COLOR TELEVISION

Manual for

TECHNICAL TRAINING

RCA

RADIO CORPORATION OF AMERICA

COLOR TELEVISION

Theory • Equipment • Operation

Manual for Television Technical Training

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CAMDEN, NEW JERSEY

"Color television opens a new era in electronic communications and adds a new dimension to the entertainment arts. It supplies a new power to advertising . . . intensifies television as a social and educational force, and opens the way for a significant advance in service to the public . . ."

(From a statement by Brig. General David Sarnoff, following the Announcement of FCC Approval of Standards for Compatible Color Television.)

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FOREWORD

This television technical training manual has been prepared especially for use by personnel concerned with the planning, operation and maintenance of color television equipment for broadcast stations.

Although this is the first edition devoted specifically to color broadcasting, it is the eighth in a series of technical training manuals previously published by RCA on television broadcast systems and practices.

Some of the equipment items described in this manual are identical to those used in monochrome broadcasting. For these items, it has been found desirable to supplant the detailed circuit descriptions (existing in previous manuals) with equally important data concerning use of the equipment for color; wherever color may require slightly different procedures for best adjustment and performance of the equipment, details are given. Much of the information presented in this manual is based on the experience of operating color broadcast stations.

The content of this training manual is divided into twelve parts and the four appendixes. Parts One and Two review the fundamentals of television and describe the basic principles employed in electronic color television broadcasting. Part Three discusses areas in a color system which greatly influence color fidelity in the transmitted picture. Part Four describes the colorplexer, which is the encoder for the color system. Part Five describes color camera equipment for live studio telecasts, and Part Six gives details on color film and slide equipment. All of Part Seven is devoted to the color monitor. Part Eight presents data on the switching and distribution of color signals. Part Nine is devoted to the planning of a color broadcast system and the integration of color and monochrome television equipment. Part Ten discusses television transmitter adjustment for color operation. Part Eleven describes important associated color equipments such as the color video tape recorder, mobile units and microwave relay equipment. Part Twelve describes color test equipment and its use in the color system.

A new and unique switching system utilizing transistors is presented in Appendix A. Tables revealing weight, space and power requirements of the rack mounted color units are given in Appendix B. Appendix C contains helpful reference charts giving details of synchronizing standards and relating values of hue and saturation. Appendix D presents block diagrams of the Colorplexer showing actual waveforms obtained at various stages in the matrixing and modulation processes. Finally, also in Appendix D, are invaluable systems diagrams to aid the engineer in the design of his color broadcasting facilities.

CONTENTS

CONTENTS

CONTENTS

CONTENTS

PART 1

Color Fundamentals

Color is a new dimension that has been added skillfully to black and white television. To the engineering fraternity as a whole it signifies one of the most dramatic technological achievements of this age.

Nearly every branch of science including chemistry and psychology contributes in some way to the reality of color television. Through chemistry, improved phosphors are continually being found for use in color picture tubes. Psychology enters into the selection of lighting arrangements and picture composition to obtain desirable interpretations by the viewer. But physics plays the leading role with intense application in optics and illumination as well as in the design of electronic circuitry and components for the complete television system.

Two specialized branches of physics, namely radio and television engineering are responsible for the electronic techniques which make color television "compatible" with black and white, or monochrome television, marking what is probably the greatest technical advance in television in the past decade.

Compatibility

The compatible color system offers tremendous economic advantages to the home viewer as well as to the television broadcaster. Because of compatibility, color telecasts can be seen (in monochrome) on existing television receivers, without any changes or added devices. Also, color receivers can receive monochrome as well as color telecasts. Since compatible color is transmitted over the same channels as monochrome, and within the same framework of standards, the television broadcaster can utilize his monochrome system as the transmitting nucleus when installing equipment to broadcast color. Moreover, he can utilize his color equipment to produce monochrome telecasts.

Another important advantage of the compatible color system is the part it plays in the conservation of the radio frequency spectrum. Compatible color requires no additional space in the spectrum. However, it employs techniques which make much more efficient use of the standards originally set up for monochrome television.

A brief review of the fundamentals of monochrome television, particularly the areas wherein specialized color methods are employed, is presented in the next few paragraphs as an aid in describing the basic color concepts.*

Television—A System of Communications

Basically, television is a system of communications consisting of the television station at one end of the system, and the television receiver at the other. As such, it is actually one of the highest capacity systems in use today, being able to transmit from station to receiver more than five million "bits" of picture information every second.

Very simply, the function of the television station is to divide and subdivide the optical image into over 200 thousand picture elements, each of different light intensity, convert these light elements to electrical equivalents, and transmit them in orderly sequence over a radio frequency carrier to the television receiver.

Reversing this process at the receiver, these electrical signals are each converted to light of corresponding brightness and reassembled to produce the transmitted image on the face of the picture tube.

Scanning

Picture elements to be transmitted in sequence are selected by a process of image scanning which takes place in the television camera focused on the studio scene at the station. Within the camera, an electron beam in a pick-up tube scans a sensitive surface containing an "electrical image" of the scene of action. The electron beam successively scans the image at great velocity,

* For detailed information on the theory and operation of monochrome television broadcast equipment, reference should be made to the RCA "Manual for Television Technical Training," Form No. 2J 8172.

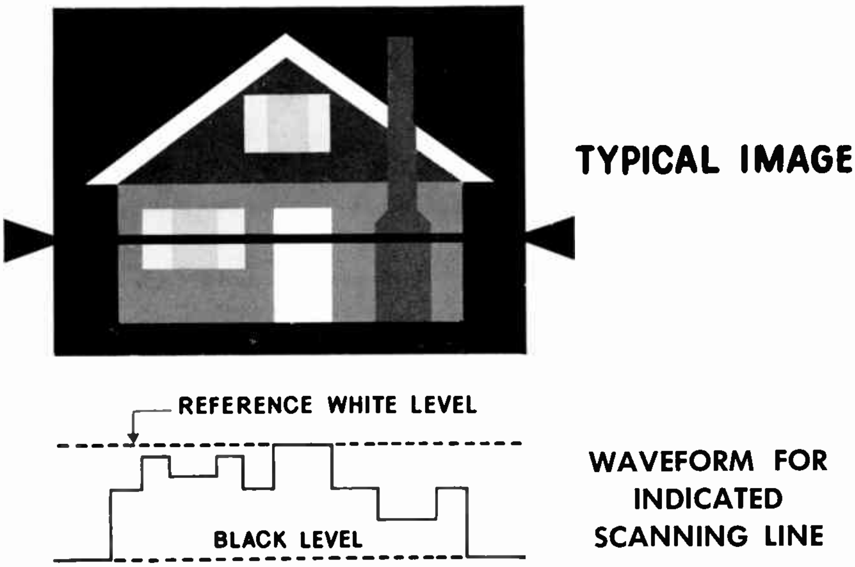


FIG. 1. Typical image and camera output waveform produced by light and dark areas during one scan along line indicated by arrows.

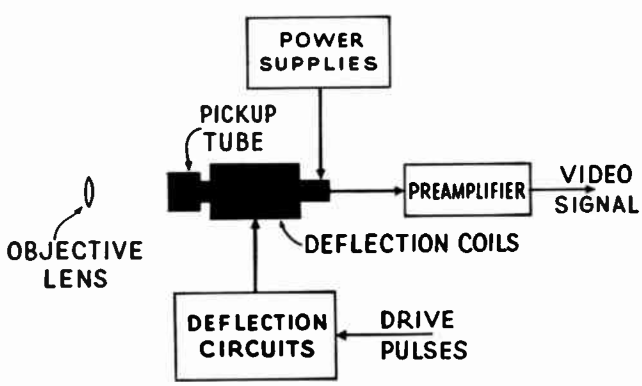


FIG. 2. Block diagram of monochrome camera circuits.

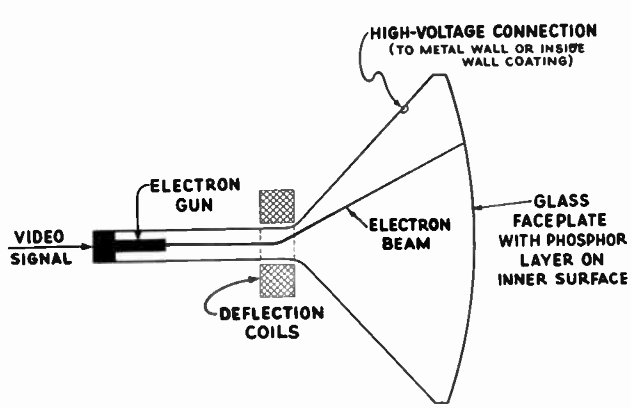


FIG. 3. Diagram showing principal elements of the monochrome kinescope picture tube.

beginning at the upper left corner and continuing from left to right in a series of parallel lines to completely scan the image. Movement of the electron beam, which is controlled magnetically by vertical and horizontal deflection coils surrounding the tube, is analogous to that of the eye in reading a printed page. The speed of movement is such, however, that 30 complete image *frames* of approximately 500 lines each are scanned every second. Of course at the receiver, an electron beam in the kinescope, or picture tube, moves with the same speed and in synchronism with the camera tube beam so that the corresponding picture elements appear in the proper relative position on the television screen.

Due to "persistence of vision" and the speed of scanning, these elements appear to be seen all at once as a complete image, rather than individually. Thus, the impression is one of continuous illumination of the screen and direct vision.

Scanning standards have been established in this country to assure that all television receivers are capable of receiving programs broadcast by any television station within range. The scanning pattern adhered to by manufacturers in the design of television receivers and broadcast equipment consists of 525 lines with odd-line *interlaced* scanning. Interlaced scanning, effective in eliminating perceptible flicker, is a method whereby the electron beam scans alternate rather than successive lines. For example, the beam begins by scanning the odd-numbered lines (1, 3, 5, 7, etc.) until it reaches the bottom of the image, whereupon it returns to the top of the image to scan the even-numbered lines (2, 4, 6, 8, etc.). Thus, each scan or *field* comprises only half

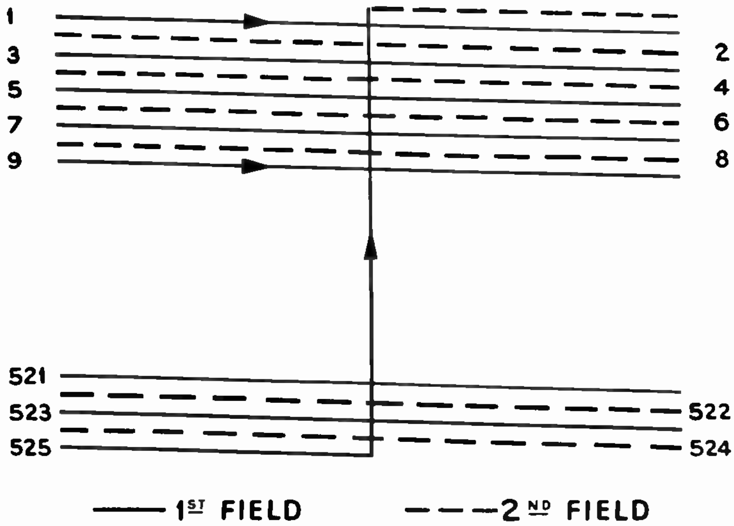


FIG. 4. Diagram showing paths of the electron beam in both the pickup tube and kinescope to produce the interlaced scanning pattern.

the total number of scanning lines, and two fields are required to produce the 525-line frame. Each field is completed in one half the frame time, the vertical scanning frequency is 2 × 30 or 60 cycles per second. The horizontal scanning frequency is 30 × 525, or 15,750 cycles per second.

Resolution and Bandwidth

The degree of resolution or fine detail that can be seen in a televised image depends upon the number of scanning lines used and the bandwidth of the transmitting and receiving system.

The relationship between resolution and bandwidth can be seen by considering the number of picture elements that can be transmitted each second.

The standard 6-megacycle broadcast channel provides a video bandwidth of approximately 4.1 megacycles (the remaining bandwidth being required for a vestigial sideband plus the sound signal). Since each cycle of a sine wave is capable of conveying two picture elements (one black and one white), the maximum rate at which picture elements can be transmitted is 4,100,000 × 2 or 8,200,000 per second. Since 30 complete frames are transmitted per second, the number of picture elements per frame would be 8,200,000 ÷ 30 or 273,333 if it were not for the retrace blanking problem, which requires interruption of the picture signal periodically by blanking pulses. Since the combination of horizontal and vertical blanking pulses requires nominally 25% of the total time, the maximum number of picture elements per frame is reduced in practice to 0.75 × 273,333 or approximately 205,000.

Synchronizing

In addition to the picture information, or *video* signals, *blanking* and *synchronizing* signals are transmitted by the television station to control the intensity and movement of the scanning beam in the kinescope of the television receiver. Both these signals are in the form of rectangular pulses. Moreover, their polarity and amplitude is such that they are received as "black" signals, and therefore do not appear on the receiver screen.

Blanking pulses eliminate the "retrace" lines which would otherwise appear between scanning lines, and at the end of each field from the bottom of the picture to the top. *Horizontal* blanking pulses, transmitted at the end of each line, or at intervals of 1/15,750 of a second, blank the beam during retrace periods between lines. While *vertical* blanking pulses, transmitted at the end of each field, or at intervals of 1/60 of a second, blank the beam during the time required for its return to the top of the picture. Because the vertical retrace is much slower than the horizontal, the vertical blanking periods are longer than the horizontal blanking periods. Vertical blanking pulses are about 20 lines duration, while horizontal blanking pulses have a duration of only a fraction of a line.

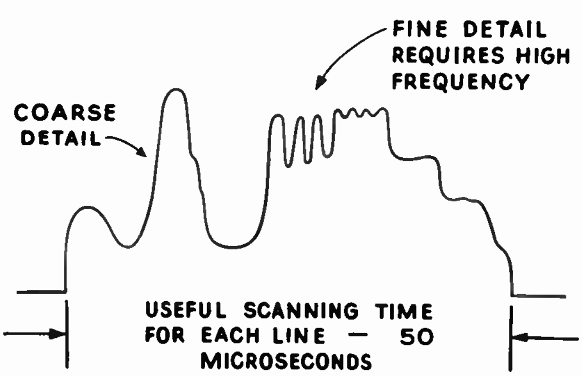


FIG. 5. Diagram illustrating the relationship between picture detail and signal bandwidth.

Synchronizing signals keep the scanning beam of the kinescope in step with that of the camera tube. These signals consist of horizontal and vertical pulses which are transmitted within the respective blanking periods. Although the sync pulses are of the same polarity as the blanking pulses, they are of greater amplitude ("blacker than black"), and thus easily separated in the receiver, and fed to the deflection circuits of the kinescope.

Since the vertical sync pulses are quite long compared to the horizontal sync pulses, and the two are of the same amplitude, separation at the receiver is accomplished through frequency discrimination. Serrations, or slots in the vertical pulses prevent loss of horizontal sync during the vertical blanking period.

The Monochrome Television System

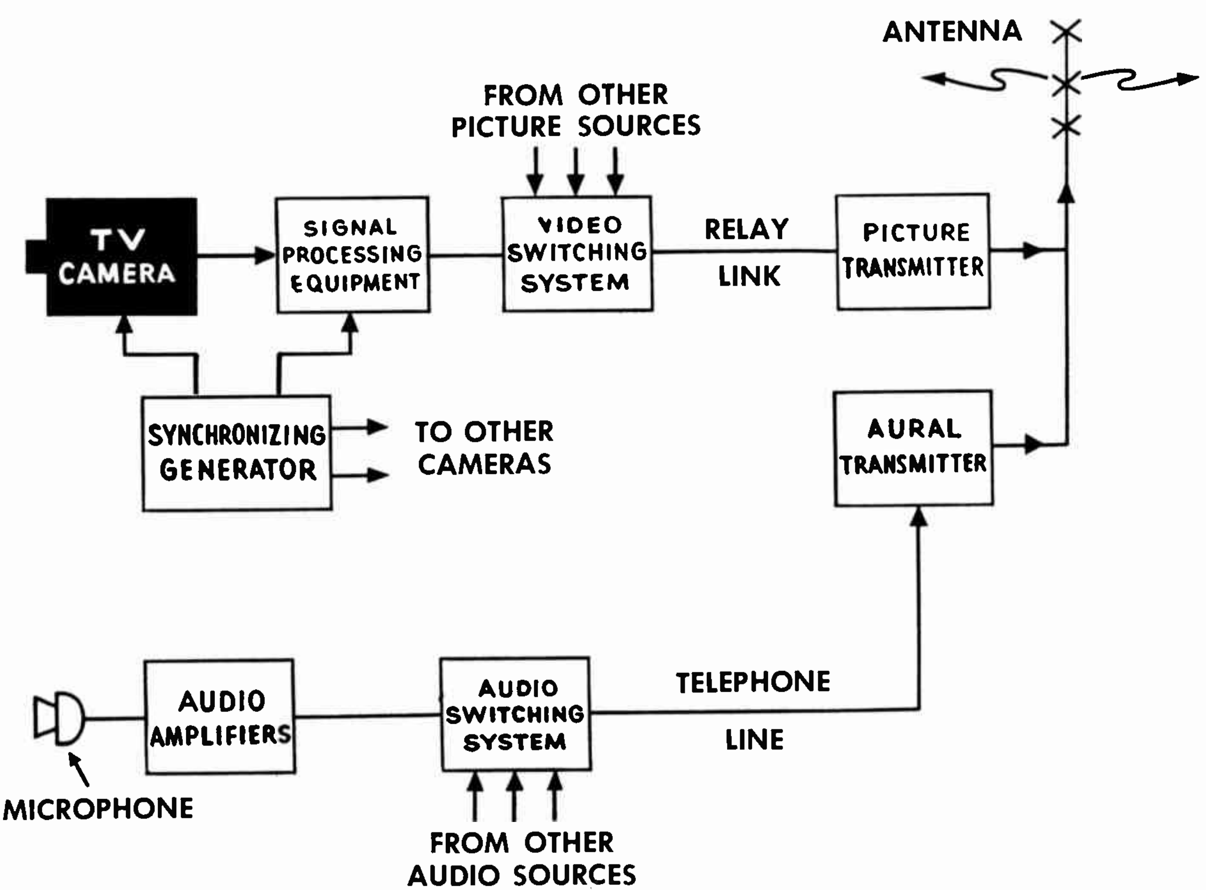
The major equipment in a typical television station consists of the aural and visual units illustrated in the block diagram of Fig. 6. In the visual channel, the video signal leaving the camera is passed through processing equipment which inserts the blanking and synchronizing signals, and performs other functions such as aperture compensation and gamma correction. From the processing chain, the video signal is fed to a switching system which provides for selection from a number of video sources. The selected signal is then sent to the visual transmitter through coaxial cable or over a microwave relay link, depending upon the distance between the television studio and transmitter. In the transmitter, the composite video signal amplitude-modulates a carrier in the VHF or UHF range, which is radiated by the television antenna.

In the aural channel, the audio signal is fed from the microphone or other sound source, through the switching system and to the aural transmitter. Frequency-modulated output from the aural transmitter is combined with the visual output and radiated from the same antenna.

The Radiated Picture Signal

Amplitude relationships between the synchronizing pulses and the tonal gradations from white to black in the picture are represented in the waveform of the radiated picture signal. From the illustration, it can be seen that modulation takes place in such a way that an increase in the brightness of the picture causes a decrease in carrier output power. Note that the reference white line indicated on the sketch is relatively close to zero carrier level. Also, the synchronizing pulses are in the

FIG. 6. Simplified block diagram of the monochrome television station.



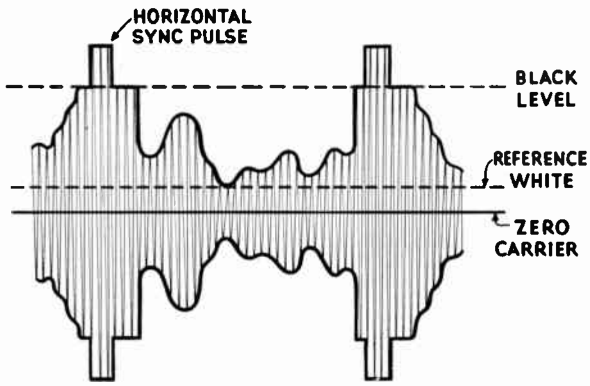


FIG. 7. Waveform of radiated picture signal.

"blacker than black" region, representing maximum carrier power. Use of a widely different range of amplitude for the sync pulses makes it possible for home receivers to separate them by a simple clipping technique.

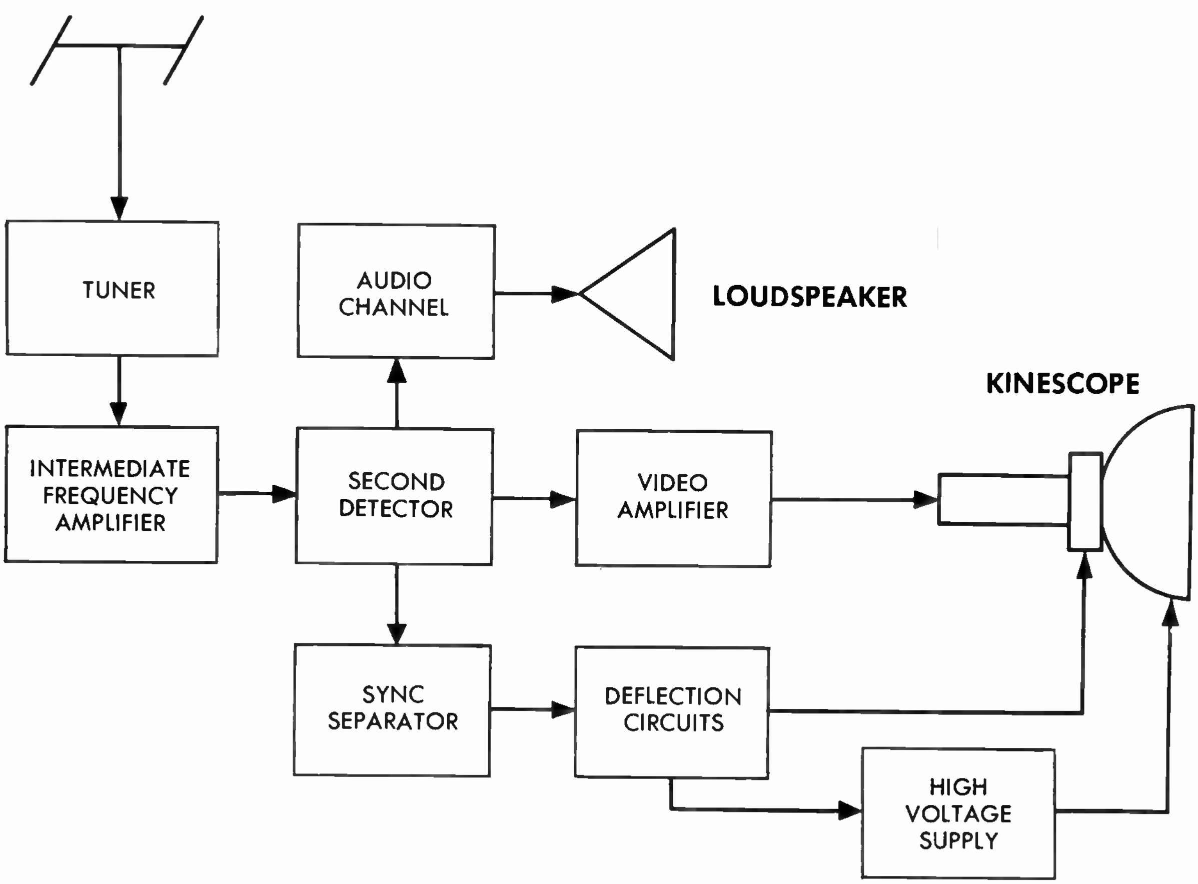
Receiver

The basic elements of the television receiving system are illustrated in the block diagram of the television receiver. The radiated television signal is picked up by an antenna and fed to a tuner which selects the desired channel for viewing. Output from the tuner is passed through an intermediate-frequency amplifier which provides the major selectivity and voltage gain for the receiver. A second detector then recovers a video signal which is essentially the same as that fed to the visual transmitter.

The sound signal is usually taken off at the picture second detector in the form of a frequency-modulated beat between the picture and sound carriers. The sound signal is further amplified in a special i-f stage, detected by a discriminator or ratio detector, and applied to the speaker through an audio amplifier.

Picture output from the second detector is fed to two independent channels. One of these is the video amplifier which drives the electron beam in the Kinescope, and the other is the sync separator, or clipper, which separates the sync pulses from the picture information. The separated pulses are then used to control the timing of the horizontal and vertical deflection circuits. The high voltage supply which is closely associated with the horizontal deflection circuit, provides accelerating potential for the electron beam.

FIG. 8. Block diagram of monochrome television receiver.



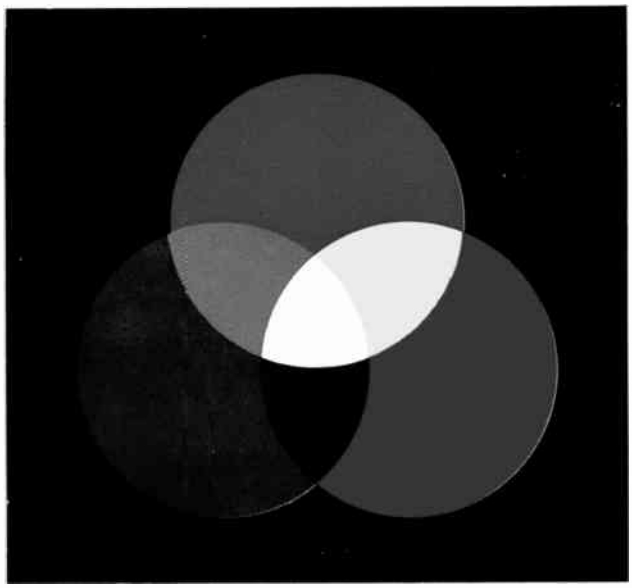


FIG. 9. The primary colors of television are red, green and blue. Virtually any color can be matched by combining proper amounts of these primaries. White is produced by a combination of all three.

The Three Variables of Color

Color is the combination of those properties of light which control the visual sensations known as *brightness*, *hue* and *saturation*. Brightness is that characteristic of a color which enables it to be placed in a scale ranging from black to white or from dark to light. Hue, the second variable of a color, is that characteristic which enables a color to be described as red, yellow, blue or green. Saturation refers to the extent to which a color departs from white or the "neutral" condition. Pale colors, or pastels, are low in saturation, while strong or vivid colors are high in saturation.

The monochrome system is limited to the transmission of images that vary with respect to brightness alone. Thus, brightness is the only attribute of a color that can be transmitted over a monochrome television system. To produce a color image, therefore, provision must be made for the transmission of additional information pertaining to all three of the variables of color. However, since the primary color process can be employed, it is not necessary to transmit information in exactly the form expressed by the three variables.

Primary Colors in Television

Experiments have proved conclusively that virtually any color can be matched by the proper combination of no more than three primary colors. While other colors could be used as primaries, red, green and blue have been selected as the most practical for color television use. A few of the many colors that can be made by mixing lights of red, green and blue are illustrated in Fig. 9. Red and green combined produce yellow; red plus blue gives purple; and green plus blue gives cyan or blue-green. The proper combination of all three of the primary colors produces white or neutral, as shown at the center of the illustration. By relatively simple optical means, it is possible to separate any color image into red, green and blue, or RGB components, as shown by Fig. 10.

Generating RGB Signals

Major components of the color television camera are shown in block diagram form in Fig. 11. Whereas the monochrome camera contains only one pickup tube, the color camera contains three separate pickup tubes mounted in three separate deflection coil assemblies. An objective lens at the front of the camera forms a real image within a condenser lens which is located where the pickup tube is usually mounted in a monochrome camera. A relay lens transfers this real image to a system of dichroic mirrors which shunt the red and blue light to the red and blue pickup tubes, and permit the green to pass straight through to the green tube. In this manner, the three pickup tubes produce three separate images corresponding to the RGB components of the original scene. These images are scanned in the conventional manner by common deflection circuits.

A single scanning line through the typical color image at the point shown, (Fig. 12), produces three separate waveforms. It is important to note the correlation between these waveforms and the image at the top. The yellow shutters in the image, for example, must be produced by a mixture of red and green, and the blue signal is not required. Thus, at this interval of scanning, the red and green signals are both at full value, and the blue signal is at zero. The white door utilizes all three color signals. Of

FIG. 10. Illustrating how a typical color image (upper left corner) can be separated by optical means into red, green and blue image counterparts.

course, similar correlations can be seen for other parts of the image along the scanning line.

Displaying RGB Signals

RGB signals are displayed in color by the tri-color kinescope, the basic components of which are shown in the diagram of Fig. 13. Three electron guns produce three beams which are independently controlled in intensity by the red, green and blue signals. These three beams are all made to scan in unison by deflection coils around the neck of the tube. The three beams converge at the screen due to the magnetic field produced by a convergence yoke.

The phosphor screen of the color kinescope consists of an array of very small primary color dots. Approximately one-half inch behind the phosphor screen is an aperture mask, which has one very small opening for each group of red, green and blue phosphors. Alignment of this aperture mask and screen is such that each beam is permitted to strike phosphor dots of only one color. For example, all the electrons emitted by the red gun must strike red phosphor dots or the aperture mask; they cannot strike either the green or blue dots because of the "shadow" effect of the mask. Likewise, the beams emanating from the other two guns strike only green or blue dots.

In this way, three separate primary color images are produced on the screen of the tri-color tube. But since these images are formed by closely intermingled dots too small to be resolved at the normal viewing distance, the observer sees a full color image of the scene being televised.

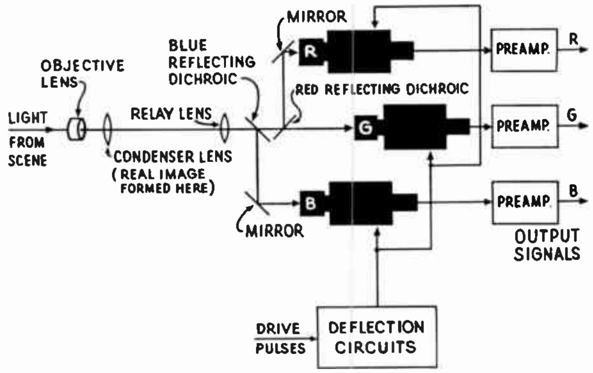


FIG. 11. Simplified block diagram of the optical and electrical components of the color camera.

