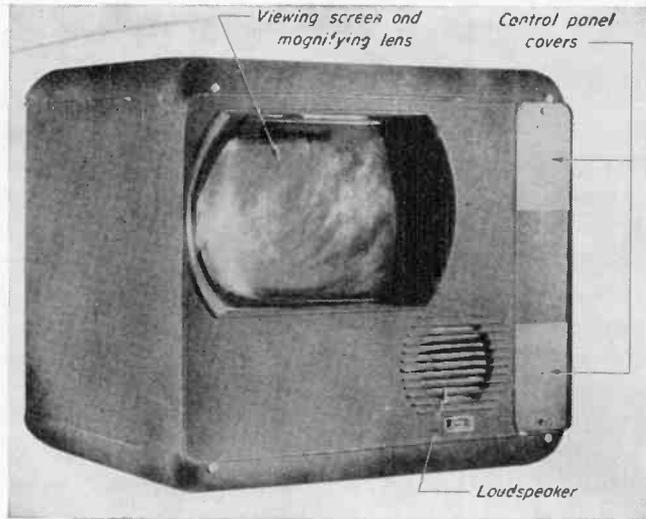


FIG. 17-13. A professional-type color-picture monitor.

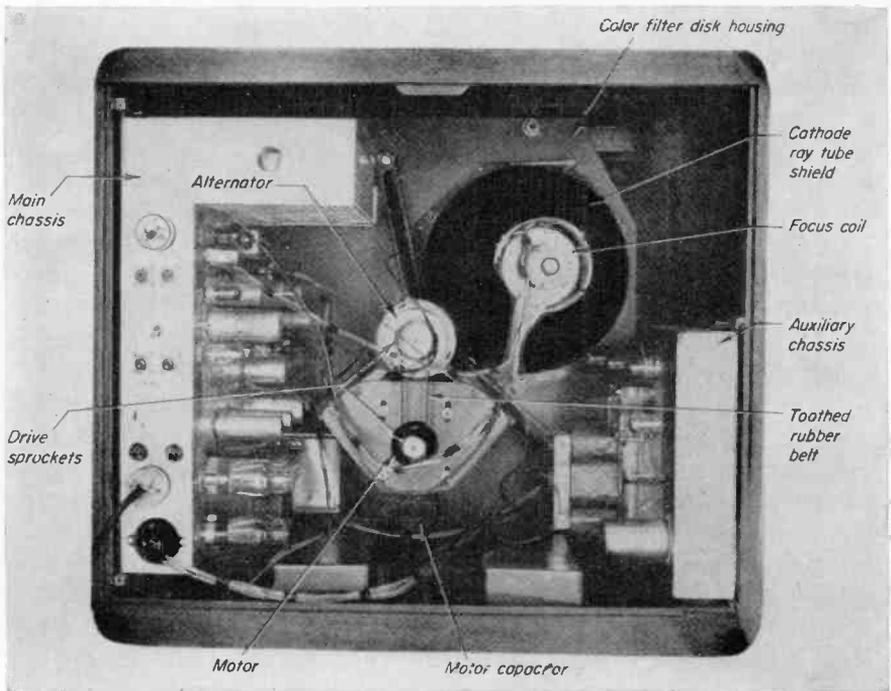


FIG. 17-14. Rear view of a color-picture monitor.

**Clamper Keying Pulses.** The keying pulses required for the operation of the red, blue, and green clamper tubes V4, V5, and V6, respectively, are derived from horizontal pulses, as shown in Fig. 17-12. Negative, horizontal driving pulses from a synchronizing waveform generator are differentiated by a resistor-capacitor network and applied to the grid of V1A. The amplified pulses from the plate circuit of this tube are applied through a lumped-constant delay line to the grid of a clipper stage V1B. The output of this tube, which consists only of the negative pulses, is applied to the input of clamper keying tube V2. By virtue of equal plate and cathode load resistors, this tube produces equal amplitude keying pulses of both positive and negative polarity. The duration of these pulses, which are applied to the red, blue, and green clamper tubes, V4, V5 and V6, is approximately 1.5 microseconds, and they are delayed about 2 microseconds after the start of the horizontal driving pulses which initiate them.

**17-9. Color-picture Monitor.** Color-picture reproduction from a standard field sequential color-television signal can be accomplished, for the most part, by techniques and circuitry similar to those employed for the reproduction of monochrome pictures. If a conventional monochrome picture tube is used for the purpose, the only new feature is the method of obtaining a color picture from the monochrome display of the picture tube.

A color-television picture monitor in which color is provided by interposing optical color filters between the tube face and the viewer, in a synchronous manner, is shown in Figs. 17-13 and 17-14. This particular color monitor employs a color filter disk which rotates synchronously in front of the picture tube. Other types of color-picture monitors employ color filters mounted on the surface of a cylinder whose diameter is larger than the picture tube is long. The picture tube is then mounted within the cylinder or drum with the axis of the tube at right angles to the axis of the cylinder.

Tricolor picture tubes rather than monochrome tubes may be used in color-picture monitors thereby eliminating the need for a rotating color filter disk. At the present state of the art, however, color-picture tubes are not only relatively expensive but are unable to reproduce the range of colors possible when optical color filters are employed. Furthermore, the use of color-picture tubes requires the use of additional circuitry for their operation.

**Video Circuits.** A schematic block diagram of the circuits employed in the color-picture monitor shown in the photographs is given in Fig. 17-15 and a circuit diagram shown in Fig. 17-16. The general arrangements of the video circuits are very similar to those employed in mono-

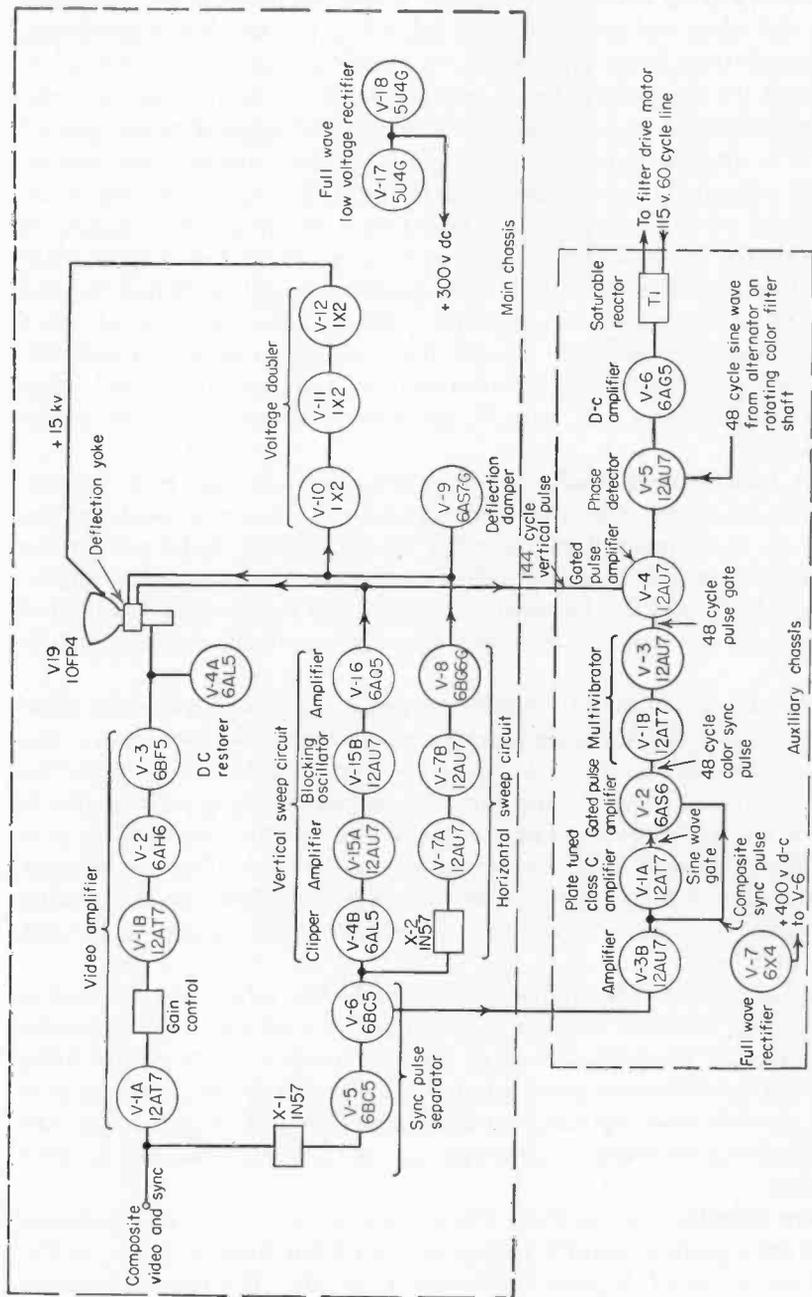


Fig. 17-15. Schematic block diagram of a color-picture monitor. The circuits contained on the main chassis are similar to those found in a monochrome monitor while those on the auxiliary chassis provide a means for automatically obtaining correct color phasing of the color filter disk.