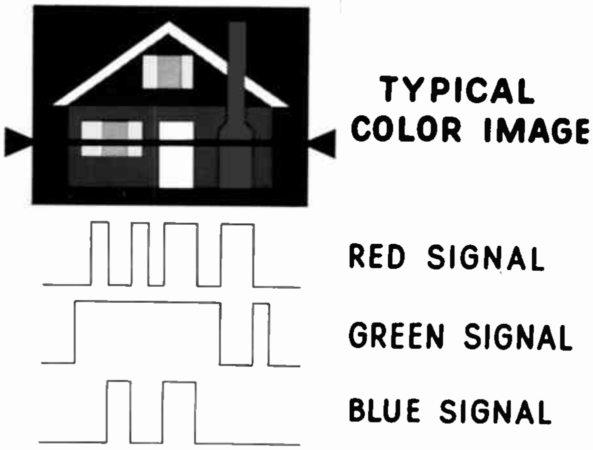


FIG. 12. Typical color image and waveforms produced by the red, green and blue pickup tubes of a color camera during one scan along line indicated by arrows.

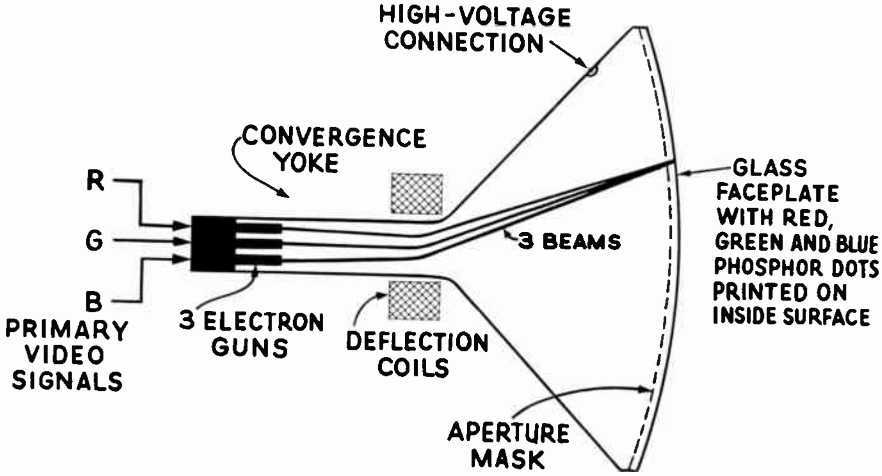


FIG. 13. Diagram showing components of the three-gun color kinescope picture tube.

PART 2

Electronic Aspects of Compatible Color Television

To achieve compatibility with monochrome television, color television signals must be processed in such a way that they can be transmitted through the same channels used for monochrome signals, and they must also be capable of producing good monochrome pictures on monochrome receivers. Since color television involves three variables in contrast to the single variable (i.e., brightness) of monochrome television, an encoding process is required to permit all three to be transmitted over the one available channel. Likewise, a decoding process is required in the color receiver to recover the independent RGB signals for control of the electron guns in the color kinescope. Moreover, the process used must enable existing monochrome receivers to produce a monochrome picture from the color information.

Encoding and decoding processes used in compatible color television are based on four electronic techniques known as matrixing, bandshaping, two-phase modulation and frequency interlace. It is these processes which make the color system compatible with monochrome, and enable the color system to occupy the existing six-megacycle channel.

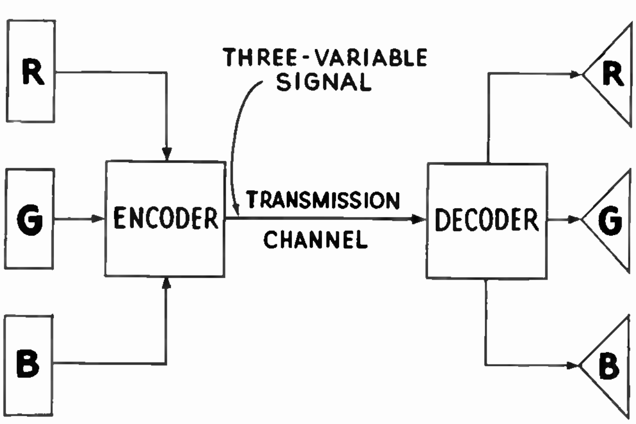


FIG. 1. Encoding of the RGB signals provides a three-variable signal which can be transmitted over existing monochrome channels.

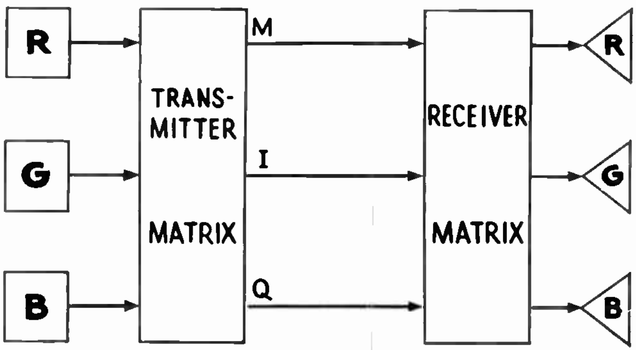


FIG. 2. A part of the encoding process is the matrixing of R, G and B signals to provide M, I and Q signals.

Matrixing

Matrixing is a process for "repackaging" the information contained in the red, green and blue output signals from a color camera to permit more efficient use of the transmission channel. The matrix circuits which perform this function consist of simple linear cross-mixing circuits. They produce these signals, commonly designated M, I, and Q, each of which is a different linear combination of the original red, green, and blue signals. Specific values for these signals have been established by FCC standards.

The M signal component, or *luminance* signal, corresponds very closely to the signal produced by a monochrome camera, and therefore is capable of rendering

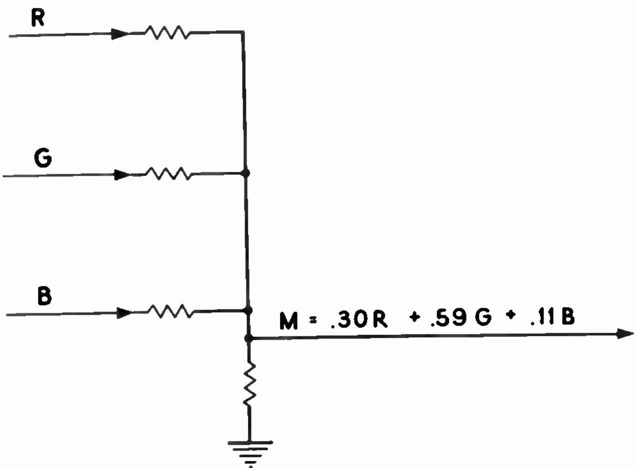


FIG. 3. Diagram of resistance matrix circuit used to produce the M luminance signal.

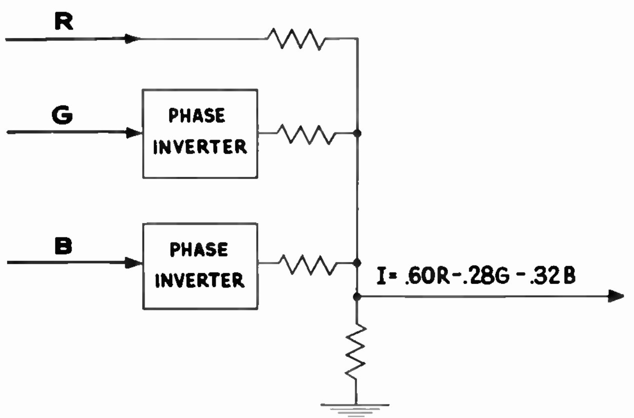


FIG. 4. Diagram of I matrix showing phase inverters to produce minus green and blue quantities.

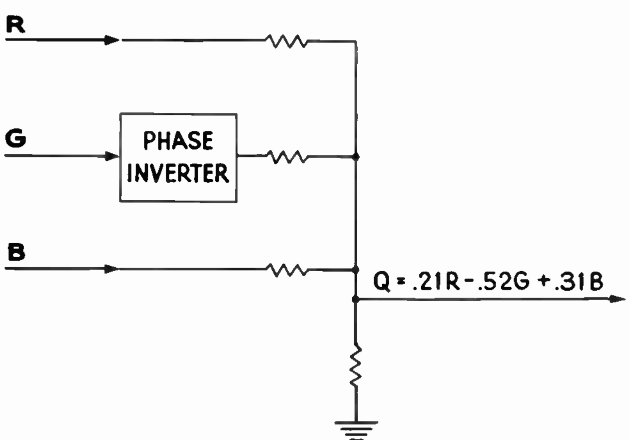


FIG. 5. Diagram of the Q matrix showing phase inverter to produce required minus green signal.

excellent service to monochrome receivers. The M component is obtained by combining red, green and blue signals in a simple resistor network (Fig. 3) designed to produce a signal consisting of 30% red, 59% green and 11% blue.

The I and Q signals are *chrominance* signals which convey information as to how the colors in the scene differ from the monochrome or "neutral" condition. The component I is defined as a signal consisting of 60% red, —28% green and —32% blue. Minus values are easily achieved in the matrix circuits by use of phase inverters to reverse the signal polarity (see Figs. 4 and 5). The Q signal is defined as 21% red, —52% green and 31% blue.

It can be seen that the quantities are related so that when red, green and blue are equal, corresponding to a neutral condition, both I and Q go to zero. Thus, when the color camera is focused on an object having no color information, such as a monochrome test chart, the I and Q signal components are absent, leaving only the M component or monochrome signal.

The matrix circuits, therefore, produce a new set of waveforms corresponding to the M, I and Q components of the image. A comparison of the MIQ and RGB waveforms (Figs. 6 and 7) obtained from the image illustrates the correlation between the types of signals. It will be seen that the M signal remains in the region between black level and reference white. It is identical to the monochrome signal derived from the monochrome version of the image. The I and Q signals, on the other hand, swing positive and negative around a zero axis.

Bandshaping

The eye has substantially less acuity in detecting variations in color than it has for resolving differences in brightness. This important characteristic of human vision was considered in setting up the I and Q equations because it permitted a significant reduction in the bandwidth of these signals, through use of low-pass filters. A bandwidth of approximately 1.5 megacycles was found to be satisfactory for the I signal, which corresponds to color differences in the range extending from orange to blue green. For color differences in the range from green to purple, as represented by the Q signal, the eye has even less acuity, and the bandwidth was restricted to only 0.5 mc. The M signal component which conveys the fine details must be transmitted with the standard four-megacycle bandwidth.

Two-Phase Modulation—Generation of Color Subcarrier

Two-phase modulation is a technique by which the I and Q signals can be combined into a two-variable signal for transmission over a single channel. This is accomplished by adding the sidebands obtained through modulation of two 3.6 mc carriers separated in phase by 90 degrees. The resultant waveform is the vector sum

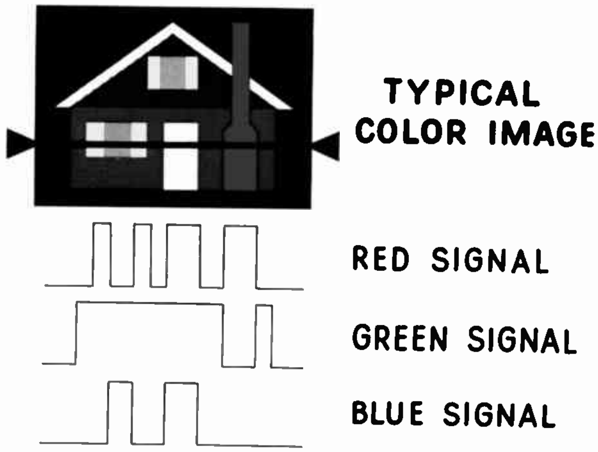


FIG. 6. Typical color image and RGB waveforms.

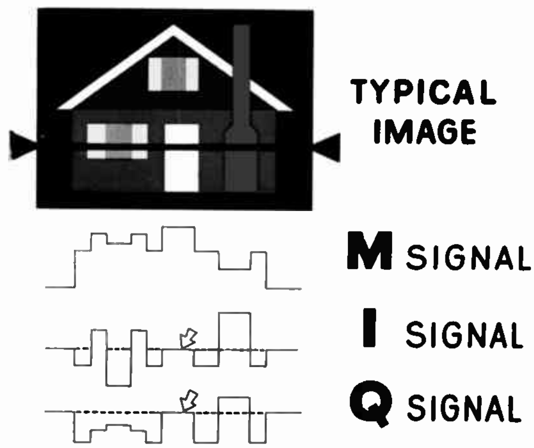
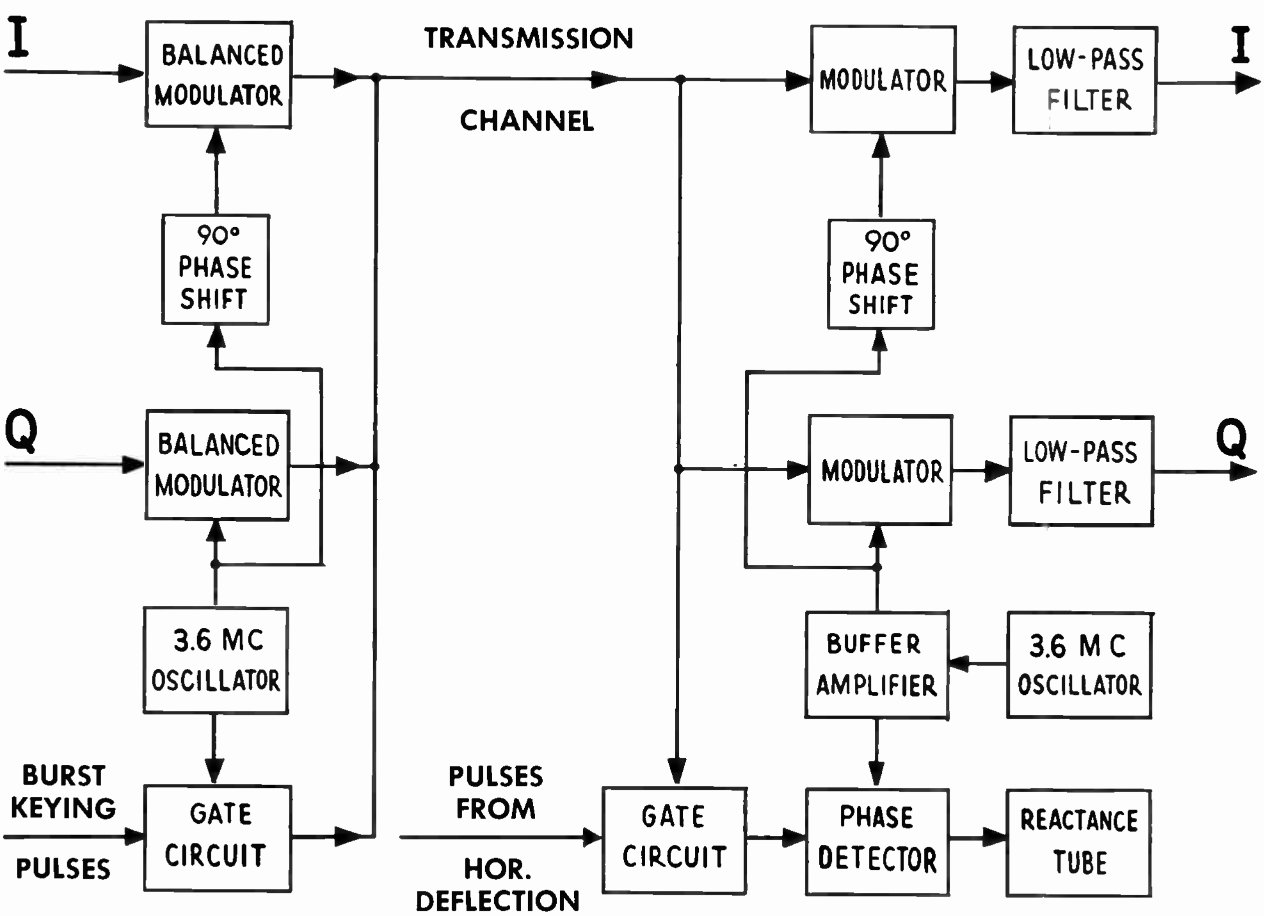


FIG. 7. Typical color image and MIQ waveforms.

of the components. Elements of the transmitting and receiving system are shown in Fig. 8. The two carriers, which are derived from the same oscillator, are suppressed by the balanced modulators. Thus, only the two amplitude-modulated sidebands, 90 degrees out of phase, are transmitted. At the receiving end of the system, the I and Q signals are recovered by heterodyning the two-phase wave against two locally generated carriers of the same frequency but with a 90-degree phase separation, and applying the resultant signals through low-pass filters to the matrix circuits. Typical signal waveforms are illustrated in Fig. 9 on the next page.

FIG. 8. Simplified block diagram showing elements for transmitting and receiving the I, Q, and burst signals.



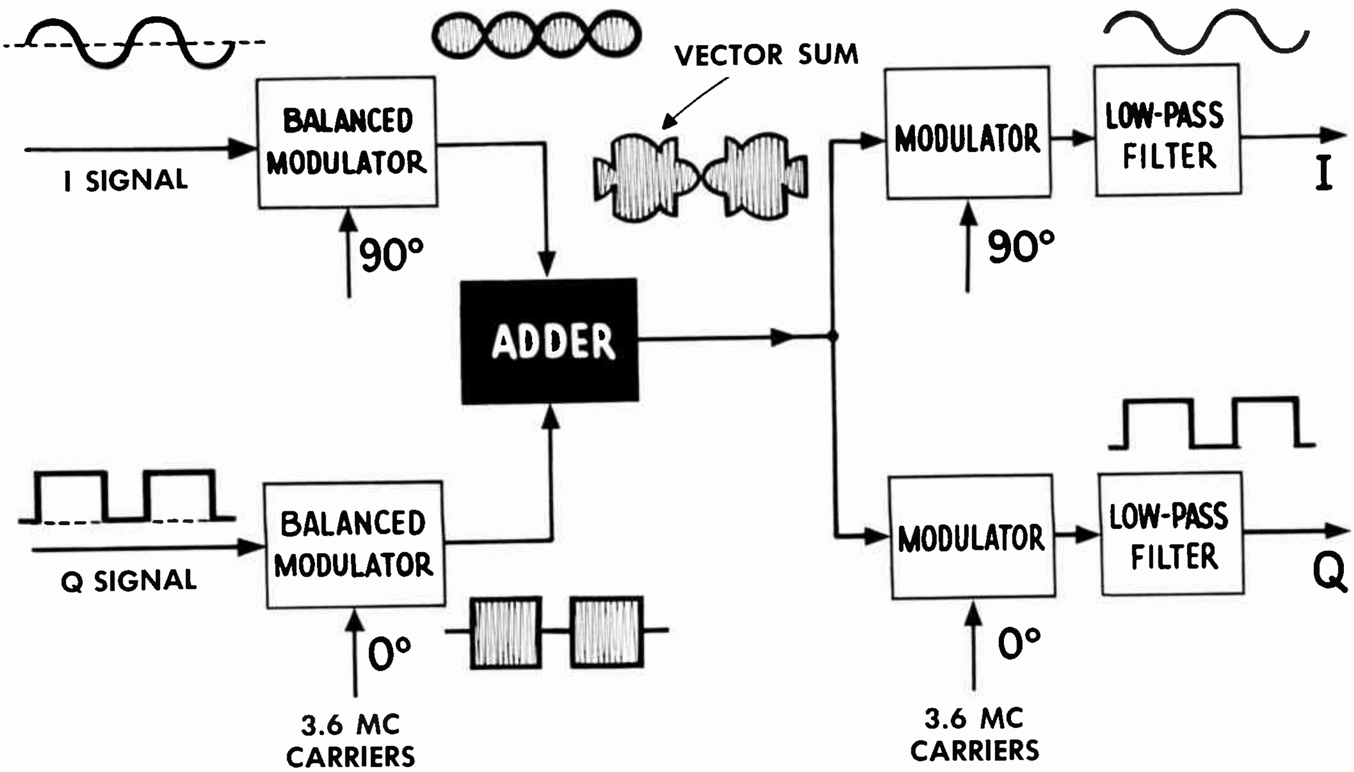


FIG. 9. Representative waveforms of the separate I and Q signals and the vector sum of the suppressed carrier sidebands at the modulator output. Original I and Q signals are recovered by heterodyning in balanced modulators at receiver.

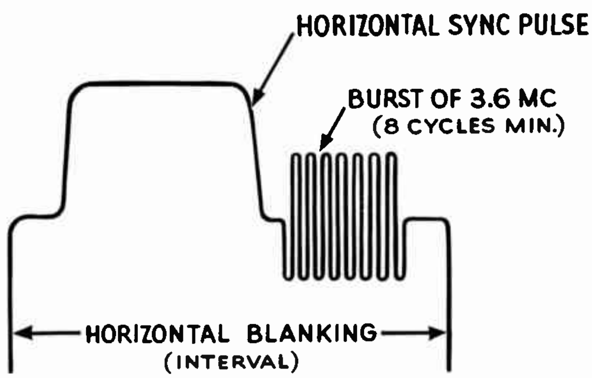


FIG. 10. Diagram showing position of subcarrier burst during horizontal blanking interval.

The 3.6 mc oscillator at the receiver must be accurately synchronized in frequency and in phase with the master oscillator at the transmitter. The synchronizing information consists of 3.6 mc "bursts" of at least 8 cycles duration transmitted during the "back porch" interval following each horizontal sync pulse. The bursts are generated at the transmitter by a gating circuit which is turned "on" by burst keying pulses derived from the synchronizing generator. At the receiver, the two-phase modulated signal is applied to another gating circuit, known as a burst separator, which is keyed "on" by pulses derived from the horizontal deflection circuit. The separated bursts are compared in a phase detector with the output of the local 3.6 mc oscillator. Any error voltage developed is applied through a smoothing filter to a conventional reactance tube which corrects the phase of the local oscillator.

FCC Standard phase relationships between the I and Q signals and the color synchronizing burst are shown in the vector diagram of Fig. 11. The I and Q signals are transmitted in phase quadrature, and the color burst is transmitted with an arbitrary 57-degree phase lead over the I signal.

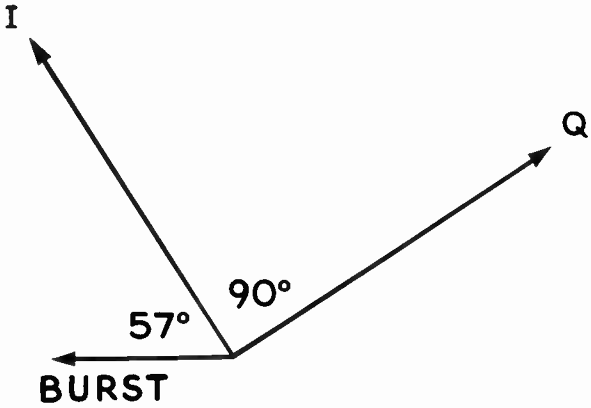


FIG. 11. Diagram showing phase relationship of I, Q and burst signals.

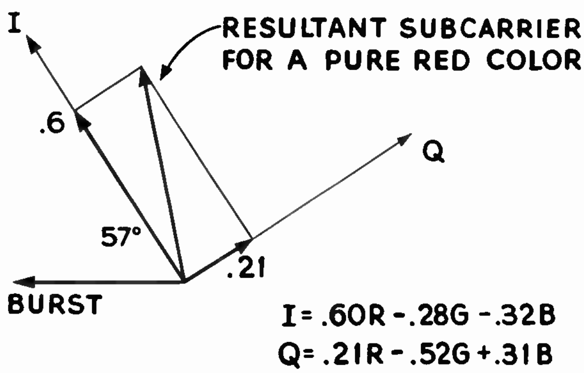


FIG. 12. Vector diagram showing phase and amplitude of subcarrier for a pure red signal.

Several interesting properties of the two-phase modulated signal are illustrated by the vector diagrams which represent the resultant signal under known transmission conditions. For example, when a pure red color of maximum amplitude is being transmitted, the green and blue components are at zero, and the I and Q signals have levels of 60% and 21%, respectively. When modulated upon their respective carrier, these signals produce the resultant shown in Fig. 12. The phase and amplitude shown is characteristic of pure red of maximum relative luminance. Fig. 13 is a composite vector diagram showing the phase and amplitude characteristics of all three primaries and their one-to-one mixtures. This composite diagram indicates that there is a direct relationship between the *phase* of the resultant two-phase modulated signal and the *hue* of the color being transmitted. There is also a relationship (although indirect) between the *amplitude* of the resultant signal and the saturation of the color being transmitted. If the phase of the resultant subcarrier and the level of the monochrome signal both remain constant, then a reduction in the amplitude of the subcarrier indicates a decrease in color saturation. The composite vector diagram also shows an interesting symmetry between complementary colors (colors are complementary if they produce a neutral when added together); the resultants for any two complementary colors are equal in amplitude but opposite in phase.

Frequency Interlace

Since the 3.6 mc carriers, consisting of the I and Q sidebands, fall within the video passband as shown in the diagram of the television channel, (Fig. 14) they become subcarriers and can be handled in many respects like unmodulated video signals. By use of *frequency interlace,*

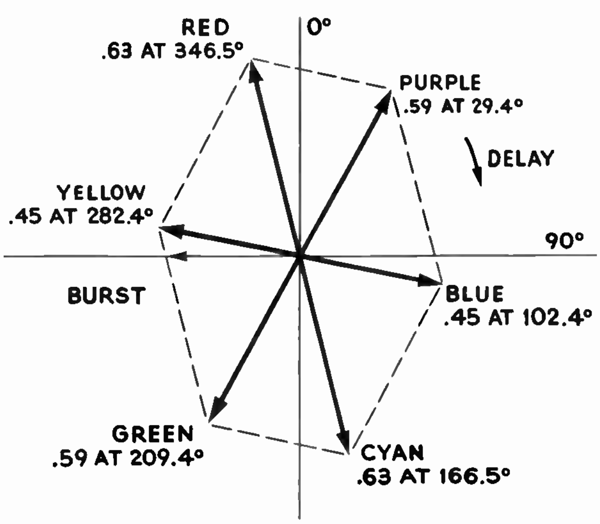


FIG. 13. Composite vector diagram showing subcarrier phase and amplitude for each of six colors.

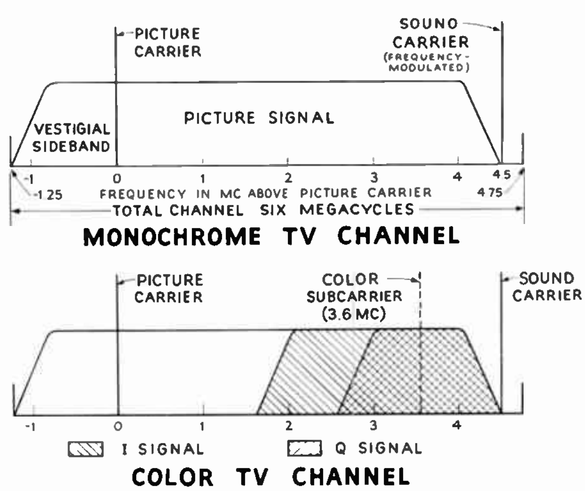


FIG. 14. Diagram of television channel showing portions occupied by color and monochrome signal components.

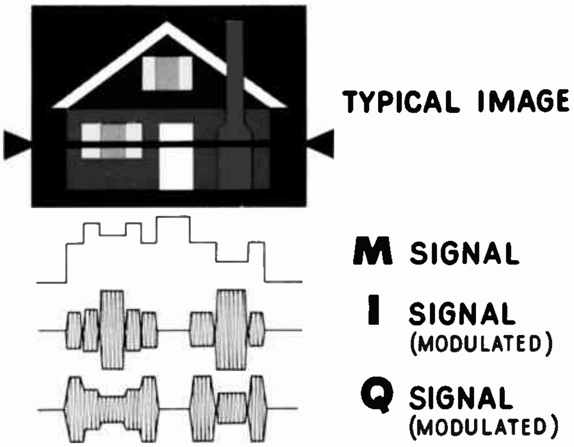


FIG. 15. Typical color image and waveforms of the M signal and modulated I and Q signals.

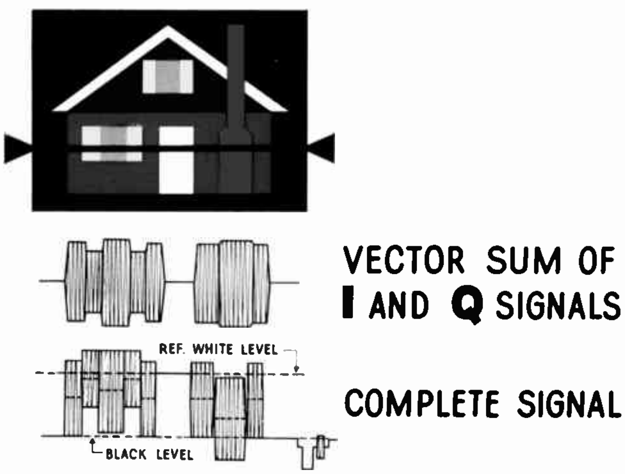


FIG. 16. Typical color image with vector sum of I and Q signals, together with composite waveform produced by adding all signal components.

it is possible to add the several components of the chrominance and monochrome signals together without causing objectionable mutual interference.

The significance of the straightforward addition of signal components made possible by frequency interlace may be brought out by a study of waveforms derived from a simple color image. Fig. 15 shows M, I, and Q signals after the latter two have been modulated upon 3.6 mc subcarriers. Note that both the I and Q signal components are at zero during the scanning of the white door, a neutral area. Fig. 16 shows the vector sum of the I and Q signals, and also the complete compatible color signal formed by adding together all the components, including synchronizing pulses and color synchronizing bursts. The most significant thing about this signal is that it is still capable of providing good service to monochrome receivers, even though a modulated wave has been added to the monochrome signal component. Although the modulated wave is clearly a spurious signal with respect to the operation of the kinescope in a monochrome receiver, its interference effects are not objectionable because of the application of the frequency interlace principle.

The frequency interlace technique is based on two factors—a precise choice of the color subcarrier frequency, and the familiar "persistence of vision" effect. By making the color subcarrier an odd multiple of one-half the line frequency, its apparent polarity can be made to reverse between successive scans of the same area in the picture. Since the eye responds to the average stimulation after two or more scans, the interference effect of the color subcarrier tend to be self-canceling, due to the periodic polarity reversals. See Fig. 17.

Color Frequency Standards

The relationships between the various frequencies used in a compatible color system are illustrated in the block diagram, Fig. 18. The actual frequency of the color subcarrier, which has been referred to as 3.6 mc, is specified by FCC standards as 3.579545 mc, or exactly 455 multiplied by ½ the line frequency.

In broadcast practice, the frequency of the color subcarrier provides a frequency standard for operation of the entire system. A crystal oscillator at the specified frequency provides the basic control information for all other frequencies. Counting stages and multipliers derive the basic frequencies needed in the color studio. A frequency of nominally 31.5 kc is required for the equalizing pulses which precede and follow each vertical sync pulse, and for the serrations in the vertical sync pulse. A divide-by-two counter controlled by the 31.5 kc signal provides the line frequency pulses at nominally 15.75 kc needed to control the horizontal blanking and synchronizing waveforms. Another counter chain provides the 60-cycle pulses needed for control of the vertical blanking and synchronizing circuits.

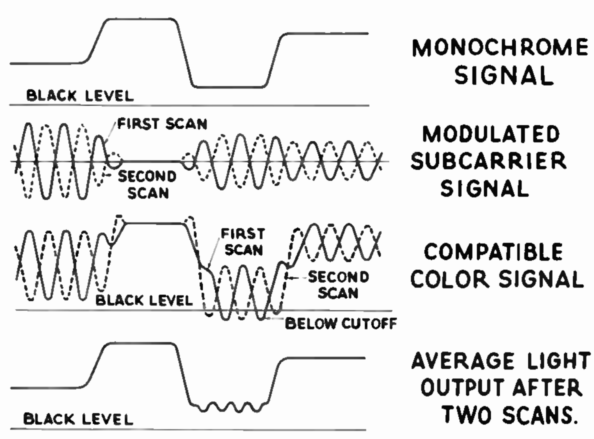


FIG. 17. Waveforms showing superposition of modulated subcarrier on scanning signals, compatible color signal, and effect of subcarrier on average light output.

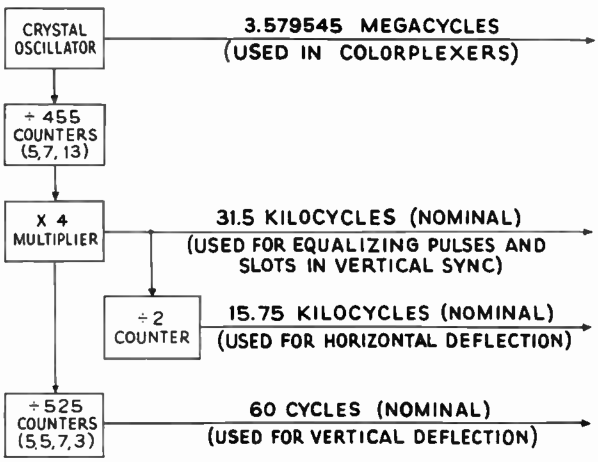


FIG. 18. Block diagram showing relationship between various frequencies used in color television station.

The synchronizing waveform adopted by the Television Committee of the Radio Electronics Television Manufacturers Association* is illustrated in the Appendix.

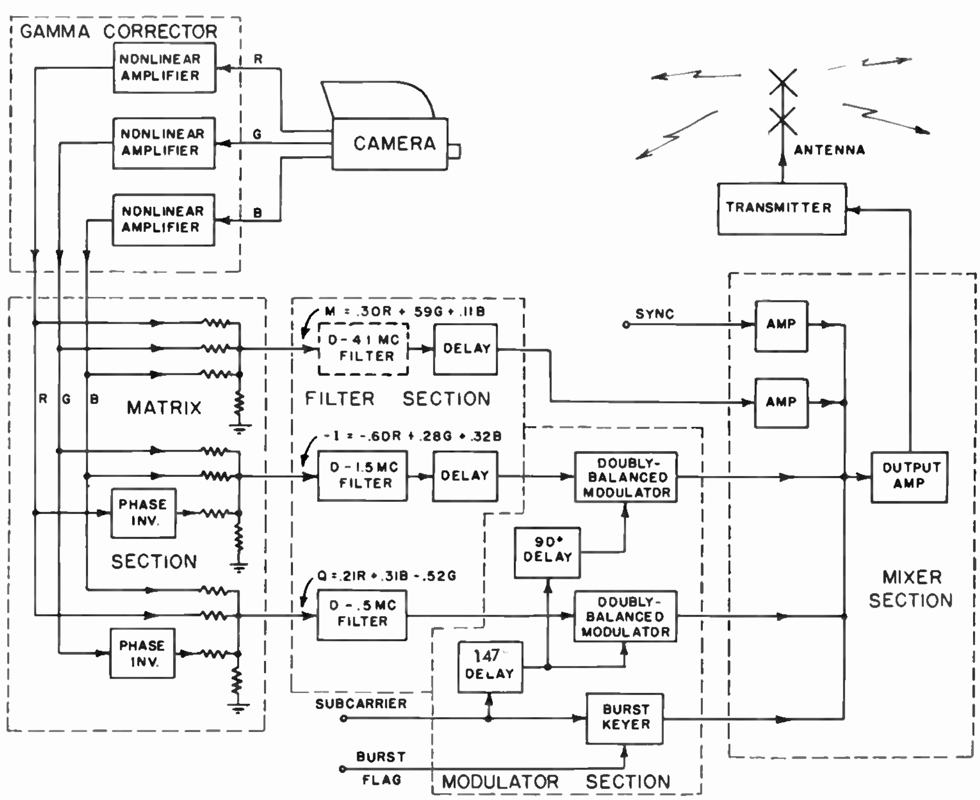
The Overall Color System

The major functions performed in transmitting and receiving color are shown in the overall block diagrams of the transmitting and receiving systems, Figs. 19 and 20.

At the transmitting end, camera output signals corresponding to the red, green and blue components of the scene being televised are passed through non-linear amplifiers (the gamma correctors) which compensate for the non-linearity of the kinescope elements at the receiving end. Gamma-corrected signals are then matrixed to produce the luminance signal M, and two chrominance signals I and Q. The filter section establishes the bandwidth of these signals. The 4.1 mc filter for the luminance channel is shown in dotted lines because in practice this bandshaping is usually achieved by the

* Now known as: Electronic Industries Association.

FIG. 19. Block diagram showing major functions of color transmitting system.



attenuation characteristics of the transmitter, and the filter is not required.

The bandwidths of 1.5 mc and .5 mc shown for the I and Q channels, respectively, are nominal only—the required frequency response characteristics are described in more detail in the complete FCC signal specifications. Delay compensation is needed in the filter section in order to permit all signal components to be transmitted in time coincidence. In general, the delay time for relatively simple filter circuits varies inversely with the bandwidth—the narrower the bandwidth, the greater the delay. Consequently, a delay network or a length of delay cable must be inserted in the I channel to provide the same delay introduced by the narrower-band filter in the Q channel, and still more delay must be inserted in the M channel.

In the modulator section, the I and Q signals are modulated upon two subcarriers of the same frequency but 90° apart in phase. The modulators employed should be of the doubly-balanced type, so that both the carriers and the original I and Q signals are suppressed, leaving only the sidebands. Some sort of keying circuit must be provided to produce the color synchronizing bursts during the horizontal blanking intervals. To comply with the FCC signal specifications, the phase of the burst should be 57° ahead of the I component (which leads the Q component by 90°). This phase position was chosen mainly because it permits certain simplifications in receiver designs. Timing information for "keying in" the burst may be obtained from a "burst flag generator", which is a simple arrangement of multivibrators controlled by horizontal and vertical drive pulses.

In the mixer section, the M signal, the two subcarriers modulated by the I and Q chrominance signals, and the color synchronizing bursts are all added together. Provision is also made for the addition of standard synchronizing pulses, so that the output of the mixer section is a complete color television signal containing both picture and synchronizing information. This signal may then be put "on the air" by means of a standard television transmitter, which must be modified only to the extent necessary to assure performance within the reduced tolerance limits required by the color signal. (Since the color signal places more information in the channel than a black-and-white signal, the requirements for frequency response, amplitude linearity, and uniformity of delay time are more strict.)

The Color Receiving System

In a compatible color receiver, the antenna, r-f tuner, i-f strip, and second detector serve the same functions as the corresponding components of a black-and-white receiver. Thus, up to the second detector, the color receiver is no different from a black-and-white receiver except that the tolerance limits on performance are somewhat tighter.

The signal from the second detector is utilized in four circuit branches. One circuit branch directs the complete signal toward the color kinescope, where it is used to control luminance by being applied to all kinescope guns in equal proportions. In the second circuit branch, a band-pass filter separates the high-frequency components of the signal (roughly 2.0 to 4.1 mc) consisting mainly of the two-phase modulated subcarrier signal. This signal is applied to a pair of modulators which operate as synchronous detectors to recover the original I and Q signals. It should be noted that those frequency components of the luminance signal falling between about 2 and 4.1 mc are also applied to the modulators, and are heterodyned down to lower frequencies. These frequency components do not cause objectionable interference, however, because they are frequency-interlaced and tend to cancel out through persistence of vision.

The remaining two circuit branches at the output of the second detector make use of the timing or synchronizing information in the signal. A conventional sync separator is used to produce the pulses needed to control the horizontal and vertical deflection circuits which are also conventional. The high voltage supply for the kinescope may be obtained either from a "fly-back" supply associated with the horizontal deflection circuit or from an independent r-f power supply. Many color kinescopes require convergence signals to enable the scanning beams to coincide at the screen in all parts of the picture area; the waveforms required for this purpose are readily derived from the deflection circuits.

The final branch at the output of the second detector is the burst gate, which is turned "ON" only for a brief interval following each horizontal sync pulse by means of a keying pulse. This pulse may be derived from a multivibrator controlled by sync pulses, as illustrated or it may be derived from the "flyback" pulse produced by the horizontal output stage. The separated bursts are amplified and compared with the output of a local oscillator in a phase detector. If there is a phase difference between the local signal and the bursts, an error voltage is developed by the phase detector. This error voltage restores the oscillator to the correct phase by means of a reactance tube connected in parallel with the oscillator's tuned circuit. This automatic-frequency-control circuit keeps the receiver oscillator in synchronism with the master subcarrier oscillator at the transmitter. The output of the oscillator provides the reference carriers for the two synchronous detectors; a 90° phase shifter is necessary to delay the phase of the Q modulator by 90° relative to the I modulator.

There is a "filter section" in a color receiver that is rather similar to the filter section of the transmitting equipment. The M, I, and Q signals must all be passed through filters in order to separate the desired signals from other frequency components which, if unimpeded, might cause spurious effects. The I and Q signals are

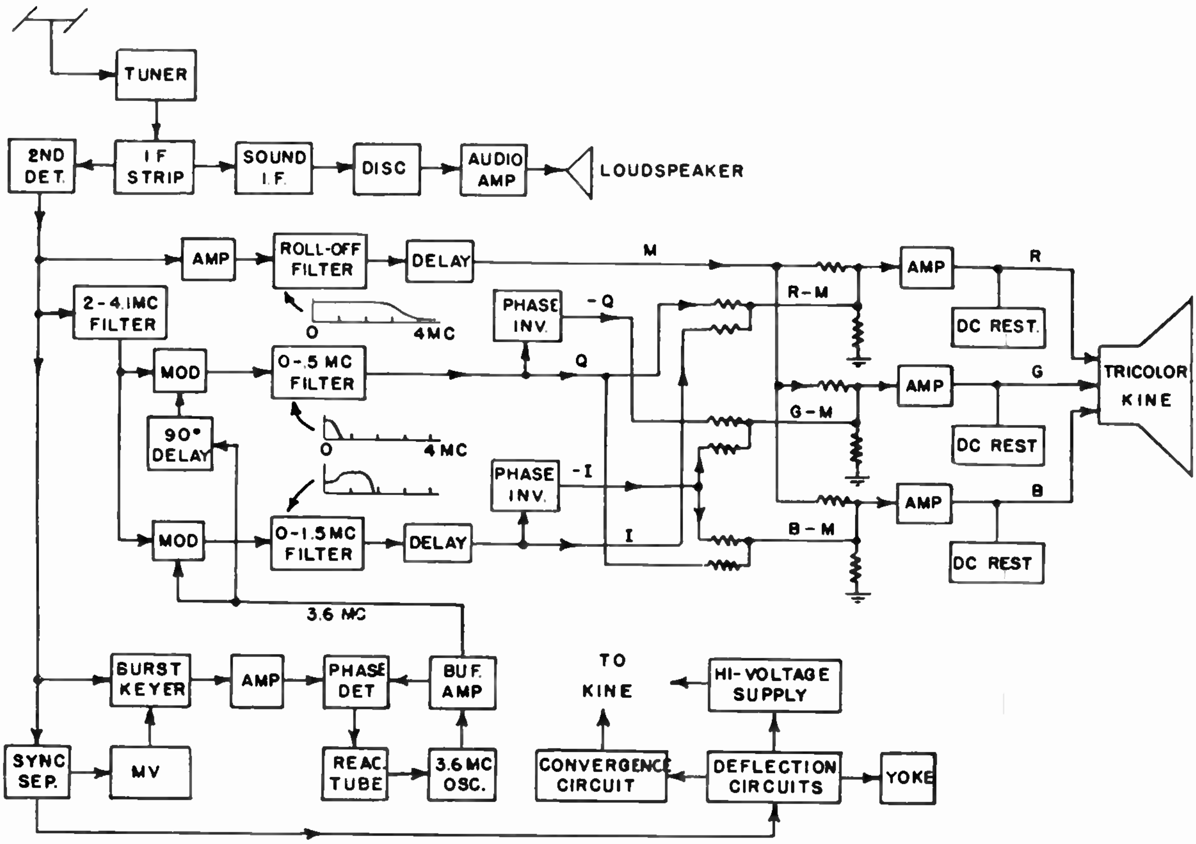


FIG. 20. Block diagram showing major functions of color receiving system.

passed through filters of nominally 1.5 and .5 mc bandwidth, respectively, just as at the transmitting end. A step-type characteristic is theoretically required for the I filter, as indicated by the spectrum sketch, to compensate for the loss of one sideband for all frequency components above about 0.5 mc. Actually, this requirement is ignored in many practical receiver designs, resulting in only a slight loss in sharpness in the I channel. A roll-off filter is desirable in the M channel to attenuate the subcarrier signal before it reaches the kinescope. The subcarrier would tend to dilute the colors on the screen if it were permitted to appear on the kinescope grids at full amplitude. Delay networks are needed to compensate for the different inherent delays of the three filters, as explained previously.

Following the filter section in the receiver there is a matrix section in which the M, I, and Q signals are cross-mixed to recreate the original R, G, B signals. The R, G, B signals at the receiver are not identical to those at the transmitter because the higher frequency components are mixed, and are common to all three channels. This mixing is justifiable, because the eye cannot perceive the fine detail (conveyed by the high-frequency components) in color. There are many possible types of matrixing circuits; the resistance mixers shown provide one simple and reliable approach. For ease of analysis, the matrix operations at the receiver may be considered in two stages. The I and Q signals are first cross-mixed to produce R-M, G-M, and B-M signals (note that *negative* I and Q signals are required in some cases), which are, in turn, added to M to produce R, G, and B.

In the output section of the receiver, the signals are amplified to the level necessary to drive the kinescope, and the dc component is restored. The image which appears on the color kinescope screen is a high-quality full-color image of the scene before the color camera.

It should be made clear that the block diagram used for illustration is intended only to illustrate the principles used in color receivers, and does not represent any specific model now on the market. Color receiver design engineers have shown great ingenuity in simplifying circuits, in combining functions, and in devising subtle variations in the basic process which have made possible significant cost reductions while maintaining excellent picture fidelity. The principles of compatible color television are firmly established, and it is to be expected that steady progress will be made in the practical application and requirement of those principles.

PART 3

Color Fidelity

"Color fidelity," as used in this Part, is the property of a color television system to reproduce colors which are *realistic* and *pleasing* to the average viewer.

Although perhaps not apparent at first, color fidelity is analogous to "high fidelity" as applied to sound reproduction. Just as a high-fidelity audio system faithfully reproduces sounds reaching the microphone, the color television system is capable of faithfully reproducing colors as seen by the television cameraman. In fact, the color television system is capable of reproducing colors more accurately than techniques presently used in color printing and color photography.

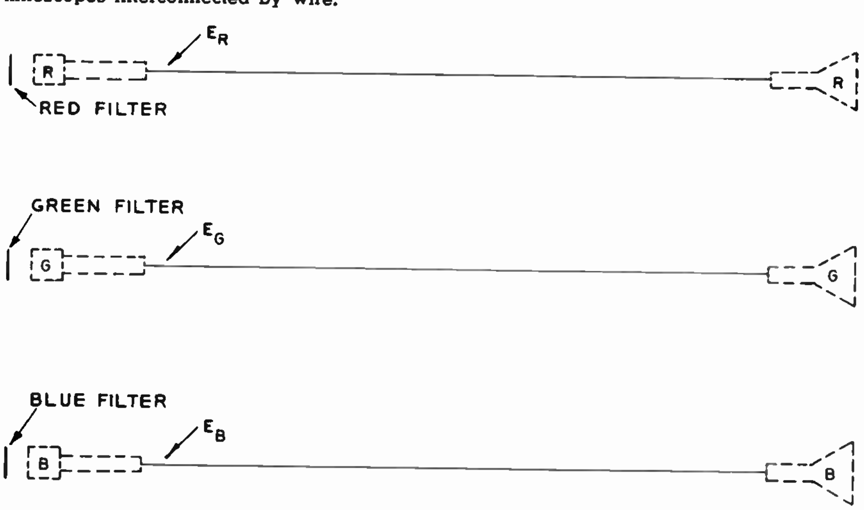
Tests have shown, however, that color television pictures are generally more pleasing to the viewer when deliberate modifications are made in the reproduced colors to compensate for the surroundings in which they are reproduced. The situation is similar to that experienced in the art of sound reproduction, in the case of a symphony orchestra recorded at high sound levels in a large hall and reproduced at lower sound levels in a small room. In this case, a more pleasing effect is obtained if the ear's new environment is taken into consideration and the reproduction modified accordingly. Similarly, in color television, the changed environment of the eye must be considered, and the reproduced colors modified accordingly.

Color fidelity, therefore, is a term used to indicate a color reproduction which pleases the viewer esthetically, and convinces him that he is viewing an accurate reproduction of the original colors in the scene being televised.[1]

This Part describes possible distortions in the color system and their effect on the picture, and prescribes amounts or degrees of distortion that can be tolerated without adverse effects on picture quality.

[1] A detailed discussion of colorimetry and perception, and how these factors affect the viewer, is presented in "Color Television Engineering" by John W. Wentworth. (published by McGraw-Hill Book Company, New York.)

FIG. 1. Diagram of a theoretical color system showing linear R-G-B pickup tubes and kinescopes interconnected by wire.



Color System Analysis

Individual elements or areas of the complete color system are discussed in the following paragraphs with the aid of the diagrams shown in Figs. 1 through 5.

Fig. 1 is a theoretical color system in that it assumes linear camera tubes and kinescope interconnected by a distortionless wire system. The only distortion that can result from this system is a flaw in colorimetry.

Fig. 2 introduces linearity correctors to compensate for color errors produced by non-linearities in the transducers.

Figs. 3, 4 and 5 successively introduce the complexities of *matrixing, bandlimiting, delay compensation,* and the *transmission system* (shown dotted in Fig. 5). These diagrams, each representing a possible color system, introduce techniques used in compatible color television, and permit the study of color distortions peculiar to each technique.

The systems diagrammed in Figs. 1 and 2 are described under "Possible Distortions in Transducers," and those in Figs. 3, 4 and 5 under "Possible Distortions in Encoding and Decoding Processes." The system shown in Fig. 5 is discussed under "Distortions in the Transmission System."

Characteristics of the Eye

To fully appreciate the significance of color fidelity, it is helpful to consider some of the characteristics of the eye associated with color perception, and to analyze

FIG. 2. The basic color system shown with necessary linearity correctors to compensate for color errors introduced by the non-linear transducers.

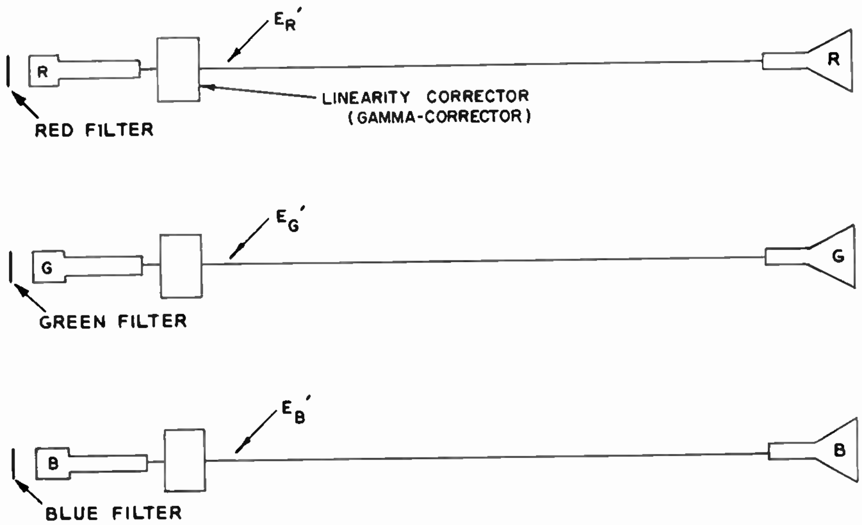
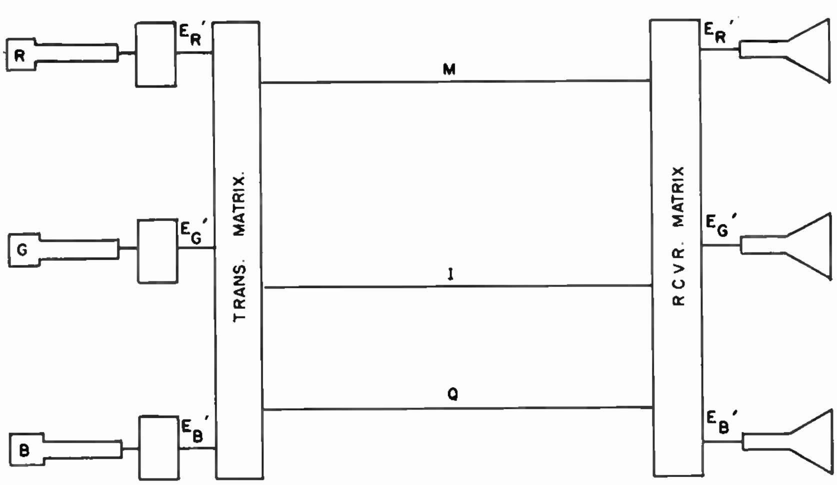


FIG. 3. Diagram showing transmitter and receiver matrix functions in the color system.



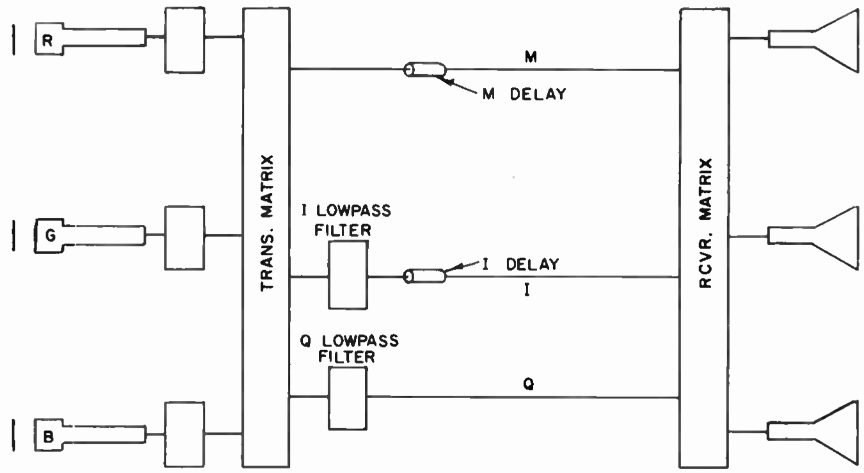


FIG. 4. Basic color system with bandlimiting and delay compensation.

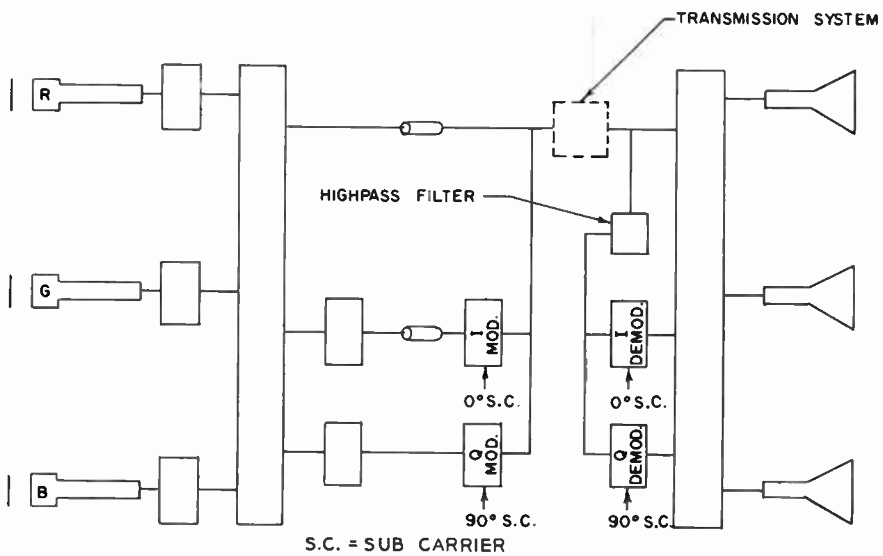


FIG. 5. Basic color system showing all major elements, including the transmission system.

such terms as color adaptation, reference white, and primary colors, and determine their relationship to a color television system.

Color Adaptation

One amazing characteristic of the eye is the phenomenon known as *color adaptation*. It is this adaptation which enables one to describe accurately the color of an object under "white" light, while viewing it in non-"white" light. That is to say, recognition of color is surprisingly independent of the illumination under which an object is viewed. For example, if sunlight at high noon on a cloudless day is taken as "white" light, then, by comparison, the illumination from a typical 100-watt incandescent bulb is very yellow light. Yet, it is known that an object viewed under sunlight looks very little if any different when viewed under incandescent light. Moreover, it is obvious to the observer, after a very few minutes in a room illuminated with incandescent lights, that the light is not yellow at all; it is really "white."

It is apparent, then that the color seen by an observer is dependent upon the illumination to which that observer has been exposed for the past several minutes. This ambient illumination will have a marked effect on his choice of what color he is going to call "white."

This phenomenon can cause a loss of color fidelity under certain conditions. Consider, for example, a theoretically perfect color system with camera viewing an outdoor scene under a mid-day sun, while the reproduced picture is being viewed in a semi-darkened room, with what little light is in the room also being derived from the mid-day sun. Under these conditions, the ambient illuminations at both camera and receiver are identical, so a man standing alongside the camera and a man viewing the receiver would both see the same colors. Now, if a change in the weather at the camera location should cause a cloud to cover the sun, the ambient illumination at the camera location would shift toward a bluer color. This shift would not disturb the viewer standing alongside the camera, because his eyes, bathed in the new ambient light, would rapidly adapt to the new viewing conditions, and he would perceive the scene as being unchanged.

The man viewing the receiver would not be so fortunate. Assuming that he is far enough away that this same cloud would not affect his ambient, he would observe that everything on his screen had suddenly and inexplicably taken on a bluish cast, which he would certainly find most disturbing.

Such errors in color fidelity can always be corrected by making the camera imitate the human eye in adaptation. The eye adapts to changes in ambient illumination by changing its sensitivity to a certain color. For example, if a light source changes from "white" to blue-white (as in the above example), the eye reduces its blue sensitivity until the light again appears to be white to the observer. Likewise, a camera operator may correct for the same situation by decreasing the gain of the blue channel of the camera, or by attenuating the light reaching the blue camera tube. In this way, the camera is made to "color-adapt," and the reproduced picture on a receiver loses its bluish cast.

Reference White

Although color adaptation can generate a problem such as the one just described, it also simplifies certain requirements. Specifically, it eases the requirement that "white" be transmitted as a definite, absolute color, for there clearly can be no absolute "white" when almost any color can be made to appear subjectively white by making it the color of the ambient illumination to which an observer's eye has adapted.

In color television, we take advantage of this characteristic in the following manner: A surface in the studio which is known by common experience to be "white"—such as a white shirt or a piece of paper—is selected to be reproduced as white on a home receiver. The relative sensitivities of the three color channels of the camera are then adjusted so that the camera "adapts" to this white—*regardless of the studio illumination.* The home receiver can then be adjusted to reproduce the surface as any "white" which the home viewer prefers, depending upon his surroundings. In the average home-viewing situation, a strong viewer preference has been shown for a bluish-white at the receiver; a subjective effect of freshness, newness, and crispness is conveyed by this "white." Therefore, a hue of this type is the common choice for reference white in the home.

It is interesting to note that the studio illumination is commonly the yellow-white of incandescent lighting; hence, a white object in the studio would appear considerably different from its image in the home. It would be possible to adjust the home receiver to reproduce the object with its "proper" whiteness, but this adjustment would result in a yellowish reference white which the viewer would find displeasing. The surprising fact appears, therefore, that *absolute* color fidelity in a reproduced picture is usually undesirable.

The change in reference white between studio and home must inevitably produce errors in all reproduced colors, but the errors are small and, more important, tend to be subjectively self-correcting, so that any given object will tend to produce the same color sensation whether viewed in relation to the studio reference white or the home reference white.

Consequently, a viewer may become familiar with an object such as a sponsor's packaged product and will recognize it either on his television screen, or under the fluorescent lighting of his supermarket, or under the incandescent lighting of his home, and furthermore, will note no difference in the colorimetric values of the package under the three conditions, even though the absolute colorimetric values would be appreciably different in the three situations.