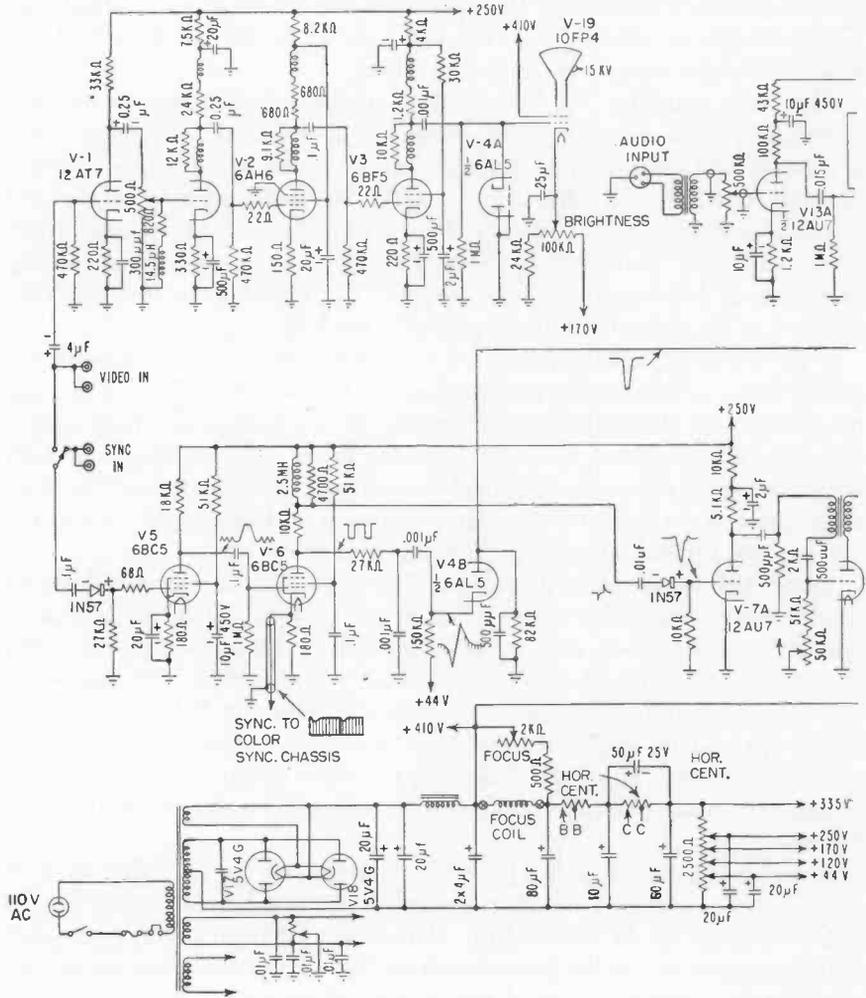
chrome picture monitors of the type used for professional applications. These circuits are contained in the main chassis visible at the left of the rear view of the monitor given in Fig. 17-14.

The video amplifier, V1, V2, and V3, employed in this picture monitor is designed to have its input terminated by a standard 75-ohm one-side-grounded load and provides sufficient gain to operate with input signals ranging from 0.5 to 4 volts, peak to peak. A combination of series- and shunt-peaked interstage coupling circuits provides a video bandwidth in excess of 7 Mc. Maintenance of black level under conditions of varying video signal information is accomplished by a diode d-c restorer V4A coupled to the grid of the 10-in. picture tube V19.

A potential of 15,000 volts d-c, for the cathode-ray tube anode is obtained from a three-tube voltage-doubler rectifier V10, V11, and V12, operating from the positive pulse present in the horizontal sweep amplifier plate circuit during horizontal retrace time. This voltage, although somewhat higher than that normally employed for monochrome applications involving a tube of this size, ensures a picture bright enough to compensate for the losses in the optical color filters.

**Color Disk Synchronizing System.** The video circuits described above produce a monochrome image from a color-television signal. Color is added to this image by rotating over the face of the picture tube a series of primary-color optical filters mounted on a plastic disk. The speed of the disk is maintained synchronous with the color signal by variation of the 60-cps voltage applied to the drive motor from control circuits in an auxiliary chassis. Since the operation is rather unusual and not similar to any of the more familiar monochrome circuits, it is described at length below.

Color synchronizing pulses from the main chassis are amplified by V3B on the auxiliary chassis and then applied to the self-biased class C amplifier V1A (Figs. 17-15 and 17-17). A resonant circuit consisting of a coil and two condensers in the plate circuit of tube V1A is tuned to a frequency equal to the repetition rate of the equalizing pulses (58.32 kc). Thus, when V1A is driven from conduction to cutoff by a positive grid pulse, its plate voltage will rise sinusoidally at a 58.32-kc rate and reach a maximum at time intervals corresponding to points exactly midway between equalizing pulses. This sine wave is used to gate the suppressor grid of V2. Simultaneously, synchronizing pulses are also fed from V3B to the grid of V2. The grid bias of V2 is adjusted to a value which will allow the tube to conduct only during the time of maximum suppressor voltage, *i.e.*, only during the interval between equalizing pulses. Therefore, the color pulse, which occupies this position, will be amplified by V2, and all other pulses in the synchronizing waveform will be rejected.



The narrow (same width as equalizing pulses) color synchronizing pulses thus selected occur at a 48-cps rate and are used to trigger a monostable multivibrator V1B and V3A which produces a considerably wider pulse. This wider 48-cps pulse is used to bias a triode V4 to cutoff for the duration of the pulse. Both sections of the dual triode V4 are connected in parallel, and its plate resistance serves as a variable element in a voltage divider consisting of a 150,000-ohm resistor (on main chassis) in series with the plate circuits of V4 and a 100,000-ohm resistor (on auxiliary chassis) in parallel. Vertical rate pulses (144 cps) obtained from ampli-

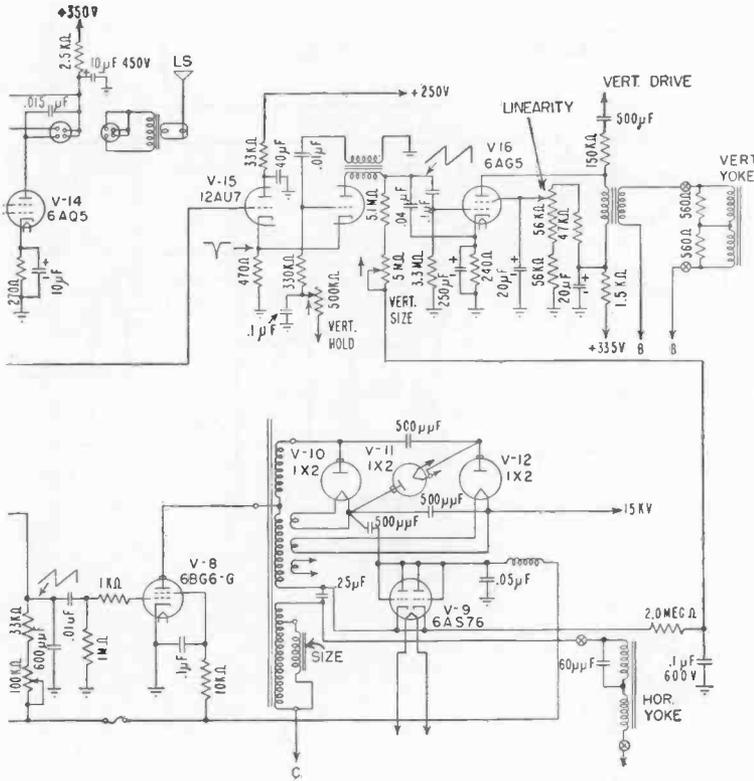


FIG. 17-16. Circuit diagram of a color-picture monitor.

fier V16 on the main chassis are applied across this voltage divider. However, since V4 is maintained at full conduction, except when momentarily driven to cutoff by the 48-cps color pulse, its shunting action prevents the appearance of any significant amount of 144-cps voltage across the 100,000-ohm resistor. On the other hand, when V4 is driven to cutoff, once every 1/48 second, a single 144-cps pulse will appear across the 100,000-ohm resistor. Thus every third vertical pulse (or 48 per second) appears across the resistor from whence it is applied to the grid of the dual triode phase detector V5.