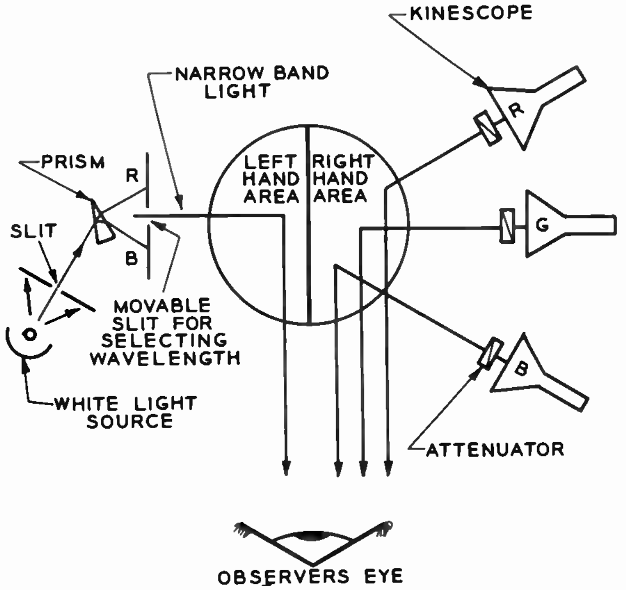


FIG. 6. Diagram showing laboratory setup arranged to compare narrow-band light source and R, G and B light produced by kinescopes to determine proper camera-filter color characteristics.

Primary Colors

Of all the characteristics of the eye, there is perhaps none more fundamental to practical color television than that characteristic which allows us to choose certain colors, called *primary* colors, and from these synthesize almost any other desired color by adding together the proper proportions of the primary colors. If it were not for this characteristic, each hue in a color system would have to be transmitted over a separate channel; such a system would be too awkward to be practical. Because of the eye's acceptance of synthesized colors, it is possible to provide excellent color rendition by transmitting only the three primary colors.

POSSIBLE ERRORS IN TRANSDUCERS

The block diagram of Fig. 1 shows a fundamental color television system using red, green, and blue primaries and three independent transmission channels. The camera tubes and kinescopes are shown dotted to indicate that any inherent nonlinearities in these devices are to be disregarded, for the moment, to simplify the discussion of the colorimetry of the system.

The general plan in a system such as that of Fig. 1 is to provide the three kinescopes with red, green, and blue phosphors, respectively, and to allow the corresponding camera tubes to view the scene through an appropriate set of red, green and blue filters. If a phosphor and a filter have the same dominant wavelength—that is, if they appear to the eye to be the same color—it might be mistakenly supposed that they would be colorimetrically suited to be used as a filter and phosphor set for the channel handling that color. Actually, the basis for choosing filters and phosphors is much more complex, and is based on the *shape* of the filter's response curve, plotted against wavelength, and the shape of the phosphor's light output curve, also plotted against wavelength. The following paragraphs will discuss briefly a technique which might be used to determine the required relationship between the phosphor curves and the filter curves.

The phosphor's color characteristics are generally less easily changed than are filter characteristics; for this reason phosphors' characteristics are taken as the starting point, and the filters' characteristics are determined from them. A laboratory set-up which could be used to determine these characteristics is shown in Fig. 6. In this figure, an observer (who must have "normal" vision) is viewing simultaneously two adjacent areas, one of which is illuminated by a source of single-wavelength light which can select any wavelength in the visible spectrum; the other of which is illuminated by a red kinescope, a green kinescope, and a blue kinescope. The phosphors of these kinescopes are the phosphors which are to be used in the color system. Starting at, say, the red end of the spectrum, a single-wavelength red is selected to illuminate the left-hand area, and the light from each

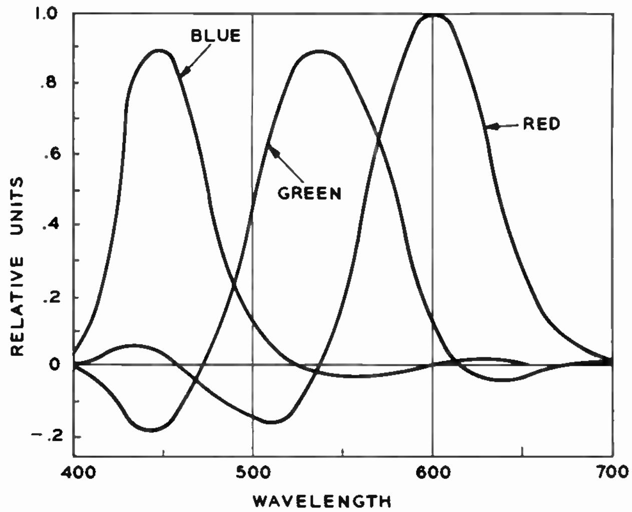


FIG. 7. Curves showing relative quantities in camera output required to produce correct kinescope colors over the visible spectrum.

of the three phosphors is varied until a color match is obtained between the left-hand and right-hand areas. The respective amounts of red, green, and blue lights needed to accomplish this match are recorded. Then another wavelength is chosen, the kinescope outputs varied to produce a match, and the new amounts of red, green, and blue needed for a match are recorded. Similarly, points are obtained throughout the entire spectrum, and a graph is plotted showing the various required outputs versus wavelength. The shapes of these three curves—one for red, one for green, and one for blue—are the required shapes for the three camera-filter response curves. The resulting curves would in general resemble Fig. 7.

(To simplify the above discussion it was assumed that the camera tubes responded equally well to all wavelengths. In practice, camera tubes show higher output at certain wavelengths than at others. The filter-response curves derived by the above technique would have to be modified so that the *combined* response of filter and camera would be correct.)

Certain practical difficulties could result in errors in the above procedure. For example, if the observer had any deviations from normality in his color-vision characteristics (as most people do), these deviations would result in "non-standard" matches, and hence, improper camera-filter characteristics. Also, if the phosphors were contaminated in any way during their manufacturing process, (as most phosphors are, at least to some small degree), the resulting phosphor characteristics would not be the proper ones, and hence would give rise to improper camera-filter characteristics. The observer errors may be normalized out by standard colorimetric procedures, but phosphor errors represent a basic error which may possibly be present not only in the above experiment but also in varying degrees in a large number of receivers. Quality control of phosphor manufacture is sufficiently good, however, to make the net effect unnoticeable in home receivers.

A striking practical difficulty would also arise regardless of observer or phosphor errors. For most wavelengths, no combination of red, green, and blue kinescope outputs could be found which would produce a match. In order to obtain a match at these wavelengths, it would be necessary to move one or two of the kinescopes over to the other side, so that they could add their light to the single-wavelength light being matched. This procedure can be described mathematically, for graphing purposes, by saying that *adding* light to the left-hand area is the same as *subtracting* that light from the right-hand area. Therefore, the amount of light added on the left would be considered as a negative quantity, and would result in a point below the axis on the graph. Since this condition would be found to exist for several successive wavelengths, the resulting graph would show one or more minor lobes *below* the axis. These are called *negative lobes.*

These negative lobes represent a need for filters with negative light transmission characteristics at certain wavelengths. Simple attenuating filters cannot yield such a characteristic; much more elaborate means would be required. However, it has been shown that excellent color fidelity can be obtained by ignoring the negative lobes, and using filters which yield the positive lobes only. Positive-lobe processes such as color photography have gained wide acceptance for years; the RCA TK-41 Color Camera, which also ignores the negative lobes; has shown by its widespread use and approval that this approach to the problem is both practical and sensible. In short, the contribution of the negative lobes is so small that any means for giving effect to them must be comparatively inexpensive to justify its use. Further advances in the art may provide such a device.

Nonlinearities in the Transducers

The assumption made in Fig. 1 of a system comprised of perfectly linear devices and circuits was convenient for the discussion of colorimetry, but since any practical system is always found to be more or less nonlinear, further discussion must take into account this non-linearity. In this section we shall discuss the inherent non-linearities of camera tubes and kinescopes, the effects of these non-linearities on the reproduced picture, and the use of conversely-non-linear amplifiers to correct for the camera-tube and kinescope characteristics.

Transfer Characteristics

A piece of window glass is perhaps the nearest approach to a perfect video system. For a piece of glass, the light output (to the viewer) is essentially identical to the light input (from the scene). This fact is shown graphically in Fig. 8. This plot could be called the "transfer characteristic" of a piece of glass, since it describes the way that light is transfered through the system.

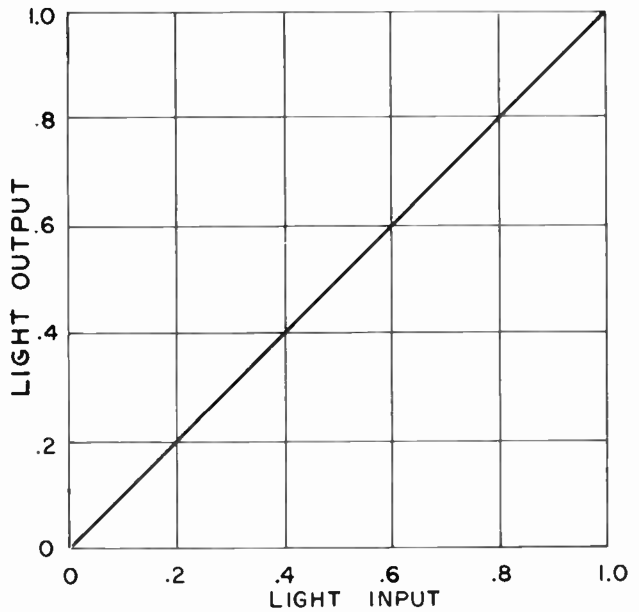


FIG. 8. Curve showing light transfer characteristics of a perfectly transparent piece of window glass.

If the window glass is replaced by a neutral-density filter which attenuates light three-to-one, the transfer characteristic will then be given by Fig. 9. The difference between Figs. 8 and 9 can be described by these simple relationship:

For the glass:
(Light output) = (Light input)

For the neutral-density filter:
(Light output) = k × (Light input)
where $k = 1/3$, in this case

Both systems are linear; that is, doubling the light input of either will double its light output; tripling input will triple output; etc. A *non*-linear system does not exhibit this simple proportionality. For example, consider a system described by

$$(\text{Light output}) = k \times (\text{Light input})^2$$

Doubling the input to this system will *quadruple* its output; a three-fold increase in input will result in a *nine*-fold increase in output; etc. The transfer characteristic for this type of system is shown in Fig. 10 Note that the characteristic is definitely non-linear; that is, it is not a straight line as were Figs. 8 and 9.

In television and photography, non-linearity is more common than linearity. For example, an ordinary kinescope is a non-linear device, having a transfer characteristic which may be approximated by the expression

$$(\text{Light output}) = k\ (\text{voltage input})^{2.2}$$

Camera tubes also are usually non-linear devices. For example, the characteristic of a vidicon is approximately

$$(\text{current output}) = k\ (\text{light input})^{0.65}$$

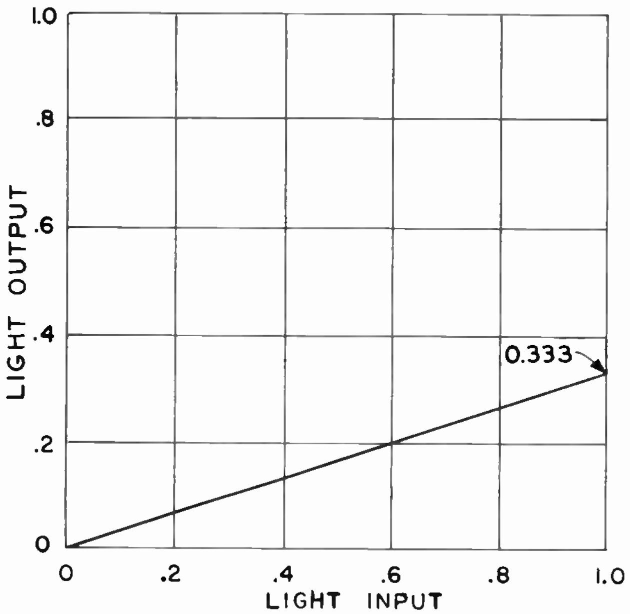


FIG. 9. Curve showing transfer characteristic of a neutral density filter with three-to-one light attenuation.

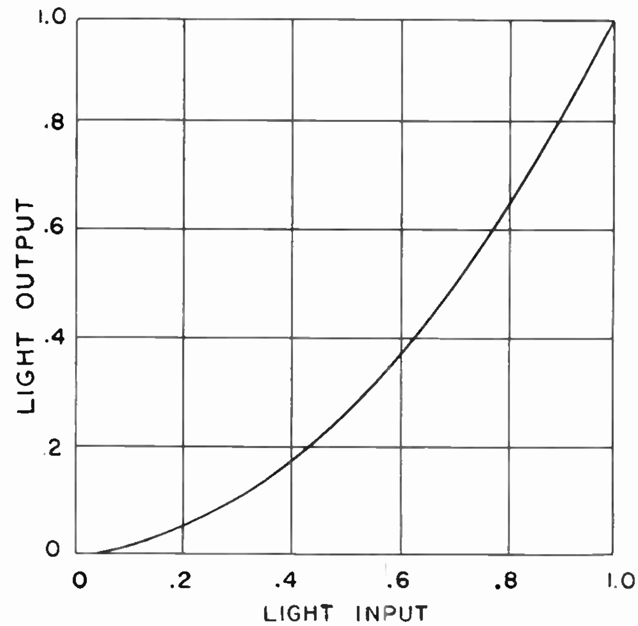


FIG. 10. Curve showing a non-linear transfer characteristic.

The general expression for a non-linear transfer charracteristic can be given approximately as

> (Output) = k (Input)$^{\gamma}$, where the exponent is the greek letter *gamma*.

Graphical Displays of Transfer Characteristics

Linear Plots: The first reaction of any person asked to display two variables (like light input and light output) on a set of X-Y coordinates is to divide X and Y coordinates into equal increments and plot the variables in this manner. A typical result of such a plot has already been described (Figs. 8 and 9). Such a plot has the advantage of showing at a glance the linearity of the device described by the variables. If the plot is a straight line, we say the device is linear; if curved, we say the device is non-linear. Moreover, the slope of the line describes the attenuation (or gain) of the device. If the slope is unity (which occures when the plot makes a 45° angle with the X-axis), there is no attenuation; we are dealing with a very good piece of glass. For the neutral-density filter described above, which has the equation (light output) = $^1/_3$ (light input), the line has a slope of one-third (see Fig. 9).

Such are the advantages of plotting transfer characteristics with equal-increment divisions of the X and Y axis. However, other advantages—very important ones —can be obtained by dividing up the X and Y coordinates logarithmically. Such a plot is called a log-log plot.

Log-Log Plots: Consider a system which has a transfer characteristic given by $L_o = (L_{in})^{2.2}$. If this equation is plotted on axes which are divided logarithmically, the resulting plot is the same as though the logarithm of both sides of the equation were plotted on equal-increment axes. Taking the logarithm of both sides, we obtain

$$\log L_o = \log (L_{in})^{2.2}$$

Since $\log (L_{in})^{2.2}$ is the same as $2.2 \log (L_{in})$, then

$$\text{Log} (L_o) = 2.2 \log (L_{in})$$

Comparing the form of this equation with an earlier equation, light output = $^1/_3$ (light input), we can see that just as the attenuation, $^1/_3$, was the slope of the earlier equation, so 2.2, the exponent, is the slope of the later equation. We see, then, that the use of logarithmically divided coordinates yields a plot in which the *exponent* is given by the slope of the line. Therefore, this plot will show at a glance the magnitude of the exponent, and will also show whether or not the exponent of the system is constant, for all light levels. It also is advantageous in showing the effects of stray light.

Figures 11a and 11b on the following page, compare the two types of plotting for three types of transfer characteristics.

The Effect of a Non-Linear Transfer Characteristic on Color Signals

Effect of Identical Non-linearities in Each Channel: In monochrome television, some degree of non-linearity may be tolerated, but such is not the case for a color television system. It can be shown that a system exponent different from unity must inevitably cause a loss of color fidelity. For an example, consider a situation in which signals are being applied through linear amplifiers to the red and green guns of a perfectly linear (theoretical) kinescope. The green amplifier is receiving

1.0 volt; the red amplifier, 0.5 volt. If everything is perfectly linear, the proportions of the light output should be 1.0G + 0.5R = a greenish-yellow. However, if the kinescope has an exponent of 2.0, the light output will be $(1.0)^2G + (0.5)^2R = 1.0G + 0.25R$ = greenish yellow with an excess of green.

From the above specific case, it may be correctly inferred that in general, a system exponent greater than 1 will cause all hues made of the combination of two or more primaries to shift toward the larger or largest primary of the combination. Conversely, a system exponent less than 1 will shift all hues *away from* the largest primary of the combination.

In the above example, an exponent of 0.5 would yield $(1.0)^{0.5}G + (0.5)^{0.5}R = 1.0G + .707R$ = a greenish-yellow which is just a shade off pure yellow.

In addition, the reader may correctly conclude that white or gray areas, in which all the primaries are equal, will not be shifted in hue by a non-unity exponent.

Effect of Differing Exponents in Each Channel: The preceding discussion assumed that all three channels (in Fig. 2) have the same exponent, whether unity or not. In practical systems, however, there is always the possibility that the exponents of the channels may differ from each other. This situation will produce intolerable color errors if the differences become even moderately large. In general, the requirements for "tracking" among the light-transfer characteristics of the individual channels are even more stringent that the requirement for unity exponent.

Figures 12a, b, c, and d, show graphically the effects of unequal exponents in the three channels. In all four figures, the red and blue exponents are taken as unity; in Figs. 12a and 12b the green exponent is taken as less than 1, and in 12c and 12d, as greater than 1. In Fig. 12a, the transfer characteristics are shown for the system adjusted to produce peak white properly. It can be seen that the bowed characteristic of the green channel will cause all whites of less than peak value to have too much green. A gray-scale step-tablet before the camera would be reproduced properly only at peak white; the gray steps would all have a greenish tinge. Relative channel gains could be readjusted to reproduce *one* of the gray steps properly (Fig. 12b), but then all highlight steps would be purplish, while lowlight steps would still be greenish.

A green-channel exponent greater than unity would reverse the above results. (Figs. 12c and 12d). With gains adjusted to reproduce peak white properly (Fig. 12c), lowlights would be purplish; with gains readjusted to provide proper reproduction for *one* of the lower steps (Fig. 12d), highlights would be green; lowlights, purple.

The Effect of Stray Light: If a kinescope is viewed in a lighted room, there will always be some illumination on the faceplate. Therefore, the eye will always receive some "light output" from the kinescope, regardless of the magnitude of the signal input voltage. Under this condition, a true black is impossible to obtain.

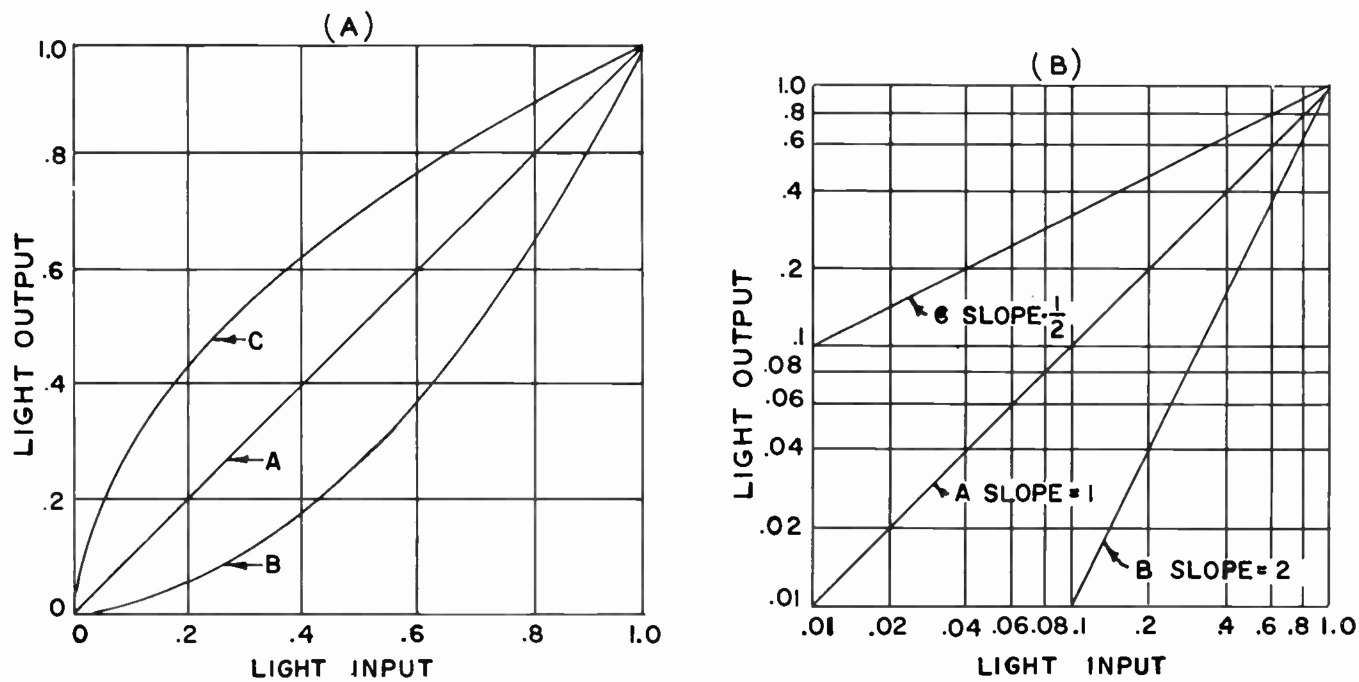


FIG. 11. Graphs showing the curves obtained by plotting A, B and C type transfer characteristics on linear coordinates (A) and on log-log coodinates (B).

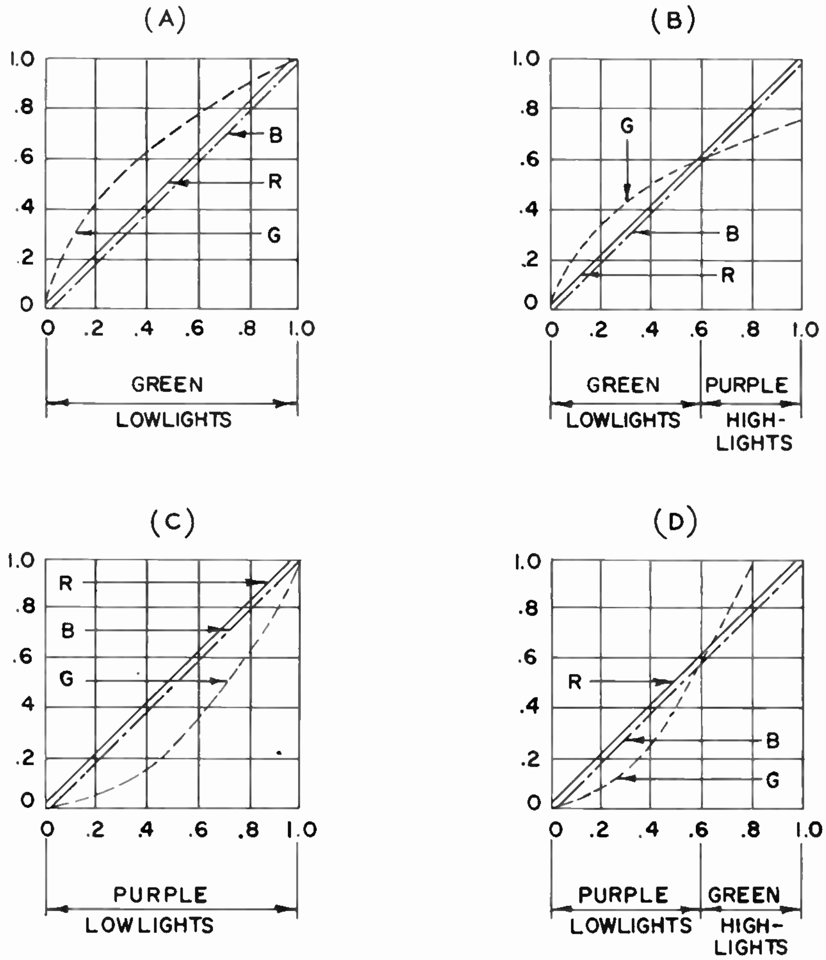


FIG. 12. Linear plots showing graphically the effect of unequal exponents in the R, G and B channels. In all four graphs the R and B exponents are taken as unity; in (a) and (b) the green exponent is taken as less than 1, and in (c) and (d), as greater than 1.

This condition is reflected in the transfer characteristic of the system. If, for example, the stray light were 5% of the peak highlight brightness of the picture, a *linear* plot of light output vs. light input would have the entire transfer characteristic shifted upwards by 5%. However, the most interesting change is found in the log-log plot, where, as seen in Fig. 13, the stray light causes a change in the *slope* in the low-light regions. Since the slope is equal to the exponent, this change shows that stray light causes an effective exponent error in the low-light regions of the picture and hence will cause color-fidelity errors which will be most marked in the low-light regions.

These errors will be noted by an observer as improper hues and saturations, with the saturation errors—a "washing-out" of the more saturated lowlight areas—being the more objectionable to a viewer.

Stray light is not the only cause of errors of this type. Similar effects will be noted whenever the kinescope bias ("brightness") is set too high, or if camera pedestal is set too high, or if stray light enters the camera (whether through lens flare or any other source). In general, any condition which prevents the system's light output from becoming zero when the light input is zero will cause errors similar to those caused by stray light.

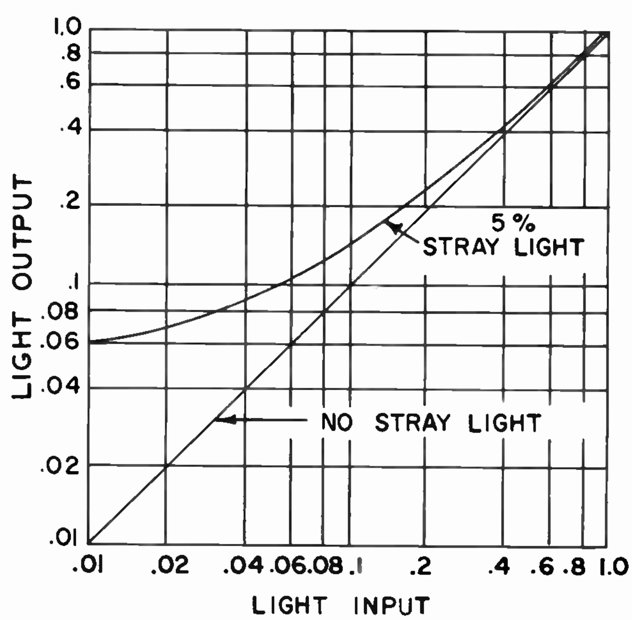


FIG. 13. Log-log plot of system with stray light, illustrating change of slope in the low light regions.

Linearizing a System: It can be shown that a system using a vidicon with an exponent of 0.65 to drive a kinescope with an exponent of 2.2 will have an overall exponent given by the product $0.65 \times 2.2 = 1.43$, assuming that all devices in the system are linear. In general, the overall exponent of a system is the product of the exponents of the cascaded elements.

This knowledge provides an excellent tool for linearizing a system. For example, a system with an overall exponent of 1.43 could be linearized by inserting *somewhere* (in a video path) an amplifier having an exponent of 1/1.43 (= 0.7), so that the product becomes unity: $1.43 \times 1/1.43 = 1$.

In Fig. 2, a non-linear amplifier or *gamma-corrector*, is shown inserted in each of the three paths.

POSSIBLE ENCODING & DECODING DISTORTIONS

The second of the two systems discussed in the preceding section bordered on being a practical system, but still required three independent 4-mc/sec channels. A fortunate characteristic of the human eye—the inability to see colored fine detail—allows us to modify this requirement to one 4-mc/sec channel for monochrome fine detail and two much narrower channels for color information. Before this modification can be made, the red, green, and blue signals must be combined to form three other signals, usually called M, I, and Q, such that the M signal alone requires a 4-mc/sec channel, and the I and Q channels, which contain the color information, are confined to narrower channels. This re-arrangement of red, green, and blue to form M, I, and Q is called *matrixing*, and was described in Part Two. A system which uses a matrix is block-diagrammed in Fig. 3. The illustration also shows that to recover the original red, green, and blue signals at the receiving end, a "re-rearranging" device is needed. This device is usually called the *receiver matrix*.

Matrixing alone offers no advantage, unless steps are taken actually to limit the I-signal and Q-signal channels to the narrow bandwidths allowed. Fig. 4 shows a system employing such bandshaping. The bandshaping filters themselves always introduce delay, which must be compensated for by placing delay lines in the wider band channels, as shown in the diagram.

To put both color and monochrome information in the spectrum space normally occupied by monochrome only requires that the color information overlap the monochrome. This overlap may be allowed for both I and Q signals, without incurring visible crosstalk, if two techniques, known as *frequency-interlace* and *two-phase modulation* are employed. A system using these techniques, which were described in Part Two, is block-diagrammed in Fig. 5.

Possible Errors in the Matrixing Process

The entire matrixing process can be summed up in two sets of equations: the first set describing how the transmitter matrix takes in red, green, and blue and turns out M, I, and Q:

$$M = 0.30R + 0.59G + 0.11B$$
$$I = 0.60R - 0.28G - 0.32B$$
$$Q = 0.21R - 0.52G + 0.31B$$

and the second set describing how the receiver matrix takes in M, I, and Q and recreates red, green, and blue:

$$R = 0.94I + 0.62Q + M$$
$$G = 0.27I + 0.65Q + M$$
$$B = 1.11I + 1.7Q + M$$

Both matrices can therefore be considered as analog computers which continuously compute the desired output from the given input. The co-efficients in the above six equations are usually determined in the "computers" by precision resistors, or, in the case of negative numbers, by precision resistors and signal-inverting amplifiers. The basic error that can occur, therefore, is a change in a resistor value or an amplifier gain, resulting in a change in one or more co-efficients. In general, the resulting picture error resembles crosstalk among the primary colors.

More specifically, the transmitter matrix can have two distinct types of errors. The first type involves the coefficients of the equation for M; the second type, the coefficients for I and Q. An error in an M coefficient will brighten or darken certain areas. In a monochrome reproduction of a color signal, such an error, if small, would not be noticed; if large, it would still likely be tolerated by the average viewer. In a color reproduction, however, even a small error would be objectionable. For example, a reduction of the red coefficient from 0.3 to 0.2 would cause a human face to be reproduced with an unnatural ruddy complexion and dark red lips.

Note that the sum of the M coefficients is 1. An error in one coefficient would change this sum, so that peak white would no longer occur at 1 volt. An operator could mistake this condition for a gain error and adjust either M gain or overall gain in an effort to obtain the correct peak-white voltage. Changing M gain would cause errors to occur in all M coefficients; changing overall gain would put errors in all coefficients. Although such an error is rare in well-engineered equipment, it is a possible source of color error which can be compounded by mis-directed attempts at correction.

Note that the sums of the Q and I coefficients are each zero, which means that when R = G = B, (the condition for white or gray), Q and I both equal zero. An error in a Q or I coefficient would cause color to appear in white or gray areas, and in addition, would cause general errors in colored areas, resembling crosstalk among the primaries. Controls are usually provided in the Q and I matrices, called *Q white balance* and *I white balance* respectively, which allow the operator to adjust the sum of the Q or I coefficients by changing the value of *one* of the coefficients. If the coefficient controlled is the one in error, adjusting white balance restores proper operation; if the controlled coefficient is *not* the one in error, then adjusting white balance restores the condition that the sum of the coefficients is zero—that is, it removes the color from white and gray objects—but it does so by giving the controlled coefficient an error which just counteracts the error of a non-adjustable coefficient, so that *two* coefficients are wrong, instead of one. Again, such an error is rare in well-engineered equipment, for the adjustable coefficient is usually the one in error. However, the possibility of an error compounded by adjustment should be kept in mind.

A far more likely cause of white-balance error is an error in input level; that is, a discrepancy between the peak white levels of input red, green, or blue. In such a case, an operator can still achieve white balance (Q and I = 0 for white input), but the entire system will be in error. The starting point for all investigations of the cause of white-balance errors should be the levels of the red, green and blue colorplexer inputs.

In the receiver matrix, only one general type of error can occur, instead of two as in the case of the transmitter matrix. This type of error, a general coefficient error, results in crosstalk among the primary colors. For example, a change in the I coefficient for the red equation from 0.94 to 0.84 would yield about a 7% reduction in the peak red output available, and would also result in unwanted red light output in green or blue areas, at about 3½% of the green or blue level.

Gain Stability of M, I, and Q Transmission Paths

In the system of Fig. 3, every gain device or attenuating device in the three transmission paths must maintain a constant ratio between its input and output, in order to maintain the proper ratios between the levels of M, I, and Q at the input to the receiver matrix. A variation in the gain of one of these paths will result in a loss in color fidelity.

For example, a reduction in M gain must obviously cause a reduction in the viewer's sensation of brightness. Not quite so obvious are the effects of I and Q gain. Since these are color signals, their amplitude would be expected to influence the sensation of saturation, but the manner of this influence is not intuitively obvious, until the factors which influenced the selection of I and Q compositions are recalled. In Part Two it was pointed out that the eye has the greatest need for color detail in the color range from orange to blue-green (cyan), and the least, in the range from green to purple. Hence I, the wider-band signal, conveys mainly orange and cyan information, and Q, the narrower-band signal, conveys principally the greens and purples. Therefore, a reduction in I gain could be expected to reduce the saturation sensation for colors in the orange and cyan gamut, leaving the greens and purples virtually unaffected. Conversely, Q gain will influence the greens and purples, without causing much change in the appearance of orange and cyan objects.

Modulation and Demodulation

The system of Fig. 4, which introduced bandwidth limiting of the I and Q signals in accordance with the capabilities of the eye to see colored fine detail, is a fairly practical and economical system, except for the fact that three individual transmission channels are employed. If we are to have a compatible system, however, these three channels must be reduced to one through some multiplexing technique. The technique used has already been described, and a system employing this technique is blocked-diagrammed in Fig. 5.

Possible Errors in Modulation

Burst phase error: Perhaps the most fundamental error in the multiplexing process would be an error in the phase of the main timing reference, burst. Since the entire system is based on burst phase, an error in burst phase will appear as an *opposite* error in every phase *except burst,* because the circuits will insist that burst phase cannot be wrong. The general result will be an overall hue error in the reproduced picture. This effect can be better visualized by referring to Fig. 14.

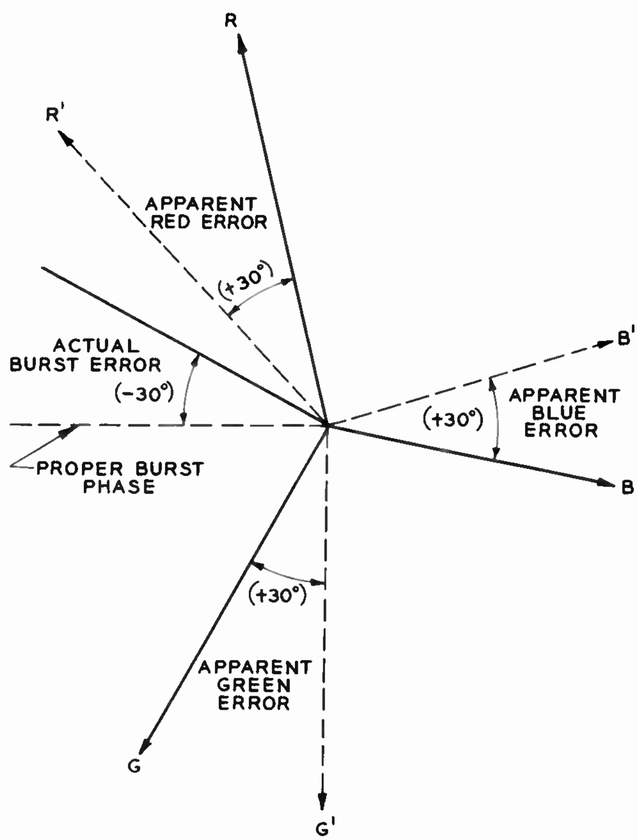


FIG. 14. Vector diagram showing how error in subcarrier phase becomes an opposite error in all other phases.

A phase error in burst produces the same result as holding burst phase stationary and allowing all other phases to slip around the circle an equal amount (but in a direction opposite to the burst-phase error). Each color "vector" then represents a hue other than the one intended.

Burst Amplitude Error

In theory, the receiver circuits which extract timing information from the burst are insensitive to variations in burst amplitude, so long as the burst is large enough to maintain a respectable signal-to-noise ratio, and not so large that some type of clipping or rectification upsets the burst circuitry. But practical receivers always exhibit some degree of sensitivity to burst amplitude, the amount of this sensitivity depending mainly upon the error in the subcarrier oscillator in the receiver. If the free-running frequency of the receiver oscillator is very different from burst frequency—particularly if the difference is so great that the burst is in danger of losing control of the oscillator—then a fairly appreciable amplitude sensitivity will be noted. This sensitivity will take the form of a phase error; the net result will be indistinguishable from a burst phase error, as discussed above.

Some receivers have a circuit which automatically adjusts the gain of the color-information channels so that the viewer always sees the proper saturations, regardless of errors which might tend either to "wash out" or to oversaturate the picture. Such a circuit, called an *automatic chroma control* (ACC), derives its control information from the ampltiude of burst, which is presumed to bear a constant ratio to the amplitude of chroma. Transmission distortions, for example, might decrease the amplitude of both burst and chroma, but since the *ratios* of their amplitudes would be preserved, an ACC-receiver could automatically modify its chroma-channel gain to compensate for the decreased chroma amplitude. However, if a colorplexer error should cause burst alone to decrease in amplitude, the ACC circuits would increase chroma gain just as in the above case, with the result that a viewer would receive an oversaturated picture.

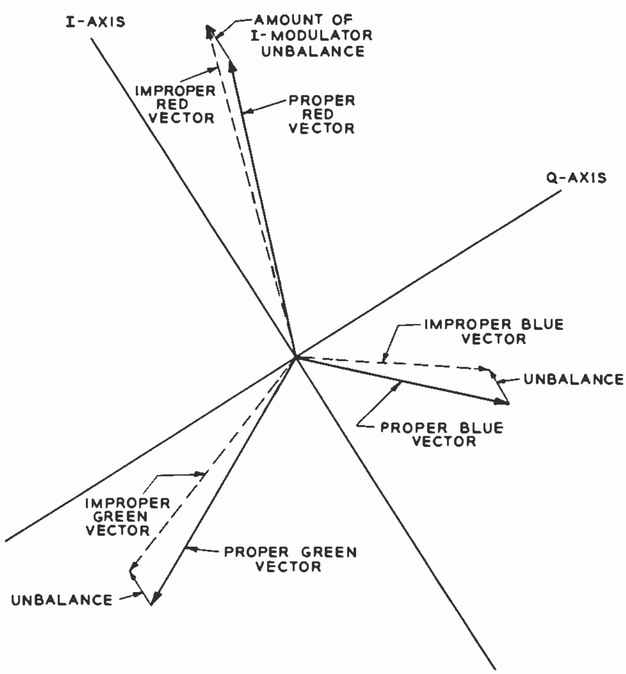


FIG. 15. Vector diagram of subcarrier phase and amplitude with positive vectors added to represent carrier unbalance in the I modulator.

Two-Phase Modulation Errors

The fidelity of color reproduction can be seriously affected if the phase separation of the Q and I subcarriers is not maintained at 90°. It can be shown that a "slip" in the angular position of the Q axis, for example, will result in crosstalk of Q and I. The final result will be the same as crosstalk among all the primary colors.

Likewise, in a receiver, the phase relationship between the reference subcarriers must be maintained to avoid a similar error. Any deviation from the proper phase relationship will have a result similar to the above; that is, crosstalk of I into Q or Q into I, with the net picture result resembling crosstalk among all the primary colors.

Carrier Unbalance

In a properly-operating doubly-balanced modulator, the carrier component of the signal is suppressed in the modulator circuit. If some error in components or operation causes this suppression to be imperfect, the carrier will appear in the output. This condition is known as *carrier unbalance.*

The effect of carrier unbalance can be evaluated by considering the unwanted carrier as a vector of constant amplitude which adds itself vectorially to every vector present in the colorplexer output. In general, such a vector will shift all vectors and hence all hues seen in the picture toward one end or the other of the color-axis represented by the unbalanced modulator. For example, a positive unbalance in the I modulator would shift all colors toward the color represented by the positive I axis —that is, toward orange. A negative I unbalance would shift all colors toward cyan.

To visualize this effect, refer to Fig. 15, in which has been added to each color vector a small positive vector which is parallel to the I axis. This small vector represents the amount of carrier unbalance. The resultant vectors will all be rotated toward the positive I axis, and changed in amplitude as well. Such changes represent errors in both hue and saturation.

Another error from carrier unbalance occurs in white and gray areas of the picture. In a normally-operating colorplexer, a white (or gray) area in the scene causes the Q and I signals to become zero, and thereby causes the modulator outputs to become zero. Hence, a white or gray area will normally appear in the signal as an interval of zero subcarrier amplitude. If one of the modulators begins to produce a carrier-unbalance vector, however, a white or gray area will become colored because of the subcarrier which will be added in this interval. Moreover, certain areas which are normally colored may have their subcarrier cancelled by the carrier-unbalance vector, and become white. Such white-to-color and color-to-white errors are very objectionable.

Video Unbalance

A doubly-balanced modulator derives its name from the fact that it balances out or suppresses both the carrier (as described above) and the modulating video (Q or I). If, for any reason, the video suppression becomes less than perfect, the resulting condition is called *video unbalance*.

Video unbalance will cause unwanted Q or I *video* to appear in the modulator output, in addition to the desired sideband outputs. This unwanted video signal will be added to the luminance signal, thereby distorting the gray scale of the picture. For example, a slight positive unbalance in the Q modulator would slightly brighten reds and blues, and slightly darken greens. A negative unbalance would have the opposite effect.

Subcarrier-Frequency Error

The color subcarrier frequency is specified by the Federal Communications Commission to be 3.579545 mc, ±10 cycles. Deviations within this specified limit are of no consequence (provided they are slow deviations). Large deviations, however, can affect color fidelity. The effect does not usually become serious within the possible frequency range of a good crystal-controlled subcarrier source driving a properly-designed receiver.

In receivers, the subcarrier timing information is extracted from the burst on the back porch and used to control the frequency of a subcarrier-frequency oscillator in the receiver. As long as the *unlocked* frequencies of the burst and the receiver oscillator remain the same, the *locked* phase relationship between the two will remain the same. But if either the burst frequency or the receiver-oscillator frequency becomes different, (and the difference between them is not so large that lock-up is impossible), then the *locked* error, which obviously cannot be a frequency error, manifests itself as a phase error. This error can become as large as ±90° before the AFC circuit can no longer hold the receiver oscillator on frequency. The frequency range over which this phase shift occurs depends upon the receiver design.

POSSIBLE DISTORTIONS IN THE TRANSMISSION SYSTEM

Preceding sections have described the processes involved in the generation and display of a color television signal. Errors in these processes are not the only possible source of distortion; in transmitting the signal over great distances the transmission system itself may contribute errors. This section discusses parameters which specify the behavior of a transmission system, and describes the effects that errors in these parameters can have on the reproduced picture.

This section is divided into two parts. The first relates to the parameters of a perfectly linear transmission system, while the second part discusses the additional parameters required to describe the non-linearities that are inevitable in any practical system.

The Perfectly Linear Transmission System

A perfectly linear and noise-free transmission system can be described by its gain and phase characteristics, plotted against frequency as the independent variable.[2] Typical plots are shown in Figs. 16 and 17, respectively. These two characteristics known, it is possible to predict accurately what effect the transmission system will have on a given signal.

[2] If the filters in the system are of the minimum-phase type, only one of the plots is needed, for either plot can be derived from the other for this type filter. Almost all common interstage coupling networks are of the minimum-phase type.

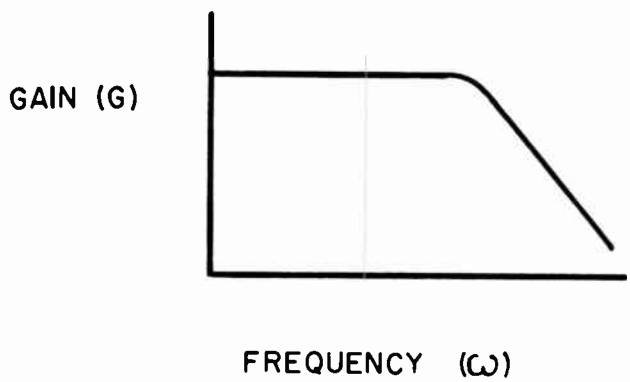


FIG. 16. Typical curve showing gain of a system plotted against frequency to determine its gain characteristic.

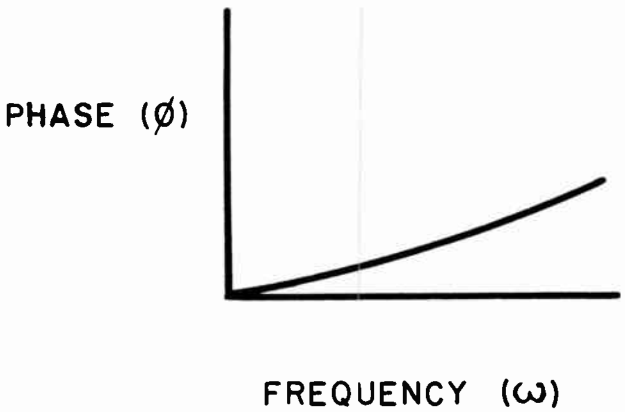


FIG. 17. Curve showing phase characteristic of a system plotted versus frequency.

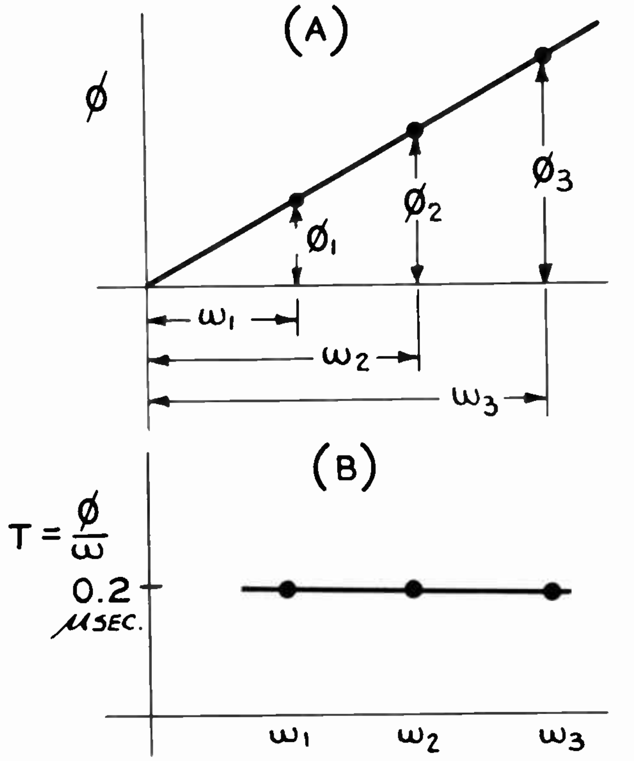


FIG. 18. Curves illustrating a system with linear phase characteristics, which will give the same time delay for signals of all frequencies.

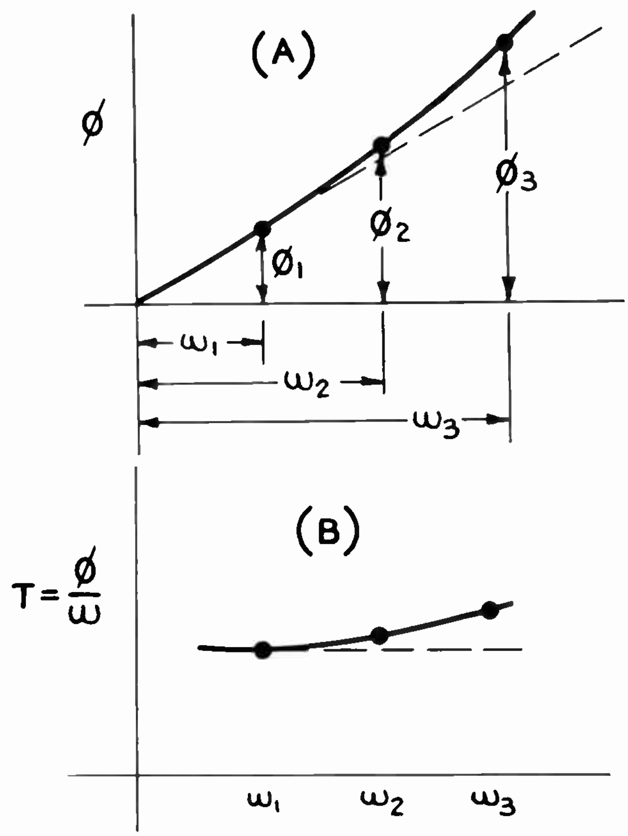


FIG. 19. Curves showing the effect of non-linear phase characteristic on the time delay characteristic.

Gain Characteristic

Figure 16 is usually known as the *frequency response* or *Gain Characteristic* of the system. Ideally, it should be perfectly flat from zero to infinite frequency; but this, of course, is impossible to attain. An amplifier has a definite gain-bandwidth product, depending upon the transconductance of its active elements (tubes or transistors), the distributed capacity shunting these elements, and the types of compensation (peaking) employed. The bandwidth of a given combination of tubes, transistors, stray capacitances, and peaking networks can be increased only by decreasing its gain; or conversely, its gain can be increased only by decreasing its bandwidth. There is a limitation, therefore, to the actual bandwidth than can be obtained. For a given scanning standard, the bandwidth required in a monochrome television system is determined by the desired ratio between the horizontal resolution and the vertical resolution. Although nominally a 4.0-mc/sec bandwidth is required for the monochrome standards, the requirement may be relaxed to the detriment of only the horizontal resolution. The subjective result is a "softening" of the picture in proportion to the narrowing of the bandwidth (neglecting the influence of the phase characteristic in the vicinity of the cut-off frequency). As pointed out in preceding sections, the entire chrominance information of the color system is located in the upper 1.5 megacycles of the prescribed 4.0-mc channel; hence, any loss of response in this part of the spectrum can have a marked effect on the color fidelity of the reproduced picture.

One of the most serious forms of distortion inflicted on a color picture by bandwidth limiting is loss of *saturation*. Consider a case in which the bandwidth is so narrow as to result in no gain at the color subcarrier frequency. The output signal then contains no color subcarrier, and hence reaches the color receiver as a monochrome signal, producing zero saturation. Nearly as poor results can be expected from an amplifier with response such that the gain at 3.58 mc is one-half the low-frequency gain. Since the saturation depends chiefly on the amplitude of subcarrier, the saturation will be correspondingly reduced. The resultant color picture will have a "washed-out" look.

Loss of high-frequency response which can be expected to contribute to loss of fidelity is usually accompanied by phase disturbance, depending on the type of networks employed in the system. The intent in this section, however, is to treat each variable separately. Therefore, discussions are based on the effects of varying only one parameter of a system; it is suggested that the reader can determine the combined effect of two or more variables by comparing the results shown for the individual variables.

Phase Characteristic

An ideal system has a *linear* phase characteristic, as in Fig. 18a. Such a characteristic implies that all frequencies of a signal have exactly the same *time* delay, in passing through this system, since the time delay is given by the phase angle divided by the (radian) frequency. It can be seen in Fig. 18 that if three frequencies are chosen arbitrarily, then the corresponding phase angles must have values proportional to their corresponding frequencies (because of the geometric properties of a right triangle). To state it another way, if $\phi_1/\omega_1 = 0.2$ microseconds, then ϕ_2/ω_2 also equals 0.2 microseconds, and ϕ_3/ω_3, too, is 0.2 microseconds. Plotting these three values and drawing a straight line through them as in Fig. 18b will show that the time delay for all frequencies is 0.2 microseconds.

A signal is not distorted by delay, as long as all parts of it are delayed by the same amount. However, when the phase characteristic is non-linear, (as in Figure T4a) the time delays for all parts of the signal are no longer equal (see Fig. 19b). For example, if a complex waveform is made up of a one-megacycle sine wave and its third harmonic, these two components will suffer unequal delays in passing through a system having the characteristics of Fig. 19. The resultant distortion can be seen by comparing Figs. 20a, b, and c.

Such distortion is detrimental to both the luminance and chrominance of a composite signal. The luminance signal will have its edges and other important details *scattered* or *dispersed* in the final image. Such a transmission system is said to introduce *dispersion*. (Conversely, if a system does not scatter the edges and other high-frequency information, it is said to be *dispersionless*.) The effect of phase distortion on the chrominance information is of a rather special nature, and can best be explained by introducing the concept of *envelope delay*.

Envelope Delay

In the preceding discussion, the time delays ϕ_1/ω_1, ϕ_2/ω_2, and ϕ_3/ω_3 were always determined by measuring the frequencies and the phases from $\omega = 0$ and $\phi = 0$. It might be said that the delay at zero frequency is commonly taken as the reference point for all other delays. This method is usually adequate for determining the performance of systems that do not carry any signals which have been modulated onto a carrier. But a carrier, with its family of associated sidebands (Fig. 21b), can be thought of as a method of transmitting signals in which the zero-frequency reference is translated to a carrier-frequency reference. This translation can be understood by referring to Figs. 21a and 21b. To calculate the delay of the carrier borne signals *after* they

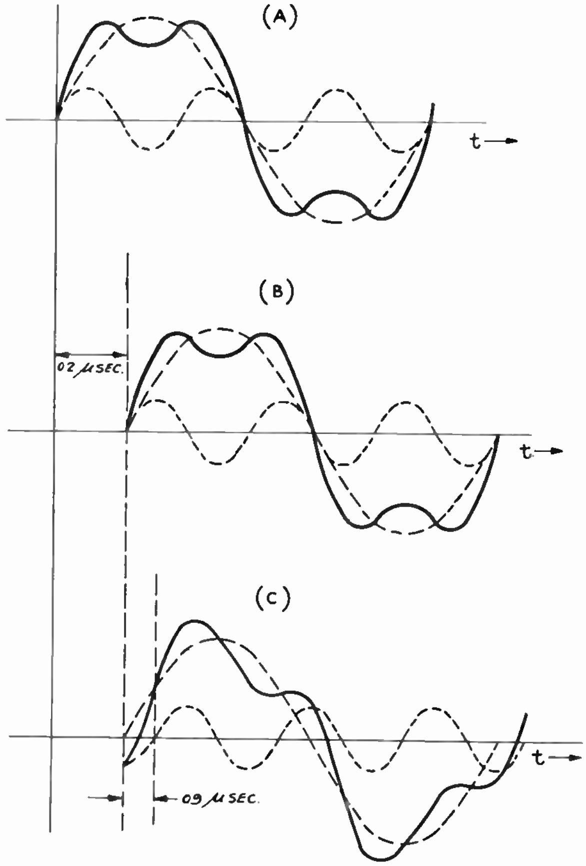


FIG. 20. Curves showing that a complex wave (A) is not distorted by time delay (B) when both components (shown dotted) are delayed by the same amount. Unequal delays (C), however, cause distortion.

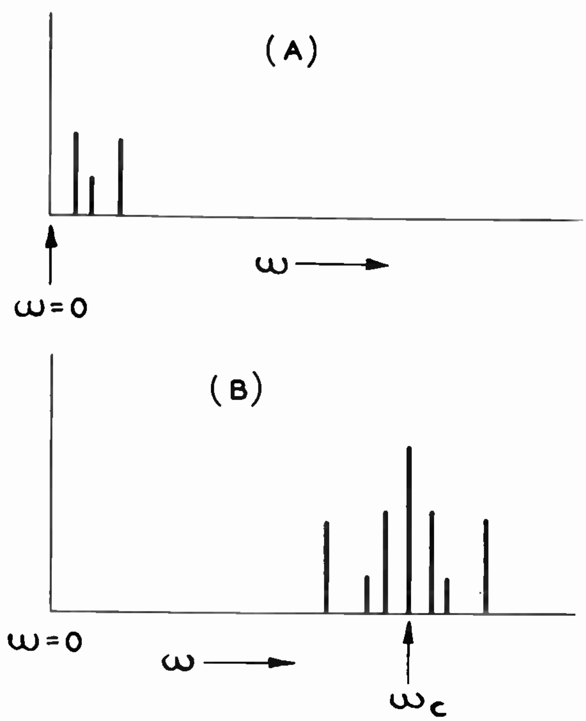


FIG. 21. Sketch showing how a group of frequencies near $\omega = 0$, see (A), can be translated by modulation onto a carrier, to a group of sidebands near ω_c—a carrier frequency (B).

have been demodulated, measurements of ϕ and ω must be referenced not from zero frequency but from *carrier* frequency.

In Fig. 22a, a rather impossible phase characteristic has been drawn to aid in further discussion of this subject. Such a characteristic, consisting of two perfectly straight lines, is never met in practice, but makes a very simple system for developing the subject of envelope delay.

First, pass two frequencies, ω_1 and ω_2, through this system. Let ω_1 be a carrier and ω_2 a sideband which might be, for example, 1000 cycles higher. If ω_1 and ω_2 fall on the characteristic as shown in Fig. 22a, the delay which the 1000 cycles will show after demodulation can be found putting new reference axes (shown dotted) with ω_1, the carrier, at zero on these new axes. Now, measuring ω_s and ϕ_s as shown, the time delay after demodulation is ϕ_s/ω_s. In this case, the delay of the 1000 cycles after demodulation is the same as it would have been had it been passed through the system directly.

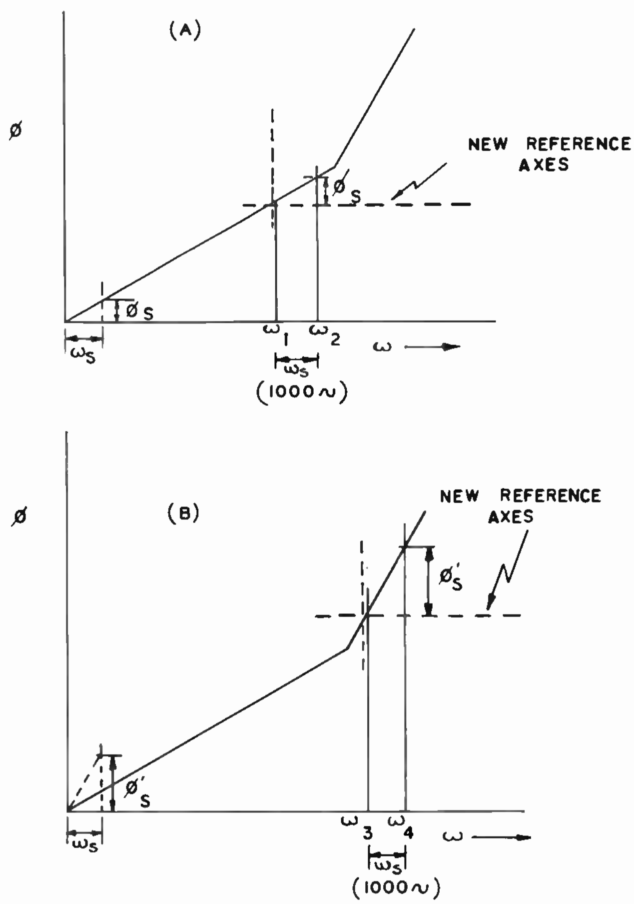


FIG. 22. Idealized straight line phase characteristics, showing how a carrier-borne 1000-cycle signal can be delayed excessively when the carrier and sideband fall on a steeper portion of the phase characteristic.

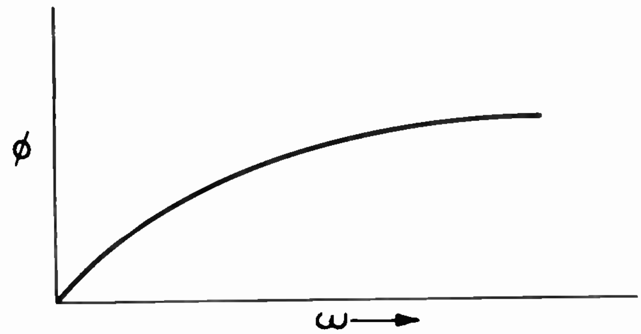


FIG. 23. Phase characteristic of an R/C network.

Secondly, pass two other frequencies, ω_3 and ω_4, through this system as redrawn in Fig. 22b. This time drawing in the new axes at ω_3, it can be seen that although ω_s is still 1000 cycles, ϕ'_s is larger than ϕ_s. Therefore, it can be concluded that the time delay ϕ'_s/ω_s for this second case is greater than for the first case. The 1000 cycles, when demodulated, will show a considerable error in timing.

Stressing the phrase "delay after demodulation" should not be taken to mean that the demodulation process produces this delay, or even makes it apparent where it was previously not detectable. Any delay that a demodulated wave shows was also present when the wave existed as a carrier having an envelope. In short, the delay of the demodulated wave appears first as a delay of the envelope; hence the phrase "envelope delay."