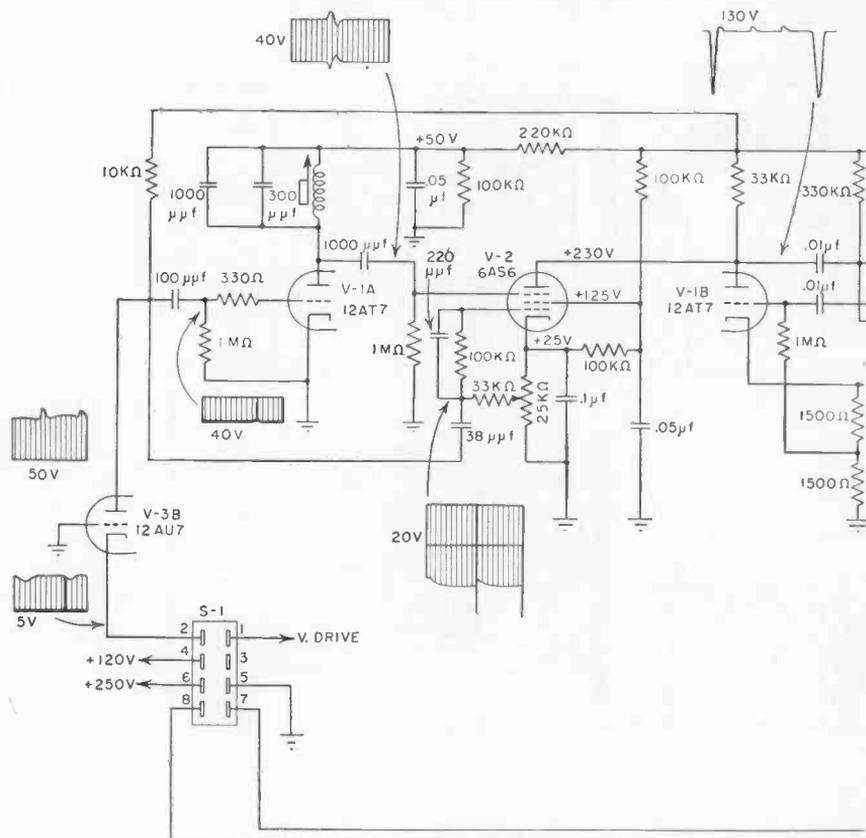


FIG. 17-17. Circuit diagram of the automatic color

The plates and cathodes of phase detector V5 are fed with a 48-cps reference sine wave derived from a small alternator mounted on the color filter shaft. V5 operates to detect the phase difference, if any, between the alternator voltage wave and the afore-mentioned 48-cps pulses. A 10,000-ohm potentiometer determines the operating point upon the alternator voltage wave. If a phase difference occurs between this operating point and the 48-cps clamping applied to the grids of V5, a voltage will be produced at the grid of V6. Such a change in grid bias of V6 will produce a change in direct current in the primary of a saturable reactor. This, in turn, produces a change in the reactance presented by the secondary winding of the unit. Since the secondary of the reactor is connected in series with the color filter disk drive motor, any change in its reactance will change the speed of the induction motor involved. The



given of the method employed to modify a commercially available projector for this service.

**Projector Operating Cycle.** The relationship between the film pulldown and dwell time, the film illumination, the primary color filters, and the scanning of the pickup tube are diagrammed in Fig. 17-18. This illustration pertains to the use of an intermittent type of film projector with a storage-type camera tube. As in monochrome applications employing these types of equipment, illumination of the film and, consequently, of