Envelope delay does not constitute a distortion. If a system such as the one shown in Fig. 22a introduces a delay of 0.2 μ sec to the 1000 cycle wave (measured after demodulation), then the *envelope delay* of the system is 0.2 μ sec. However, it was shown that a 1000 cycle signal passed directly through the system, (without first being modulated into a carrier) would also suffer a delay of 0.2 μ sec. As long as the envelope delay ϕ_s/ω_s is the same as the time delay (ϕ_1/ω_1), the envelope delay introduces no timing errors. But in the second system (Fig. 22b) the demodulated 1000-cycle wave suffered a *larger* delay, say 0.29 μ sec. A 1000 cycle signal passed directly through this system, however, would still be delayed only 0.2 μ sec. Therefore, the second system has an *envelope delay* of .29 μ sec. and an *envelope-delay distortion* of .09 μ sec.

It is probably wise to point out that the time delay ϕ_3/ω_3 in Fig. 22b is considerably less than the 0.29 μ sec. estimated for the value of envelope delay. Although ϕ_3/ω_3 would be greater than 0.2 μ sec., (say, for example, that ϕ_3/ω_3 is 0.22 μ sec.), the value would be optimistic about the amount of timing error that would be shown by the demodulated 1000-cycle signal. The need for a knowledge of the envelope delay ϕ_s/ω_s of the system is therefore obvious.

Effect of Envelope Delay Distortion on a Color Picture

A transmission system which exhibits envelope-delay distortion will destroy the time coincidence between the chrominance and luminance portions of the signal. This will result in misregistration between the color and luminance components of the reproduced picture. The following paragraph explains briefly how envelope-delay distortion causes this error.

Any colored area in a reproduced picture is derived from two signals—a chrominance signal and a luminance signal. Since these two signals describe the same area in the scene, they begin and end at the same time. The chrominance signal arrives at the receiver as a modulated subcarrier; the luminance signal does not. Therefore, as shown above, the delay of the chrominance signal is determined principally by the envelope delay of the system; delay of the luminance signal is determined principally by the ordinary time delay ϕ/ω. If the two delays are not identical, (that is, if there is envelope delay *distortion*), then the chrominance signal does not coincide with the luminance signal, and the resultant picture suffers *color/luminance misregistration* in a horizontal direction.

For example, in a system having the characteristic of Fig. 22b, the luminance signal is delayed by 0.2 μ sec., but the chrominance signal is delayed by 0.29 μ sec. The error in registration then amounts to .09 μ sec., or about 0.2% of the horizontal dimension of the picture, which is about 0.3" on a 21" (diagonal) picture.

Although the subject of compatibility is outside the scope of this chapter, it is worth noting in passing that envelope delay distortion adversely affects compatibility, since it causes wideband monochrome receivers to display a misregistered dot-crawl image, in addition to the proper luminance image.

General Method for Envelope Delay

The specific cases described above (Figs. 22a and 22b) made use of simple idealized straight-line approximations to develop the concept of envelope delay. Practical circuits are not so simple. For example, a simple RC network has a ϕ vs. ω plot as in Fig. 23. Finding the envelope delay of this curved-line plot will clarify what is meant by envelope delay.

Referring back to the plots of Figs. 22a and 22b, it can be seen that the characteristic of the plot that determines the value of envelope delay is its *slope*. The larger envelope delay, which was suffered by the ω_3-ω_4 pair (Fig. 22b) was a result of their lying on the steeper slope. The envelope delay of *any* system is equal to the slope of the phase-vs.-frequency characteristic. If this characteristic is a curved line (as for the RC network; Fig. 23) then the slope is different at every frequency,

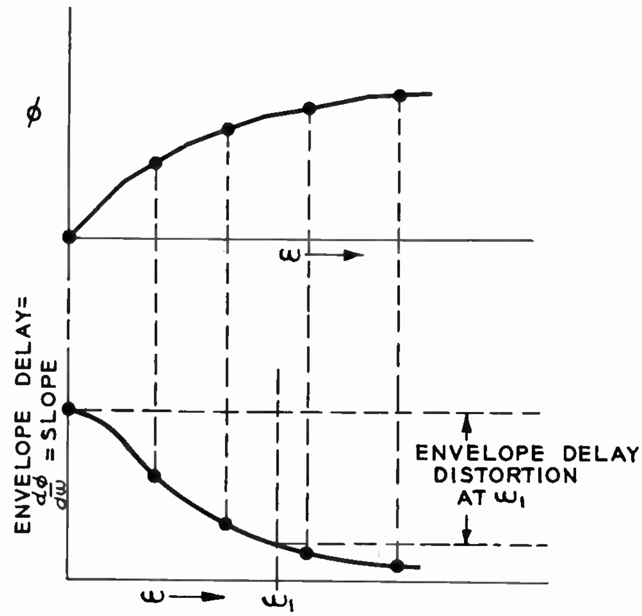


FIG. 24. Graphs showing how a series of straight line segments may be used to approximate the smooth curve of Figure 23 (top) and how the slopes of these segments may be plotted to approximate the envelope delay characteristics (bottom).

and therefore, the envelope delay is different at every frequency.

The slope of a curved line can be found by the methods of the differential calculus, or to a good approximation by breaking up the line into a number of straight-line segments, as in Fig. 24. If the slope of each of these straight lines is then plotted against its corresponding frequency, (that corresponding to the center of the line), the resulting curve will be approximately the envelope delay characteristic.

Non-linearities of a Practical Transmission System

It is important to emphasize that the effect of non-linearities in a color television system depends upon whether these non-linearities precede or follow the matrixing and modulation sections of the system. Non-linearities in transfer characteristics detract from color fidelity; the same degree of non-linearity after matrixing and modulation also affects color fidelity although in a different way. The purpose of the following paragraphs is to discuss how a non-linear transmission system affects a *composite* color signal. It is assumed that all other non-linearities in the entire system are either negligible or have been cancelled by use of non-linear amplifiers such as gamma correctors.

The major sources of non-linearity in a transmission system are its amplifying devices.[3] These devices—tubes

[3] FM systems can have non-linearity as a result of *passive* networks, but this case is not considered here.

and transistors—have a limited dynamic range: For example, if too much signal is supplied to them, an *overload* results. The transfer characteristic of such a system can be sketched as in Fig. 25a.

Such a non-linearity is one of three types commonly encountered in video transmission systems. These three types are:

1. incremental gain distortion
2. differential gain
3. differential phase

The paragraphs below will show that type 2 is merely a special case of type 1.

Incremental Gain

The concept of the slope of a plot, developed in the discussion of envelope delay, will be useful here as well. Consider a plot as in Fig. 25a which shows output voltage of an amplifier plotted against input voltage. Idealized straight-line plots are shown for simplicity. It can be seen that the amplifier has a maximum output of 3 volts, for 1 volt input. Larger input voltages result in no more output; the amplifier *clips* or *compresses* when inputs larger than 1 volt are applied.

The gain of the amplifier is

$$\text{Gain} = \frac{E_o}{E_{in}} = \frac{3 \text{ volt}}{1 \text{ volt}} = 3$$

The gain is obviously constant below the clip point. For example, an input voltage of 0.5 volts gives

$$\text{Gain} = \frac{1.5 \text{ volts}}{0.5 \text{ volts}} = 3$$

But at an input of 1.5 volts, the output is still 3 volts, so the "gain" is only 2. (The word "gain" is of doubtful use here, because of the clipping involved.) The "gain," defined as E_o/E_{in}, is plotted against E_{in} in Fig. 25b. It can be seen in this figure that the gain is constant only as long as the *slope* of Fig. 25a is constant.

It is useful, then, to establish a new term, called *incremental gain*, which will be defined as the *slope* of a plot such as Fig. 25a. For the particular plot of Fig. 25a, the slope is constant up to $E_{in} = 1$ volt, and then suddenly becomes zero. The corresponding plot of slope versus E_{in} is shown in Fig. 25c.

The importance of incremental gain in color television can be assessed by applying the input signal shown in Fig. 26 to the distorting system of Fig. 25a. Before being applied to the distorting system, such a signal could be reproduced on a monochrome receiver as a vertical white bar, and on a color receiver as a pastel-colored bar; say, for example, a pale green. After passing through the distorting system, the signal would still be reproduced as a white bar on the monochrome receiver with the only apparent error being a luminance distortion; that is, a

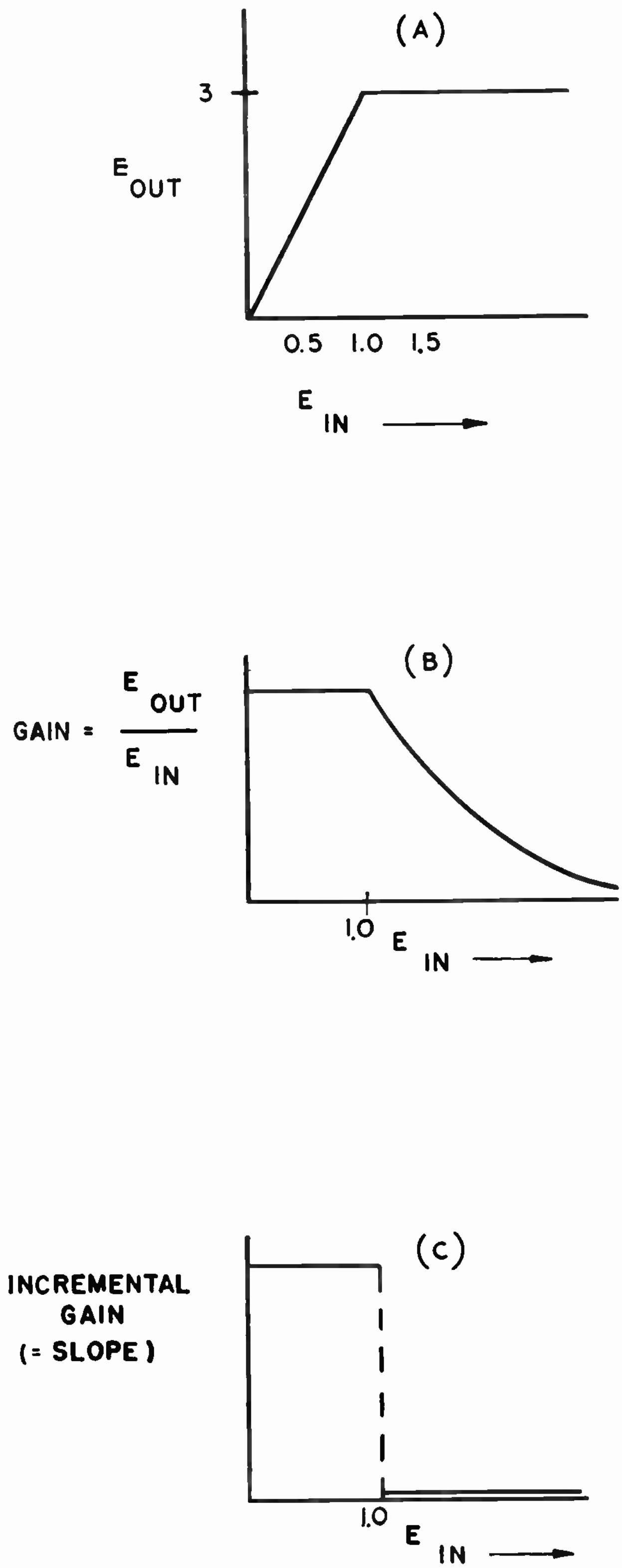


FIG. 25. Idealized straight line plots showing (A) output voltage of an amplifier versus input voltage; (B) gain of the amplifier versus input voltage; and (C) incremental gain of the amplifier versus input voltage. Curve (C) is the slope of curve (A).

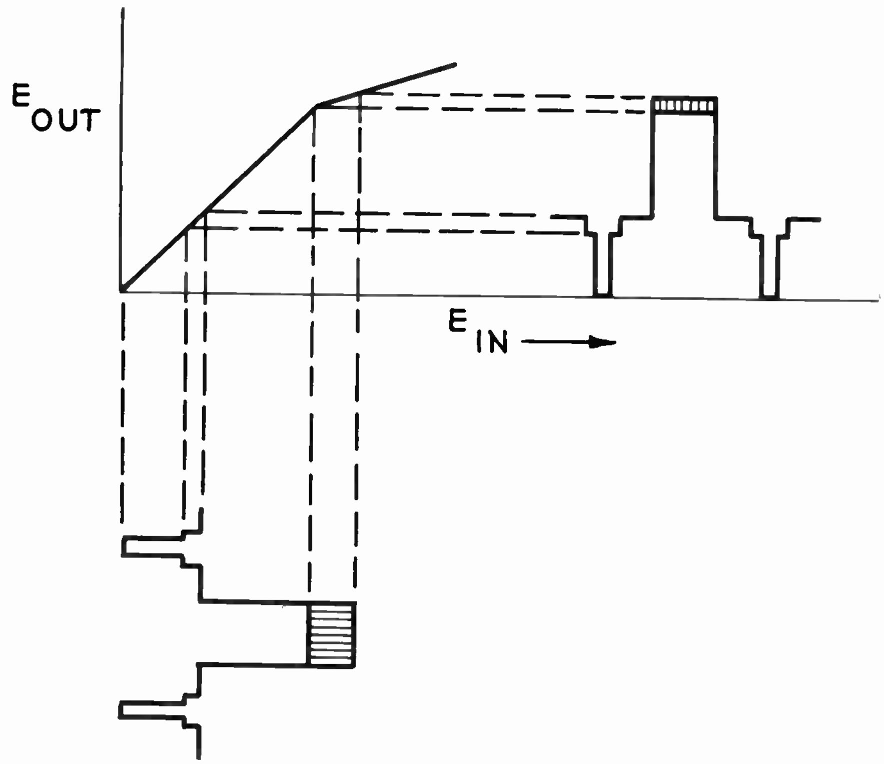


FIG. 27. Diagram showing effect of incremental gain distortion in reducing amplitude of color portion of signal.

slight reduction in brightness, which, for the magnitudes shown here, would probably pass unnoticed. The color receiver, however, would receive a signal completely devoid of any color information and would reproduce a white bar in place of the former pale green one.

A less extreme case is shown in Fig. 27. For the system represented by this characteristic, the slope (incremental gain) does not become zero for inputs above 1 volt, but instead falls to one-half its below-one-volt value. The color signal of Fig. 27 would not lose all color in passing through this system, but the amplitude of the subcarrier would become only one-half of its proper value. Since saturation is a function of subcarrier amplitude, the pale green of the undistorted reproduction would, in this case, become a *paler* green. The luminance distortion would also be less than in the extreme (clipping) case.

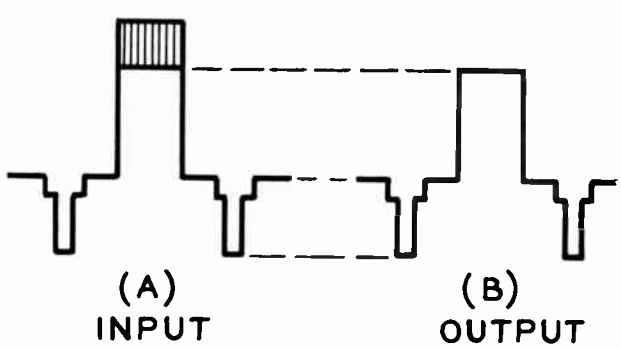


FIG. 26. Extreme case of distortion resulting from passing signal at left (A) through the amplifier represented by Fig. 25. The output (B) has no color information remaining.

It can be seen, then, that unless the incremental gain of a system is constant, that system will introduce compression, which will distort the saturation and brightness of reproduced colors. Usually, the error is in the direction of *decreased* luminance and saturation. For certain systems, however, exceptions can be found. For example, the effect that the system represented by Fig. 27 will have on a signal depends on the polarity of the signal. For the signal as shown, the usual *decrease* in luminance and saturation is exhibited. For an inverted signal, however, the subcarrier amplitude would not be reduced, but the luminance signal would still be diminished. The subjective result of this distortion would be an *increase* in saturation. The unusual behavior of this particular system is attributable to its peculiar transfer characteristic, which was drawn with curvature at one end only to simplify the discussion. Most practical system transfer characteristics exhibit curvature at both ends and therefore have an effect on the signal which is essentially independent of polarity.

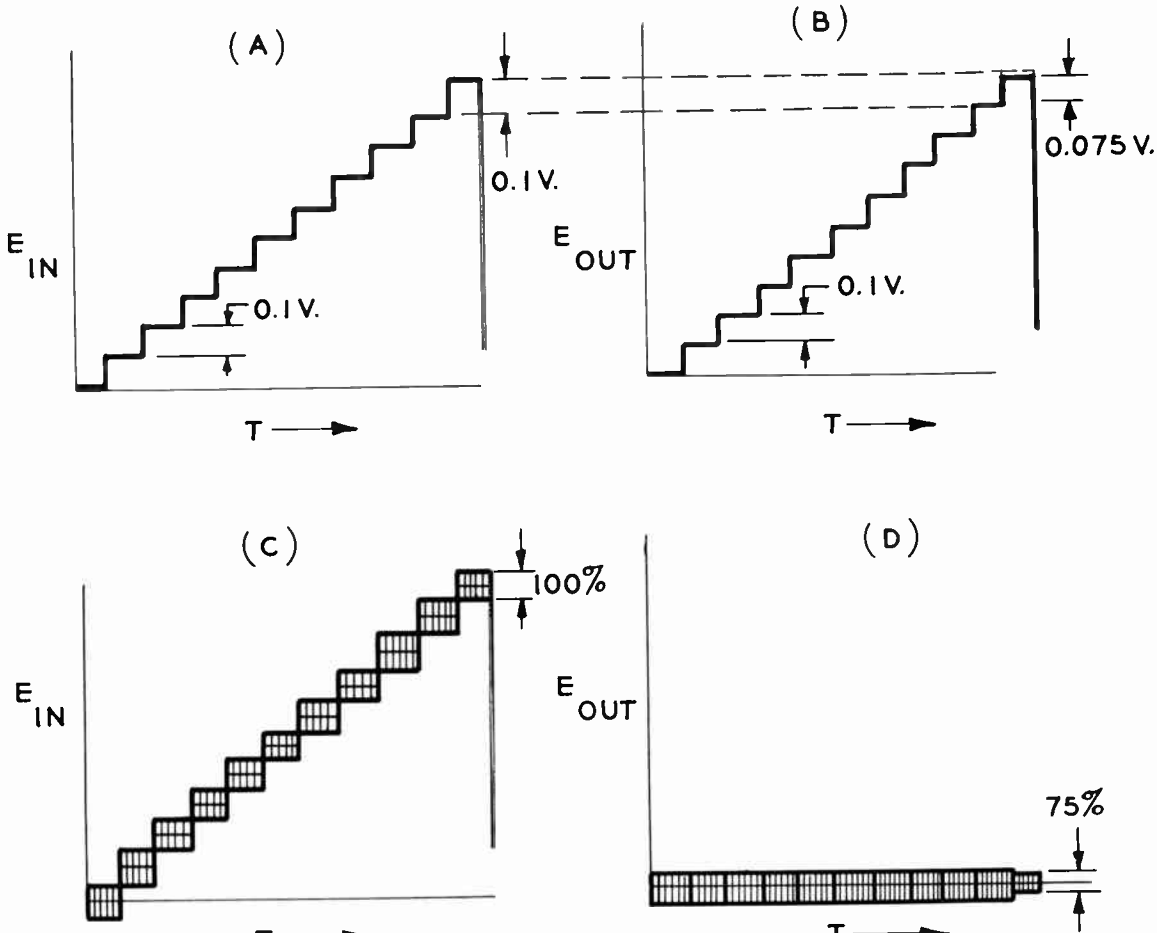


FIG. 28. Diagrams showing two methods of measuring incremental gain distortion, namely in (A) and (B) by its contribution to luminance distortion; and in (C) and (D), chrominance distortion.

Incremental gain can be measured in two ways, the first of which stems from its contribution to luminance distortion, and the second, from its contribution to chrominance distortion.

In the first method, an equal-step staircase waveform such as shown in Fig. 28a is applied to the system to simulate a signal having equal luminance increments. If the system has constant incremental gain, the output will, of course, also have equal-step increments. But if the system does not have constant incremental gain, certain of the steps will be compressed, as in Fig. 28b. If the compression is as in the figure, the *incremental gain distortion* (I.G.D.) is indicated by the distorted amplitude of the last step. Numerically, it can be stated as a percentage:

$$\text{I.G.D.} = \left(1 - \frac{S_{\text{distorted}}}{S_{\text{undistorted}}}\right) \times 100\%$$

where S is a step amplitude.

For example, if an undistorted step is 0.1 volt, and the distorted one is 0.075 volt, then the incremental gain distortion would be 25%.

Using the other (chrominance distortion) technique, an input signal consisting of the step wave plus a small, high-frequency sine wave, as shown in Fig. 28c, is applied to the system. After the signal has passed through the system, it is fed through a high-pass filter which removes the low-frequency staircase. The incremental gain distortion then is indicated by the differences in the amplitude of the high-frequency sine waves (see Fig. 28d). In this case, the high-frequency sine wave associated with the top step is shown as having 75% of the amplitude of the sine waves associated with the lower steps, which are assumed to be undistorted. Again, the incremental gain distortion is 25%.

A most important point must be made regarding the equivalence of these two techniques. Certain systems which show incremental gain distortion when tested by the luminance-step technique may or may not show the same distortion when tested by the high-frequency and high-pass-filter technique. Moreover, a system which shows distortion by the second technique may or may not show distortion by the first. In other words, the incremental gain distortion may be different for different frequencies. Such differences are frequently found in staggered amplifiers, feedback amplifiers or amplifiers having separate parallel paths for high and low frequencies, such as might be found in stabilizing amplifiers.

A thorough test of a system, therefore, should include tests of its incremental gain by both techniques. The staircase-plus-high-frequency waveform may be used to provide *both* tests by observing the system output (for this test waveform input) first through a lowpass filter and then through a highpass filter. The first test will show low-frequency distortions; the second, high-frequency distortions.

Differential Gain

On the basis of the above discussion of incremental gain distortion, the extremely important concept of *differential gain* can be presented merely as a simple definition. Differential gain is identical to incremental gain distortion when the latter is measured by observing "... the difference in the gain of the system for a small high-frequency sine-wave signal at two stated levels of a low-frequency signal upon which it is superimposed."[1] In other words, differential gain is a special form of incremental gain distortion which describes the I.G.D. of a system for the super-imposed high-frequency case only.

One of the reasons for selecting the high-frequency aspect of incremental gain distortion for the IRE definition of differential gain was applied in Fig. 26, when the "... high frequency sine wave ..." of the definition was made equal to color subcarrier. This special case of differential gain explores the system gain-linearity in the vicinity of this particularly important frequency. The definition of differential gain was purposely made in the broad terms of a "... high-frequency sine wave ..." to allow the greatest possible versatility in devising methods of measurement. In present color television practice, however, the "... high-frequency sine wave ..." is always color subcarrier, and the low-frequency signal mentioned in the definition is a 15,750-cycle staircase, sine-wave, or sawtooth. The complete specifications for the signal presently used in this measurement will be found elsewhere in this manual.

[1] From the definition of differential gain by IRE subcommittee 23.4.

Another reason for emphasizing high-frequency I.G.D. was implied on page 37 in the sentence "... the signal ... would ... be reproduced ... with the only apparent error being a luminance distortion ... which, for the magnitudes shown here, would probably pass unnoticed." The magniture shown was a 25% I.G.D., which is passing unnoticed, indicated that large incremental gain distortions usually cause no detectable luminance errors. Incremental gain distortion is almost too sensitive a tool to measure luminance distortions. For this purpose, simple gain distortion (compression) is more useful. Therefore, the luminance-distortion aspect of I.G.D. was deliberately omitted from the definition of differential gain.

Incremental Phase and Differential Phase

The phase characteristic sketched in Fig. 17 indicates that the system described by this plot will introduce a certain amount of phase shift for any given frequency. For example, it might be found that a certain system would introduce a phase shift of 60° at 2 mc/sec. If the system in question were perfectly linear, this 60° phase shift would be produced, regardless of how the 2 mc/sec. signal might be applied to the system.

It can be shown, however, that some systems, when presented with a signal of the type shown in Fig. 29, will introduce a delay *different* from 60°, depending on where the zero axis of the sine wave falls on the system's transfer characteristic. For the case sketched in the figure, a phase shift of 70° is drawn for the largest zero-axis displacement.

By analogy with the incremental gain and differential gain arguments above, it is possible to define three quantities which pertain to this type of distortion. These quantities are *incremental phase*, *incremental phase distortion*, and *differential phase*. It can also be shown that of the three, differential phase is the most important quantity.

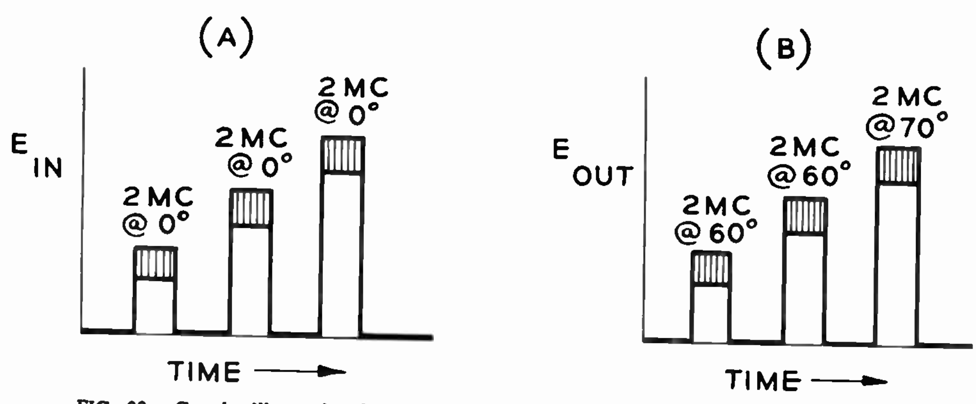


FIG. 29. Graphs illustrating how a signal (A) may undergo different phase shifts (B), depending upon where the zero axis of the sine wave falls on the system transfer characteristic. This distortion is called differential phase.

Incremental phase is the least exact analogue, since it is not very similar in form to incremental gain. Incremental *gain* is a *slope;* incremental phase is simply the absolute value of phase shift. In the above system, the incremental phase was 60° or 70° (or somewhere in between) depending upon the location of the zero axis.

Incremental phase distortion, like its analogue, *incremental gain distortion,* depends upon the magnitude of the error. It should be zero for a perfect system. In the system of Fig. 29 the 2 mc/sec. signal with 70° incremental phase would be said to have 10° incremental phase distortion, so it is clear that the difference between two phases (one of which is assumed to be "correct") gives the incremental phase distortion.

As previously stated, *differential gain* is identical to *incremental gain distortion* for the superimposed-high-frequency case only. Similarly, *differential phase* is identical to *incremental phase distortion,* but there is no need to limit the definition to the superimposed-high-frequency case, since there is no other case which is meaningful for phase distortion. Without the superimposed sine wave, no phase measurement is possible. Therefore, differential phase is identical to incremental phase distortion. In practical work, the first two terms are seldom used, for the last, differential phase, has been found completely adequate to describe this aspect of a system.

In summary, the differential phase of a system is ". . . the difference in phase shift through the system for a small high-frequency sine-wave signal at two stated levels of a low-frequency signal on which it is superimposed."[5]

It is important that the phrases "differential phase *distortion*" and "differential gain *distortion*" be avoided, since differential phase *is* distortion, as is differential gain, since they are defined as being identical to incremental phase distortion and incremental gain distortion respectively. To add the word *distortion* to either, is redundant. A sample of proper usage is "this amplifier has a differential gain of 1.5% and a differential phase of 0.5°."

Effect of Differential Phase on a Color Picture

The phase of subcarrier in a composite signal carriers information about the *hue* of the signal at that instant. If the signal passes through a system which introduces differential phase, the subcarrier phase (and hence, the hue) at the output will become dependent upon the amplitude of the luminance associated with the hue, since it is the luminance signal which determines the location of the subcarrier's zero axis. For example, a system introducing 10° of differential phase might be adjusted to reproduce properly a low-luminance hue such as saturated blue or a high-luminance hue such as saturated yellow, but *not both*. One or the other would have to be in error.

[5] From the definition of differential phase by IRE subcommittee 23.4.

STATE OF THE ART

The preceding portions of this Part have discussed in general terms the possible sources of color errors in a color television system. In no practical system can any of these errors be reduced to zero; therefore, anyone working with practical systems should know how nearly perfect any given paramenter should be to be considered acceptable, according to the present state of the art.

System Colorimetry

Talking qualitatively about colorimetric accuracy is one thing; assigning numbers and magnitudes is quite another. For the practical purposes of this Part, however, we are spared the need of digging deeply into the quantitative aspects of colorimetry by one simple fact: At the present time, color errors attributable to phosphor errors, filter errors, and other basic colorimetric errors, are negligible in comparison with other sources of error.

System Exponent

At the present state of the art, adjusting a system to pre-compensate for a kinescope exponent of 2.2 is not enforced by the Federal Communications Commission, since this parameter is not yet well-established. Adjusting the system to pre-compensate for this median value, however, can be done with precision. A gamma-corrector which uses four or five diodes to make a series of straight-line approximations to a 0.7 exponent can be made so as to have a maximum error of less than 2% of the peak signal amplitude. The exponents of the three channels can be made to match within 1% of the peak signal amplitude.

Matrix Coefficients

A high-quality matrix, such as would be found in a well-engineered colorplexer or studio monitor, uses 1% precision resistors for all resistances which will influence the values of the coefficients, while inverters and amplifiers are either stabilized by feedback or made adjustable. Errors of greater than 2% are rare in such circuits.

White balance in the transmitter matrix, which is a special case of the subject of matrix coefficients, can usually be adjusted and held to a tolerance of the order of ½% of peak white.

Phase Accuracies

Adjustment of Q subcarrier, I subcarrier, and burst to within 1° of their proper relative phases is easily accomplished using standard commercial equipment and techniques. This accuracy is ten times that required by the Federal Communications Commission.

Subcarrier Frequency Accuracy

Subcarrier frequency can be easily adjusted to within ±1 cycle, the real limit on the accuracy of the adjustment being in the inherent accuracy of the standard used for frequency comparison. Long-term stability of well-engineered equipment should be easily within the required limits of ±10 cycles.

Transmission Characteristics

A single amplifier should have a gain characteristic with less than ±½ db variation out to 8 mc. Its envelope delay error should be of the order of 0.001 microsecond at 3.58 mc, relative to 200 kc. Differential gain of ½% and differential phase of 0.25° represent good performance.

TOLERABLE COLOR ERRORS

The eye's sensitivity to color errors depends upon the manner in which two colors—the original and the reproduction—are compared. For example, if the two colors are placed side-by-side, the eye becomes a very sensitive indicator of color errors. However, if the comparison is made only by color memory, the eye is far more lenient in its requirements of perfect reproduction. Furthermore, if the reproduced color is one that the eye has never viewed before, the eye requires only that the color relayed to the brain be plausible; that is, that it be a reasonable color for the object concerned.

Fortunately, side-by-side comparison of colors never occurs in home viewing of color television. However, the system is frequently called upon to reproduce objects whose colors may be well known to the viewer, such as flesh tones, or a sponsor's packaged product. The reproductions of these objects must be accurate enough to satisfy the viewer's color memory. And if the system can satisfy the color memory of the viewer, the color plausibility requirement will be easily met.

Several investigations have been made to determine the sensitivity of the eye to color errors expressed as burst phase errors, Q amplitude errors, etc. The results of two of these investigations[6, 7] are summarized briefly in in the following paragraphs:

Above all, it must be borne in mind that the following information represents the effect of changing only the parameter specified, while every other parameter in the system remained constant and as nearly perfect as possible. In all cases, the data resulted from subjective tests of a fairly large number of viewers, and almost every viewer used flesh-tone reproduction as the criterion of acceptability. All but the phase data below are from the second reference. The error-magnitudes indicated resulted in marginal pictures; larger errors caused the average viewer to class the pictures as "Not Quite Passable."

The amplitudes of the three primary colors themselves proved to be the most critical, in general, of all the variables measured. A —27% change in Green could be tolerated; a —28% change in red was found allowable. The permissible positive changes in these colors were 40% and 32%, respectively. Tolerable blue changes were —35% and +53%. Subcarrier amplitude, it was found, could vary ±45% before the pictures were objectionably degraded. A comparatively small negative change in M amplitude —30%, raised viewers' objections, but a fairly large position error —72%, could be tolerated. The amplitude of I could fall only 34% before the pictures were rejected, but it could rise 70% before the reproductions were classed as definitely below par. The least sensitivity was shown by Q (namely, —94% and +135%), but the reader should again be reminded that observers admitted using flesh-tone reproduction as the criterion of acceptability, and Q contributes very little to flesh tone.

Also of interest are the approximate variations allowed before the reproductions were downgraded from "Excellent" to "Good." The three primaries were allowed approximately a ±20% variation; subcarrier amplitude, about a ±30% variation; M and I both about +40%, —20%; and Q about +60%, —55%.

Both of the investigations referred to[6, 7] agree that the maximum phase error for tolerable picture reproduction was about ±20°, for the average observer. The first investigation reported, in addition, that although this figure represented the numerical average, a phase tolerance of about ±11° was all that could be tolerated by 90% of the observers.

If the reader finds these tolerances to be large in comparison with the magnitudes discussed before, he is reminded that a number of cascaded elements in a system may provide an appreciable fraction of these magnitudes; and that furthermore, the errors in a typical operating system will include simultaneously *several* of these degrading factors. Also, the subcarrier amplitude and phase in the receiver are under the control of the viewer, who sets them without the aid of any measuring device other than his eyes' judgment. Therefore, careful attention to all parameters at the point of origin is essential to the production of good pictures in the viewer's home.

Conclusion

Although this Part may appear to be negative in its approach to the subject of Color Fidelity, the reader should bear in mind that, in spite of these seemingly unfavorable descriptions of what *might* happen in a system, the picture quality at the output of a *properly-adjusted* color television system is excellent. The apparent pessimistic attitude results, of course, from the need for defining the boundaries of system performance. Therefore, in conclusion, let it never be forgotten that, within these boundaries, there lies one of the best commercial color-reproducing systems that has ever been devised.

REFERENCES:
[6] PRITCHARD—"*Visibility of Hue Change Versus Overall Phase Error in N.T.S.C. Proposed Color Television Specifications*" —RCA Internal Report.
[7] WEISS—"*Significance of Some Receiver Errors to Color Reproduction*"—Proc. I.R.E.; Vol. 42, No. 9; Sept. 1954.

PART 4

The Colorplexer

The RCA Colorplexer performs the required encoding and processing of RGB signals emanating from the color camera, and produces a color video signal conforming to FCC specifications.

As the "heart" of the color system, the colorplexer centralizes a number of very important operating adjustments. Figure 1 shows the functional location of the equipment in the basic color television system.

Basic Functions

The principal operations and functions performed by the colorplexer include:

(a) Matrixing of RGB video signals to produce luminance and chrominance signals.

(b) Filtering of chrominance signals to required bandwidth.

(c) Delay compensation to correct for band limiting.

(d) Modulation of 3.58 mc carriers by chrominance signals.

(e) Insertion of color sync burst.

(f) Aperture compensation of luminance signal.

(g) Optional insertion of sync.

(h) Addition of signal components to form complete color signal.

Derivation of luminance and chrominance signals, and the principles of matrixing, bandwidth limiting and color subcarrier modulation are described in Part Two. Aperture compensation is employed to boost the amplitude of the high frequency component of the video signal, improving the overall video response characteristic. This technique is desirable because the finite size of the camera scanning beams, together with the limited resolving power of lenses, produces a video signal with deficient contrast range in picture areas with fine detail. The

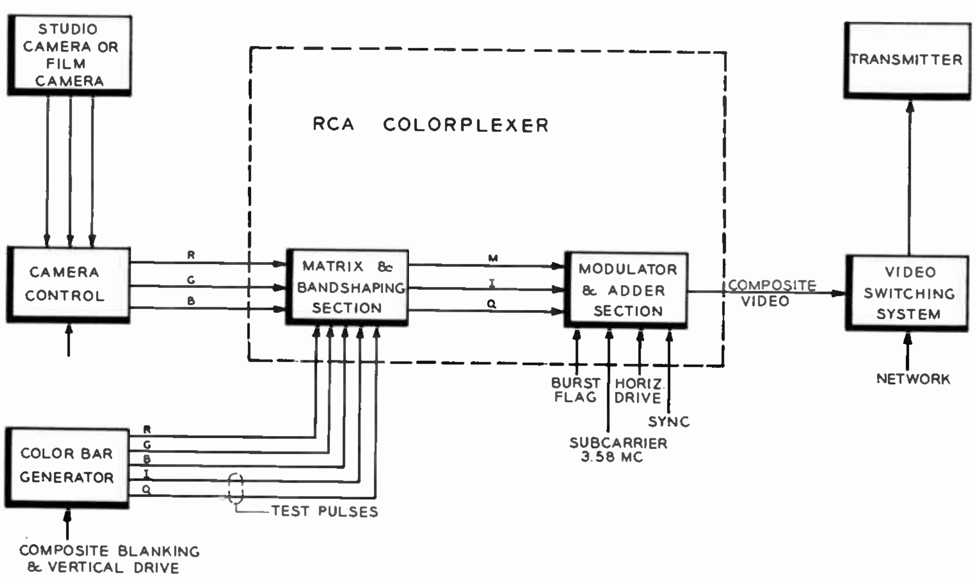


FIG. 1. Basic color television system showing functions and major components of the colorplexer.

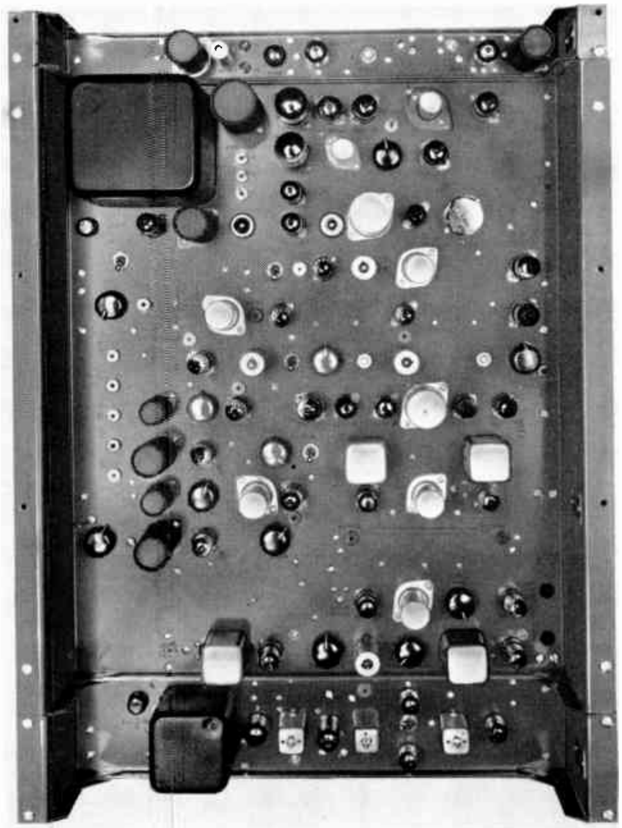


FIG. 2. Colorplexer rack-mounted between the aperture compensator, above, and automatic carrier balance control, below.

aperture compensation circuit, which is described in later paragraphs, is of a type that boosts high-frequency components without distorting their phase.

Design Features

The colorplexer illustrated in Fig. 2 is the Type TX-1. It consists of three chassis units designed for installation in a standard 19-inch rack, requiring a total height of only 26 inches. Equipment includes the small aperture compensator shown at the top of the photo, and the automatic carrier balance control unit at the bottom. The complete colorplexer is powered by a standard Type 580-D power supply.

Several features are incorporated in the colorplexer circuits to facilitate operation and to enhance picture quality.

Provision is made for shifting the phase of the incoming 3.58 mc carrier through 360 degrees to permit signals from several colorplexers to be lined up with respect to subcarrier phase at some common point, such as the output of the switching system.

An automatic carrier balance control circuit provides instantaneous correction voltages for maintaining carrier balance in the modulators at all times; although manual balance adjustments are provided in the modulators to permit both differential gain and a-c impedance measurements to be made.

A selector switch in the colorplexer gives the operator a choice of two inputs—camera signals or test signals from a color bar generator. The color bar generator provides a total of five signals. These signals consist of the RGB video signals plus special test pulses which are very useful in checking phase adjustments of the I and Q modulators. I and Q test pulses are inserted directly into the I and Q channels as shown.

Operating controls for the various functions are mounted on the front of the chassis. Test jacks installed at several points in the circuits provide for observation of waveforms. A few of these waveforms are discussed later, under "colorplexer operation."

Circuit Description

To aid in describing the circuits, the colorplexer has been divided into two sections in accordance with their functions (see Diagrams A and B contained in the Appendix). In the matrix and bandshaping section (Diagram A), the red, green and blue signals are transformed into M, I and Q signals which are then adjusted with respect to bandwidth and delay. The multiplexing operations required to produce a composite signal from the M, I and Q signals take place in the modulator and adder section (see Diagram B).

Matrix and Bandshaping Section

With reference to the basic circuit arrangement for the matrix and bandshaping section of the colorplexer, RGB signals at one-volt levels are fed through coaxial jacks, and applied through the matrix resistor network to the grids of separate M, I and Q pentode amplifiers.

In the M amplifier, sync is combined with the matrixed RGB signals to form the composite monochrome signal, which is fed through a coaxial delay line to amplifiers in the modulator/adder section.

The I signal is developed in the I amplifier by application of a red signal to the control grid, and blue and green signals to the cathode. This I signal is then fed through a coaxial delay line, a 1.5 mc band-limiting filter, and a phase splitter, to the I modulator tubes. It so happens that the signal produced by the I channel is inverted in polarity relative to the M and Q signals, but this poses no problem in view of the fact that the polarity is readily corrected by proper connections in the modulator which follows.

The Q signal is obtained by applying the green signal to the control grid of the Q amplifier, and the red and blue signals to the cathode. The Q signal then passes through an 0.5 mc filter, amplifier, and phase splitter, to the Q modulators. Delay networks, which compensate for band-limiting of the chrominance signals, consist of specified lengths of high-impedance delay cable. A sync delay line is not required since sync is added to the monochrome signal ahead of the delay line.

Aperture Compensation

As previously mentioned, the aperture compensator is employed to compensate for the finite size of the electron scanning beam in color studio or film cameras. The aperture compensator is connected electrically to the colorplexer, and no other aperture compensation is necessary in the system.

Since the monochrome channel is a wide-band channel and the I and Q channels are narrow band, it is necessary to apply compensation to only the monochrome channel. It is not desirable to aperture compensate the sync signal, therefore provision is made for adding sync after compensation.

Circuitry of the aperture compensator is shown in the simplified block diagram of Fig. 3. The circuit consists of a differential amplifier which feeds an open circuited delay line. The open circuited end of the delay line is connected to the grid of an output amplifier which drives the monochrome delay line. Part of the plate load of the output amplifier is common to the sync amplifier, thus sync can be added at this point if desired.

Modulators and Automatic Carrier Balance

Circuits required to produce the I and Q color subcarrier, insert the color burst, and multiplex the monochrome and color video signals are shown in simplified

FIG. 3. Simplified block diagram of aperture compensator.

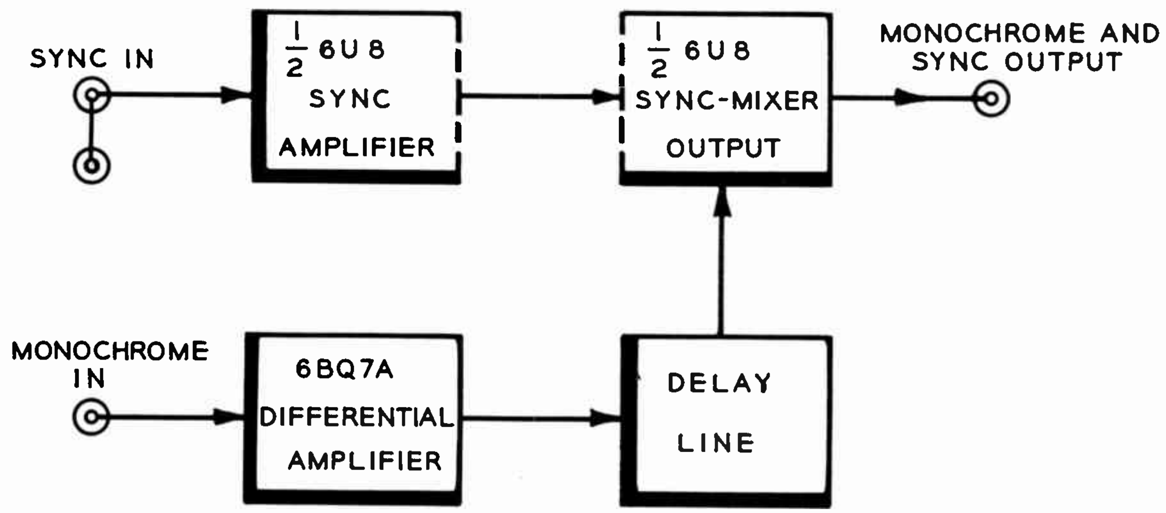
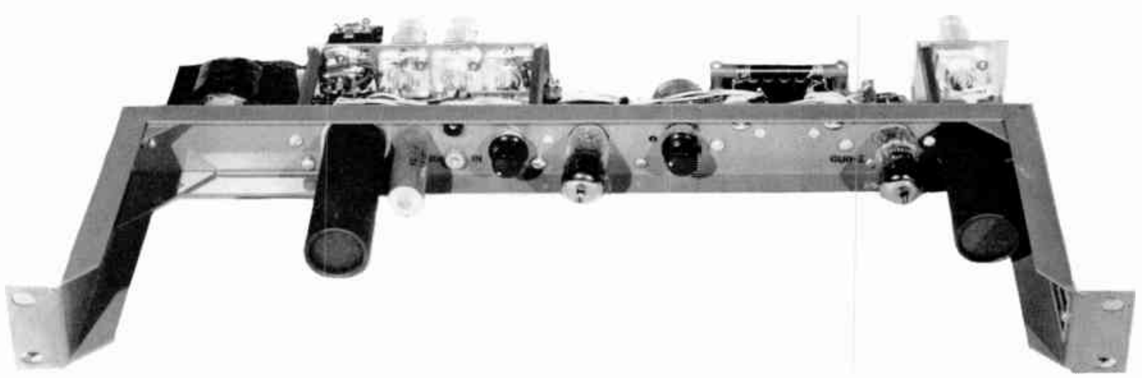


FIG. 4. Components of the aperture compensator are mounted on a recessed type chassis.



form in Diagram B. The basic components consists of two pairs of balanced modulators, amplifiers for the 3.58 mc carrier with provision for 90-degree phase displacement, "adder" stages for combining the composite M signal with the color and burst signals, and automatic carrier balance control circuitry to maintain complete 3.58 mc carrier suppression in the output of the modulators.

I and Q signals developed in the matrix and band-shaping sections of the colorplexer are applied through tube type phase splitters (in phase opposition) to the control grids of the balanced modulators, while 3.58 mc carrier voltages with a 90-degree phase difference are applied to the suppressor grids. Since the plates of the modulators are in parallel, the carrier voltages in each pair of modulators cancel out, leaving only the signal which is the vector sum of the I and Q sidebands in phase quadrature.

The composite color signal from the output of the adders is applied to a two-stage gate in the automatic carrier balance control unit. This gate is normally biased in the "off" condition, but it is keyed by horizontal drive pulses, which make it conduct only during the horizontal blanking time (prior to color sync burst) so that only the unbalanced subcarrier signal components are amplified. Output from the gated amplifier is fed to two bridge type diode discriminators through tuned circuits. Reference subcarrier signals are applied in phase quadrature to the two discriminators in such a way that each develops an output voltage proportional to the carrier unbalance in either the I or the Q channel. These correction voltages are then applied as bias voltages to the I and Q modulators to maintain a state of proper balance.

Adders and Output Amplifiers

The complete color signal is formed in the common plate circuits of the monochrome, chroma and burst adder stages. From these stages the color signal is passed through two feedback amplifiers. The first of these provides most of the required voltage gain, and contains a low-impedance video gain control. The second feedback amplifier is the output stage which has sufficiently low output impedance to permit the connection of three separate 75-ohm outputs with a high degree of isolation. The composite color signal is clamped at the proper level in the first feedback amplifier by a clamp tube driven by horizontal drive.

The subcarrier signal, supplied from a frequency standard operating at 3.579545 mc, is applied through an amplifier and adjustable phase-shifting network to phase displacement networks that provide subcarrier signals of correct phase displacement for the burst gate, modulators, and automatic carrier balance circuits. A keying signal from the burst flag generator is applied through an inverter tube to the suppressor of the burst gate. The 57-degree and 33-degree delay elements shown in the block diagram provide the necessary phase relationship between burst and I and Q signals as described in Part Two.

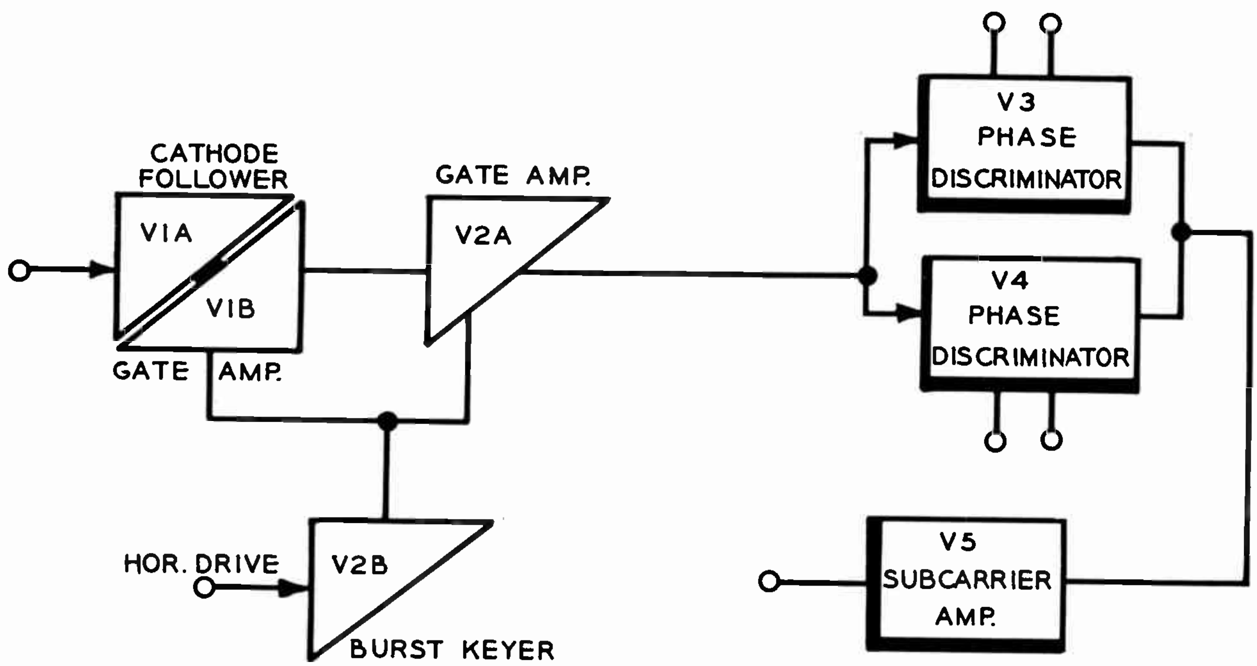


FIG. 5. Block diagram of automatic carrier balance control circuits.

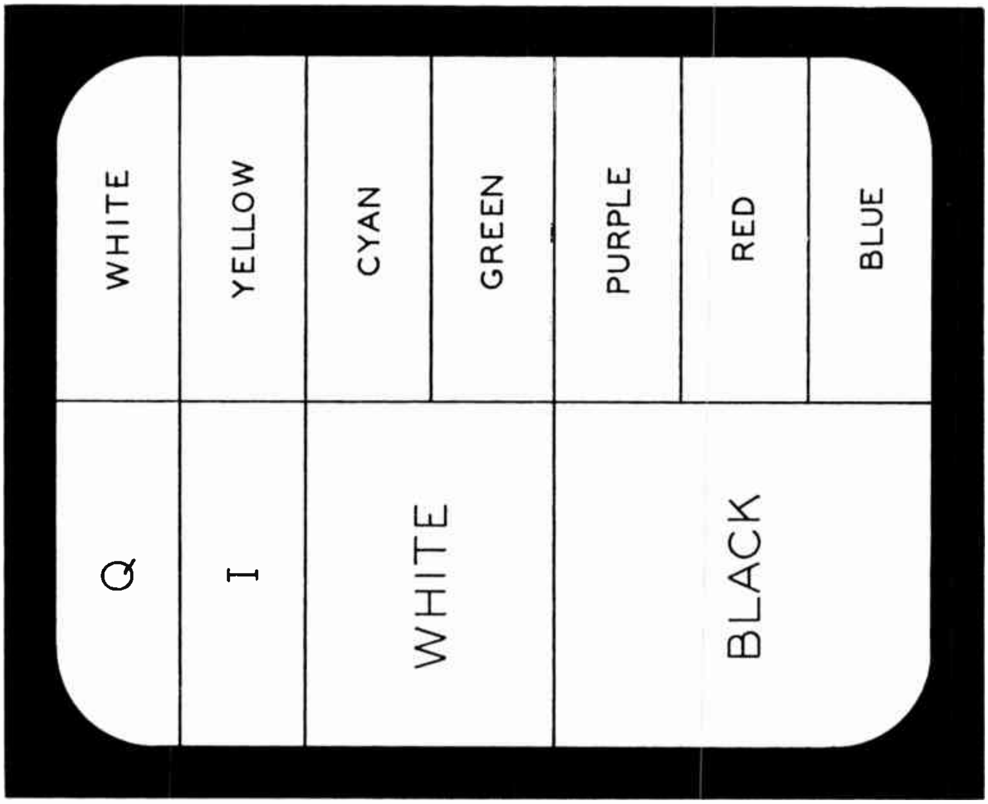


FIG. 6. Diagram showing color monitor display of color and test bars electronically produced by RCA Color Bar Generator.

Operation of the Colorplexer

Correct settings for the operating controls of the RCA Colorplexer are obtained by following a step-by-step procedure described in the Colorplexer Instruction Book. Thereafter, tests verifying proper adjustment are usually made at the beginning of each operating day. Personnel soon become familiar with the controls and their effects on the output signal, and the detailed initial adjustment procedure then resolves itself to a few routine steps.

Colorplexer setup involves adjustment of signal amplitudes and phase with the aid of test equipment, some of which is designed especially for color use. Actual reproductions of waveforms displayed by an oscilloscope connected to significant points in the circuitry, are presented in this section to assist the reader in visualizing colorplexer operation.

Test equipment required to produce these waveforms consists of the RCA Color Bar Generator (which is fully described in Part Twelve) and the RCA Type TO-524 Oscilloscope. The color bar generator is capable of producing on the screen of a color monitor all the signal bars illustrated in Fig. 6. Colors in the top portion of the pattern are arranged from left to right in their order of luminance. The lower portion of the pattern contains, from left to right, a special I signal, a special Q signal, a white signal and a black signal. The special I and Q signals simplify subcarrier phase adjustments, and the white signal facilitates white balance adjustment. Limiting action assures constant level output of one volt, peak-to-peak, for all signals. Connection of the color bar generator to the colorplexer is shown in Diagram A in the Appendix. In addition, the generator requires input signals consisting of composite blanking and vertical drive, both at standard four-volt p/p levels. The TO-524 Oscilloscope has a bandwidth of 10 megacyles together with the excellent transient response required in making accurate waveform analysis.

Waveforms

The composite color waveform obtained at the output jack of the Colorplexer, and illustrated in the upper right corner of Diagram B, can serve to verify all adjustments of the colorplexer excepting the phase of the color burst. Colors from left to right, in descending order of lumi-

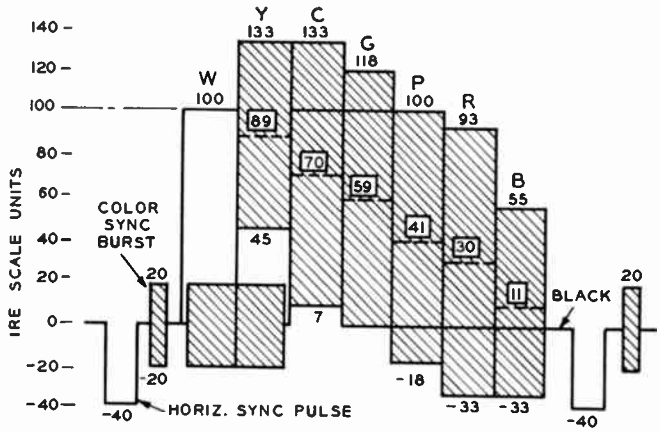


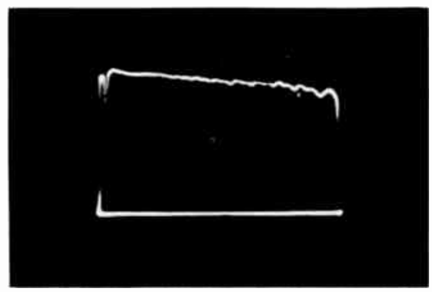
FIG. 7. Correct relative amplitudes for color bars, burst and sync pulses, expressed in IRE scale units. (One volt peak-to-peak equals 140 IRE scale units.)

nance, are white, yellow, cyan, green, purple, red and blue. Correct amplitudes for these bars and other signal components in the waveform, expressed in IRE scale units (one volt p/p equals 140 IRE scale units), are given in the corresponding line diagram of Fig. 7. The photograph shows only the waveforms corresponding to the sequence of color bars shown on the top half of the raster in Fig. 6, but the line diagram in Fig. 7 also shows the test bursts produced by the special I and Q test pulses adjacent to the color sync burst. As seen, the yellow and cyan bars should be adjusted to coincide at 133 units, and the red and blue bars should coincide at —33 units. The bottom edge of the green bar should just touch the black level, and the top of the purple bar should meet the reference white level.

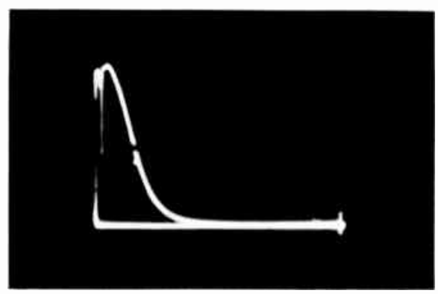
Other output waveforms illustrated in Diagram B include that of the monochrome signal, obtained by switching out the I and Q amplifiers, and the separate I and Q waveforms obtained with the monochrome switched out. The monochrome signal contains the luminance information of the color bar signal, and hence produces the descending step pattern shown. The I and Q waveforms are useful in setting the proper peak amplitudes for these signals as well as the 90-degree phase separation. The slow rise time apparent in components of the Q waveform is due to the 0.5 mc Q channel filter. The effects of the I filter are not as pronounced and are barely visible in the I waveform. A still better illustration of Q band limiting can be seen in Diagram A, where the Q signal waveform can be compared to that of the I signal and the RGB input signals.

The special I and Q test bursts shown in Fig. 7 may be used to check phase adjustments of the I and Q modulators relative to each other, and the burst gate. The instrument used for the purpose is the WA-6 Color Signal Analyzer, which is described in a later section.

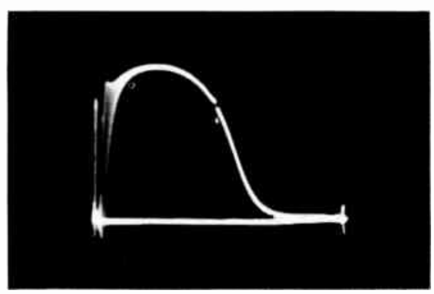
Bandpass characteristics of the colorplexer are illustrated by the waveforms shown in Fig. 8. These waveforms are typical for a properly adjusted colorplexer, and where obtained at the output jacks of the colorplexer.



(a)



(b)



(c)

FIG. 8. Waveforms showing response characteristics of colorplexer monochrome, I and Q channels. (a) Response of monochrome channel without aperture correction, marker at 8.0 mc.; (b) Output of I filter, marker at 2.0 mc.; (c) Output of Q filter, marker at 500 kc.