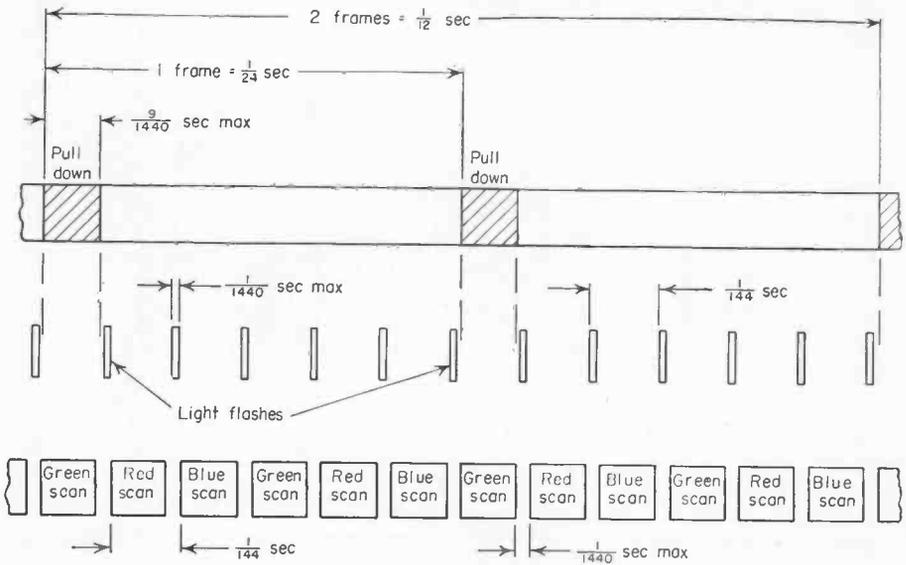


FIG. 17-18. Timing relationship between the pulldown and dwell time, the light flashes produced by shutter action, and the camera tube scanning in a 16-mm color-film projector and pickup system.

the photocathode of the camera tube takes place during the vertical blanking interval of the television system. As detailed in Sec. 17-4, this interval in the standard color-television system may range from 0.07 to 0.10  $V$ , where  $V$  is the vertical period, or  $1/144$  second. Thus, the maximum time available for film illumination is  $1/1440$  second. This allows the film to be pulled down during the remaining  $9/1440$  second duration of a television field. In motion-picture projector terminology, this is equal to a pulldown time of 54 degrees. Thus it is seen that, after making allowance for the film to come to rest and for working tolerances, a pulldown time of less than about 50 degrees is required.

Because of their spectral distribution, the light from commercially available pulse light lamps has not been found particularly adaptable to color-

television applications. However, the required pulses of light can be conveniently obtained by mechanical interruption of an incandescent light source. A conventional rotating shutter of proper configuration may be used with a synchronized color filter disk on the camera (see Sec. 17-6), or the latter may be eliminated and the color filters placed in the projector shutter openings. Of the several possible configurations, one is described below as typical of the procedures that may be followed for converting existing monochrome-type film projectors for color-television service.

**Projector Modifications.** A number of commercially available 16-mm film projectors provide the basic needs for color-television transmissions. Some, however, require extensive mechanical modification while others lend themselves readily to conversion. For example, those with a shutter drive motor separate from the intermittent drive motor usually may be easily modified for color-television applications. One such projector is shown in Fig. 9-12.

Projectors of this type may be converted to color-television service by replacing the original shutter with a new one having two 5-degree openings and operating it at a speed of 4,320 rpm. This rotational speed may be obtained by gearing up the original 3,600-rpm synchronous shutter motor by a 1.2-to-1 ratio, although, in one unit that was converted, the same result was accomplished more conveniently by employing a 72-cps source of power to operate the original shutter motor. In any event, the two-slot shutter operating at 4,320 rpm provides the required six light pulses per film frame. The pulldown time of the projector under discussion is 48 degrees, and no changes are required in this respect although provisions must be made for automatically phasing the intermittent motor with respect to the synchronizing waveform generator.

Although 35-mm film projectors with sufficiently fast pulldown mechanisms have not been commercially available, there is no reason to believe that existing projectors cannot be satisfactorily modified. Work in connection with 35-mm film cameras for television recording indicates that pulldown times of less than 50 degrees are not unreasonable. In this connection, it is to be noted that regulation 24-frame-per-second projectors are required for field sequential color systems rather than the special 2-3-2-3 scanning action 35-mm projectors employed for monochrome applications.

**17-11. Summary.** In this chapter there has been presented a review of the characteristics of FCC standard color-television signals and information as to the manner in which typical monochrome television pickup equipment may be converted for color-television operation. The latter material is not presented with the thought that it represents either the

only method or necessarily the best method of making conversions of this type. Rather, it is meant to serve as an example of the ease with which monochrome television broadcasting equipment may be converted for use with the standard field sequential color transmission system. In addition, the equipment described has been in regular service since 1950 and, with normal preventive maintenance, continues to operate in accordance with FCC standards and to produce color transmissions meeting the operating standards established by the Columbia Broadcasting System.

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