PART 5

Live Color Cameras

Development of the first color television camera of commercial design was begun by RCA as early as 1950. Subsequently, several color camera chains were produced and made a part of the NBC experimental color television operations in their New York studios. Months of daily operation, including many experimental programs, made it possible to rigorously test the equipment for all the known qualities of good commercial operation already well established in monochrome equipment. Experience gained in this early work was utilized in 1952 in producing the first commercial color studio camera, the RCA TK-40, so enthusiastically welcomed by Broadcasters across the nation. The TK-40 is now superseded by the RCA TK-41, which embodies new technological advances and the knowledge gained from the performance of the first color camera.

TK-41 Image Orthicon Color Camera Chain

The RCA TK-41 Color Camera has gained wide acclaim by Broadcasters for its superior performance in the color studio while affording greatest efficiency and ease for the operator. Already "proved-in" by thousands of hours operation in scores of broadcast plants, the TK-41 continues to set higher standards of quality in the telecasting of live color.

Broadcast engineers will recognize the TK-41 color camera chain as similar in many respects to the RCA monochrome chains now in use. The block diagram of Fig. 2 shows the major components of the complete color camera chain and their relationship to the units of the camera. Red, green and blue video output from the camera is fed through the camera cable to the remote

FIG 1. Image orthicon color television camera.

camera control panel and processing amplifier. The processing amplifier and control panel, which can be compared to the camera control in monochrome systems, insert blanking, shading and pedestal control for the three image orthicons, and perform other functions which are described later in this section. From the processing amplifier, RGB video signals are passed to the Colorplexer where aperture compensation and the addition of sync to form the composite video signal is performed, as described in the preceding section. A master monitor provides both kinescope and waveform displays of the processed color camera signal, and a color monitor provides a composite color image. The camera cable is a multi-conductor cable which also conveys the driving and blanking signals and d-c plate voltage to the camera circuits.

Color Camera

The TK-41 Color Camera consists of a light-splitting optical system with four-position lens turret, three separate image orthicon tubes to provide red, green and blue signals, three plug-in video preamplifiers, an electronic viewfinder, deflection circuits for the image orthicons and a high voltage supply derived from the horizontal deflection unit. The electronic viewfinder utilizes a 7TP4 kinescope with necessary deflection and video circuits to provide a monochrome picture for the operator. Handles projecting from the rear of the camera provide for panning and tilting. The handle on the right side of the camera is also used for focusing the optical system.

Optical System

Elements of the optical system, which include the camera objective and field lenses, vertical astigmatism corrector, iris, optical orbiter, relay lenses, dichroic mirrors and trim filters are diagrammed in Fig. 3 and described in the following paragraphs.

The rotatable lens turret accommodates four objective lenses of different focal lengths. Normally, lenses with focal lengths of 50, 90, and 135mm are used in three positions of the turret, and a telephoto or 35mm lens is used in the fourth. The "taking" position is at the bottom of the turret. Rapid selection of any one of the four lenses is easily accomplished by rotating a positioning handle at the rear of the camera. Accurate positioning is insured by a positive detent mechanism.

Details of the lens turret assembly are shown in the photograph of Fig. 4. The lens turret rotates over a stationary drum support attached to the front plate of the camera frame. This drum serves simultaneously as a light trap, a support for the rotatable shaft and a mount for the detent mechanism. The field lenses are mounted on a spider support housed within the drum. The ob-

FIG. 2. Block diagram showing major components of complete color camera chain.

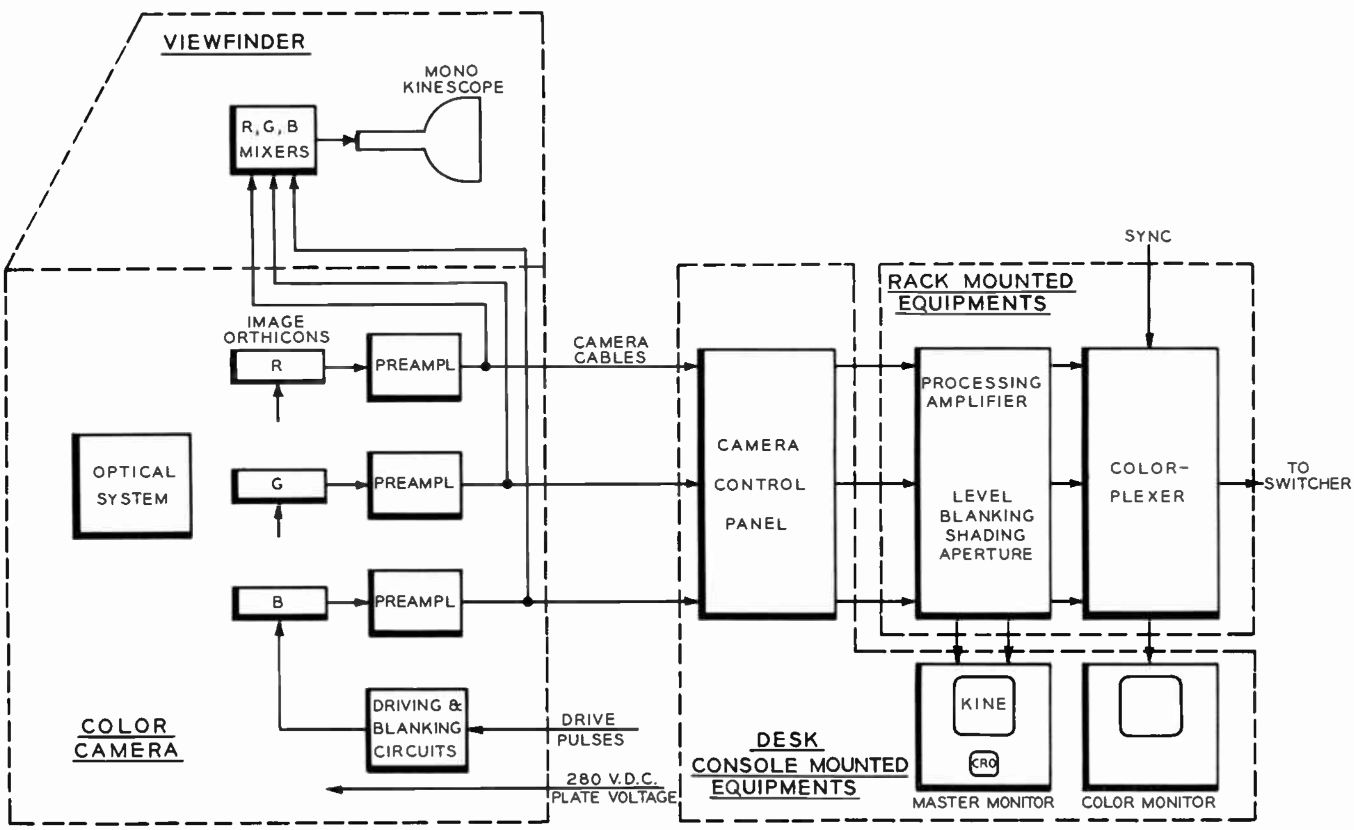
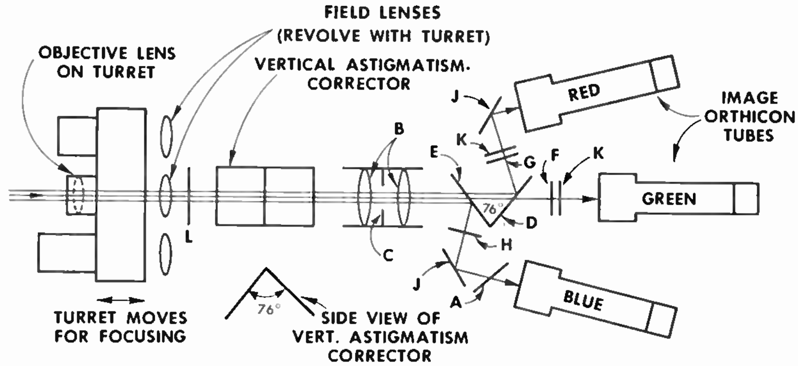


FIG. 3. Elements of lens turret and optical system.



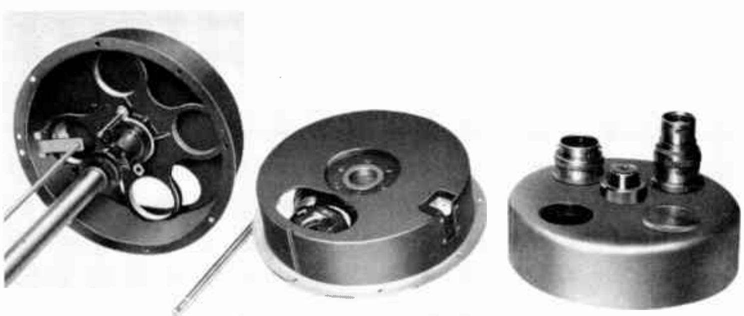


FIG. 4. Components of camera lens turret assembly.

jective lenses and associated field lenses rotate as an integral part when the turret is rotated, and thus remain properly matched at each position of the turret. Optical focus is obtained by a mechanical linkage from the focus handle which moves the lens turret (and objective lenses) longitudinally, or along the optical axis, while the field lens spider remains fixed. The image from the objective lens is focused on the field lens, and a secondary image is formed on the image orthicon photocathodes by the relay lens. Focusing of the secondary images on each image orthicon is achieved by sliding the individual yoke assemblies along their optical axis. Since each objective lens requires a particular field lens, provision is made for convenient change of the field lens by partial removal of two retaining screws, and a half-turn rotation of the field lens holder.

As seen by the diagram, light from the field lens passes through a dichroic trimming filter which removes the ultra-violet and infra-red portions of the spectrum, to the vertical astigmatism compensator. The astigmatism compensator corrects the distortion of optical focus caused by the fact that light passes through the thick dichroic mirrors at an angle. Since the blue light passes through only two thicknesses of glass, as compared to four for the red and green light, an additional horizontal astigmatism compensator (A) is placed in the blue path as shown.

Following the vertical compensator are the two f:4, 9½-inch focal length relay lenses which increase the length of the optical path to provide space for the dichroic mirrors and associated elements. Between the relay lenses is an iris diaphragm which serves as the major overall gain or sensitivity control for the camera chain during operation. The iris is driven by a selsyn which is controlled remotely from the operator's console.

Wratten filters and glass filters are used in conjunction with the dichroic mirrors to adjust the overall spectral response of the camera. Filters are held in place by frames secured to the block assembly which mounts the dichroic mirrors. The dichroics are mounted in a fixed position and require no adjustment. Neutral density filters are used in the light paths to adjust the relative sensitivities of the three image orthicon channels. Filters are chosen to reduce the sensitivity of two of the channels to match the third, or least sensitive.

In studio use, where illumination is obtained from tungsten lamps, the blue channel is usually the least sensitive because of the deficiency of blue energy in the light source. Therefore, neutral density filters are generally used in the red and green channels.

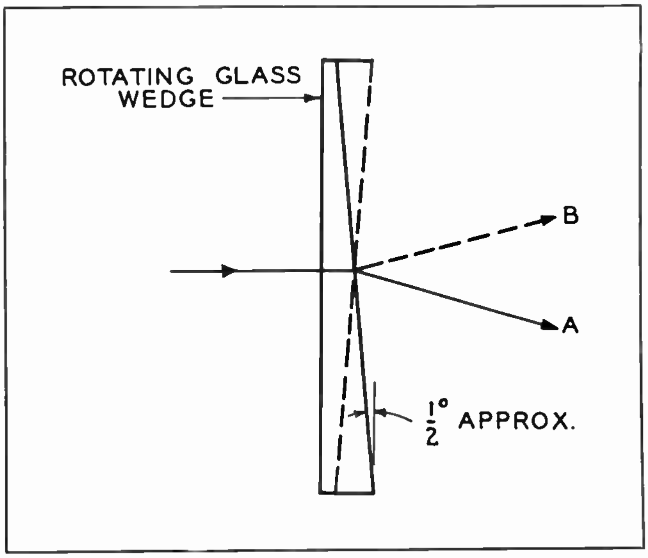


FIG. 5a. Sketch showing exaggerated deviation of image resulting from use of optical orbiter.

FIG. 5b. Ring gear and optical wedge for the optical orbiter.

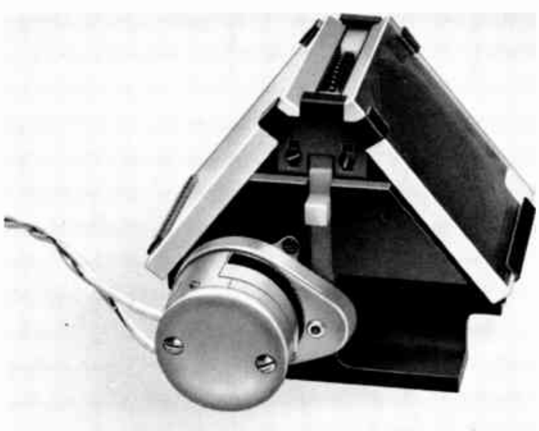


FIG. 5c. Complete optical orbiting unit for use with color camera.

Optical Image Orbiter

The image orbiter is a device which rotates the camera image in a slow, continuous elliptical orbit, undetectable to the TV viewer. Its purpose is to prevent image "burn-in" or "sticking" of the image orthicon pickup tube.

Sticking occurs after a camera is held stationary on a high contrast scene for 10 to 30 seconds or more. When "panned" away, the scene persists in the form of a well-defined negative image, and remains visible for intervals ranging from a few seconds to several minutes, depending upon the age of the tube and the severity of the burn.

The photocathode of the image orthicon under all normal operating conditions has in itself no tendency for image retention. The sticking effect resides in the thin glass target. Continuous, high-velocity bombardment of electrons emitted from the photocathode, together with the scanning of the target by the electron beam, causes a net flow of charge through the target glass. As a result, certain physiochemical and electrolytic changes take place in the glass target material. These gradually increase the susceptibility of the tube to target burn.

Rotation of the optical image falling on the photocathode is a practical way to prevent the image orthicon from sticking. This is accomplished in the color camera by the optical orbiter assembly illustrated in Figs. 5a, 5b, 5c. It consists of a rim-driven glass wedge located in the optical system, and positioned in the portion of the image path which is common to all three color channels (Fig. 3). The wedge, slowly driven by a small d-c motor, causes the optical images in the three pickup tubes to move in a circular orbit. Since the red, green and blue images move together, there is no resultant misregistration; the small optical taper required for orbiting produces no adverse effects on optical image quality. (In monochrome cameras, the small space in back of the lens makes it difficult to apply optical orbiting; however, an electromagnetic technique, utilizing a special deflection yoke placed over the image section of the tube, and specially generated dirve signals, rotates the electrical image on the photocathode to accomplish orbiting.)

The rotating wedge has a taper of 0.5 degrees. An exaggerated deviation is shown in Fig. 5a. The image moves in a circle with a diameter of approximately three percent of picture height, and the duration of each orbiting cycle is approximately one minute. The d-c motor, acting through a suitable gear train, drives the optical wedge mounted in the ring gear shown in Fig. 5b. The complete optical orbiting unit shown in Fig. 5c is easily installed in existing equipment, and is directly substituted for an existing assembly.

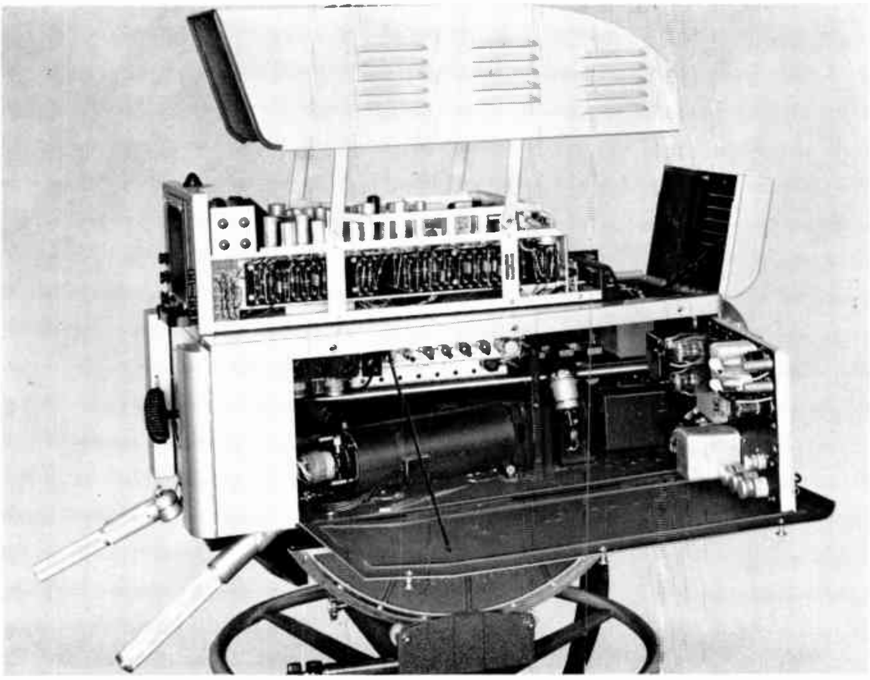


FIG. 6. View of color camera with hinged deflection chassis (right) swung out, and side door open exposing red channel, yoke assembly and video preamplifier.

Video Preamplifiers

The three video preamplifiers are identical plug-in units, each employing four shunt-peaked amplification stages followed by two feedback output stages which supply video to the viewfinder and 51-ohm camera cables. A screwdriver-operated cathode peaking control in the second stage provides for adjusting tilt at the low frequency end of the amplifier response curve. A knob control in the third stage provides adjustment for equalizing the frequency response of the video input circuit (high-peaking). These preamplifiers are located below the viewfinder in the approximate center of the camera, as can be seen in Figs. 6 and 7. Those on the right side and left side of the camera as viewed from the operator's position, are in the red and blue channels, respectively; while the one in the center is in the green channel. The three preamplifiers can be removed from the camera after first removing the viewfinder.

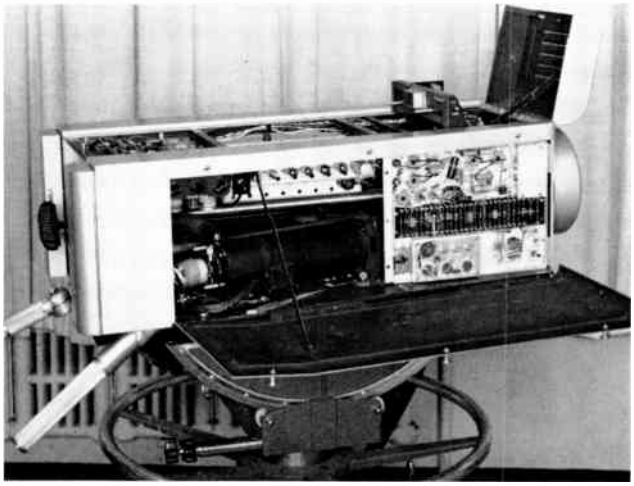


FIG. 7. Color camera with viewfinder removed to show central location of red video preamplifier.

Vertical and Horizontal Deflection Chassis

Deflection, blanking and high voltage circuits for the image orthicons are contained on two separate chassis units hinged to the corners of the camera frame, and connected to the camera circuits through plugs and jacks.

The vertical deflection and target blanking chassis is hinged to the left front corner of the camera. The vertical deflection circuits, beside producing sweep signals, also provide "skew" signals to the red and blue horizontal yokes. The skew signals serve to adjust the red and blue rasters rectangularly to match that of the green, and are controlled in amplitude and polarity by "T" pads and switches on the rear panel of the camera. The target blanking circuit utilizes two clipping amplifiers in cascade which reshape and mix the horizontal and vertical drive pulses to provide the required blanking signals. The chassis can be swung outward to provide access to the tubes of the unit and to the front portion of the camera optical system. The horizontal deflection and high voltage chassis is hinged to the right front corner of the camera, and also can be swung outward for access.

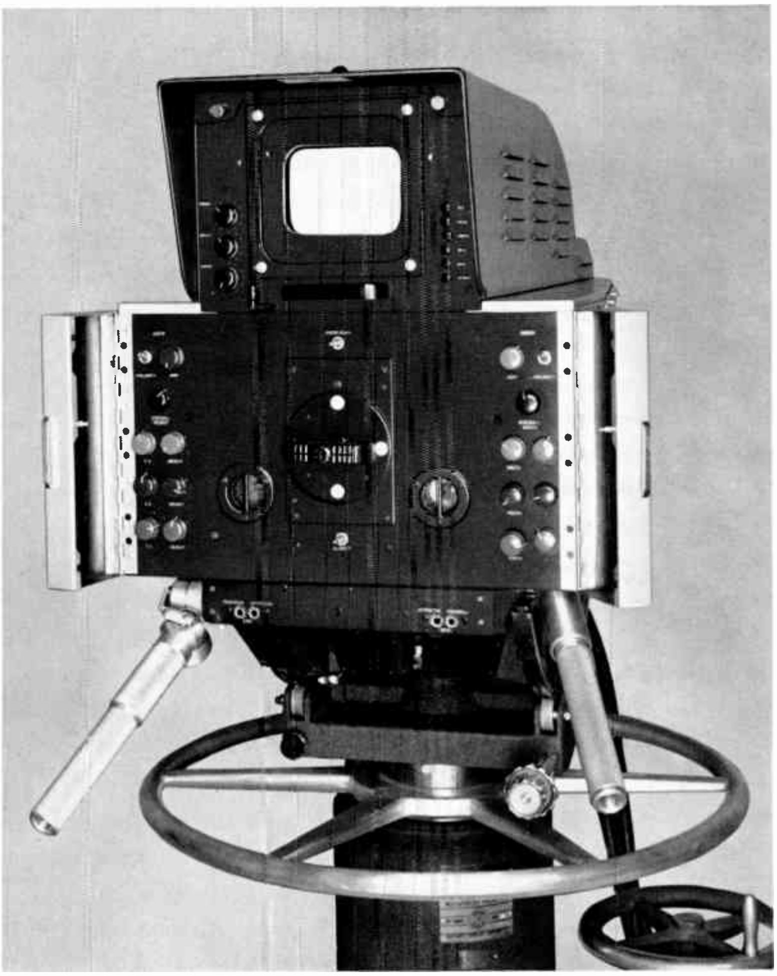


FIG. 8. Rear of camera showing setup controls and viewfinder.

Controls

Color camera system controls required for initial setup and adjustment are located at both the camera and the camera control panel. Operating controls are located at the camera control panel only.

Controls for adjustment of the camera and viewfinder circuits are arranged at the rear of the camera as shown in Fig. 8. At the top on the left side of the viewfinder panel, are focus, brightness and contrast adjustments for the viewfinder kinescope. On the right side of this panel, a series of six pushbuttons permit the camera operator to observe a monochrome image of any single channel, combinations of the red and green or blue and green channels, or all three channels combined, to facilitate registration adjustments of the three image orthicons.

Camera adjustment controls include the red and blue skew controls (with polarity reversing switches), the conventional height and width controls for three channels, and "Q" controls for the three channels. As previously stated, the skew controls are used to correct variations in some deflection yokes which produce rasters that are not perfectly rectangular. The Q controls are used to restore linearity following adjustment of the height and width controls. During program operation, these controls are enclosed by the hinged covers. The camera operator is required only to move the camera as directed via headphones connected to the intercom panel below, select the proper lens, and keep the picture in focus by observing the viewfinder image.

FIG. 9. View of camera control panel showing setup and operating controls.

Camera Control Panel

Fig. 9 shows the camera control panel on which is mounted a group of symmetrically arranged operating controls for each of the image orthicons. Colored knobs identify the controls with their respective channels. The individual channel controls include horizontal and vertical centering, alignment, orthicon focus, image focus, multiplier focus, image accelerator voltage, target voltage, and beam current. Switches adjacent to the target control knob provide a convenient means for adjusting the target two volts above cutoff. A selector switch and pin jacks permit metering of the target, orthicon focus, image focus and image accelerator voltage settings in each color channel. Also included is a synchro control for operating the remote iris of the optical system. A master pedestal control provides simultaneous adjustment of the pedestal voltage in the three channels.

The master gain (Iris) and master pedestal controls, both of which are located on the camera control panel, serve as the only operating controls once the camera has been aligned. The master gain control operates a selsyn generator which drives a selsyn motor in the camera to control the iris in the optical system. The master pedestal controls the level of pedestal voltage inserted into the signals at the processing amplifier.

Processing Amplifier

The processing amplifier performs the majority of signal processing functions of the color camera chain. The processing amplifier is usually mounted in a console section as illustrated in Fig. 10, although it is easily adapted to rack-mounting if desired.

Major circuit components consist of three plug-in video amplifiers which, in addition to amplification, perform the functions of cable compensation, blanking insertion, feedback clamping and gamma correction. A fourth and identical plug-in amplifier serves as the video section of an electronic switcher which provides a sequential display of the red, green and blue video information on the CRO.

The gamma corrector of the processing amplifier is a plug-in unit with no adjustable controls. The transfer characteristics of this unit are fixed by precision components to meet compensation requirements. Gamma stability is achieved by placing the corrector at a point in the system where black level is clamped solidly. The gamma unit is made plug-in so that the transfer characteristics can be readily changed if necessary.

The shading circuits provide both parabola and sawtooth shading for the red, green and blue channels. The horizontal shading circuit utilizes half a dual triode. A horizontal pulse of large amplitude is integrated to form a sawtooth, then integrated a second time to form a parabola. Vertical shading voltages are generated in a similar manner, but are added to the video signal at another point in the system.

All the pulse inputs required for operation of the camera chain are high impedance, loop-through connections. Thus, it is possible to operate a number of color

FIG. 10. Processing amplifier mounted in a console desk section adjacent to the camera control.

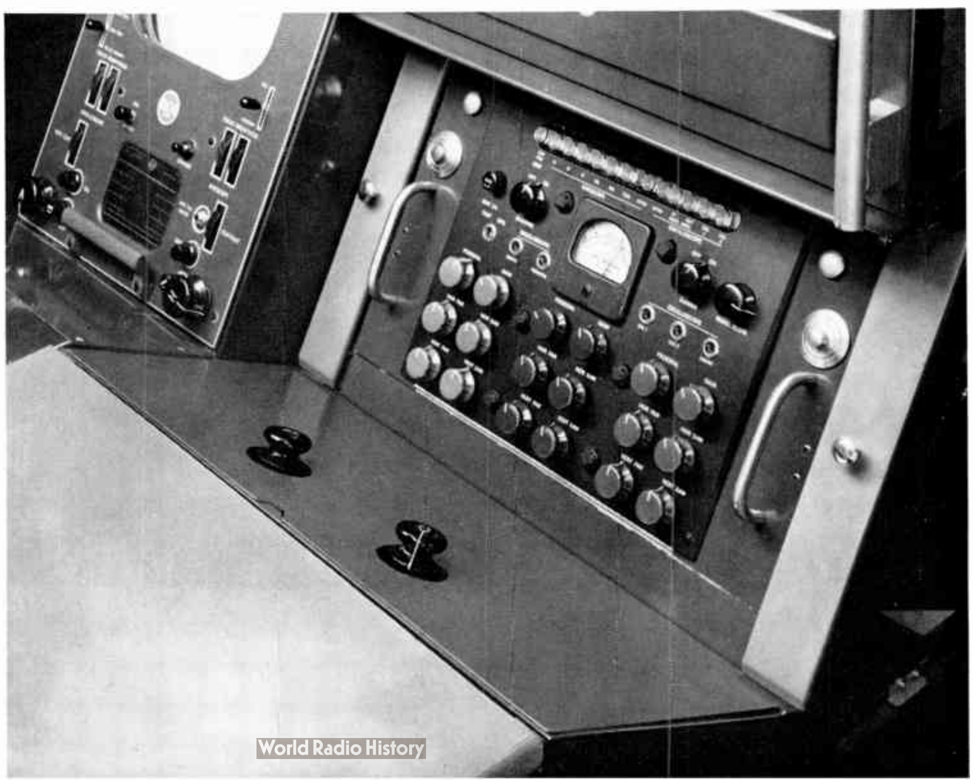


FIG. 11. Alternative method of mounting processing amplifier and master monitor in a standard cabinet rack. Camera control is shown in desk below amplifier.

camera chains without auxiliary pulse distribution amplifiers. In the case of horizontal and vertical drive, the pulses are actually regenerated in stabilized multivibrators so that the outgoing pulses are independent of the width and amplitude of the incoming pulses.

The electronic switcher and master monitor enable the video operator to simultaneously monitor all the video inputs to the colorplexers and then properly operate the gain and pedestal controls. A closeup of the pushbutton selectors is shown in Fig. 12. Seven signals can be viewed on the kinescope. The first six of these are the single color channel signals and their combinations, which are used for individual camera tube setup and registration. In addition, the output signal from the colorplexer can be viewed. Resistive isolation of the various kinescope monitoring points eliminates cross talk and prevents switching transients from appearing on outgoing lines. Simultaneous display of the R, G and B signals on the CRO is accomplished by electronically switching the CRO input at a 20-cycle rate to present sequentially one field each of the red, green and blue video waveforms. A step waveform is added to the normal sawtooth horizontal sweep of the oscilloscope to display the three signals in side-by-side fashion. Since the switching is done at a relatively slow rate, any transients generated are removed by the clamping circuits.

FIG. 12. Closeup view of processing amplifier showing pushbutton selection switches.

Factors Affecting Color Camera Performance

The following general principles underlying proper alignment and operation of the color camera, as they differ from those for monochrome cameras, are presented to assist the station engineer in understanding the effect that each adjustment can have on the composite picture. No attempt is made to present step-by-step alignment procedures, as these are outlined carefully in the TK-41 instruction book.

Although the controls for the three image orthicons in the color camera are similar to those of the monochrome camera, a few additional controls and new alignment techniques are required to permit registration of the images and proper level control of the three signals.

It is important to point out that color camera setup should be made by viewing the proper test chart. This is the only tool for a true indication of the required camera adjustments. The practice of making indiscriminate adjustments during a scene to "paint" a pleasing picture should be avoided in color camera setup; it is successful for only the specific scene, and there is too little time during programming to make the required readjustments for subsequent scenes. Also, certain controls of the camera when improperly set, give false indications that other controls are misaligned. Therefore, maximum effort should be given to correct alignment of the controls before program time. During operation, a properly aligned camera requires no more than routine adjustments of the master gain control, and an occasional adjustment of the master pedestal.

"Q" and "Skew" Controls

The "Q" controls are located on the rear panel of the camera. These controls, one for the horizontal and one for the vertical, are interconnected to the individual deflection circuits, and are utilized to affect the linearity in order to match the scans over the entire raster. A change in the settings of the individual height and width controls changes the reactance-to-resistance ratio in the deflection circuits, affecting the linearity of the channel. Adjustment of the Q control keeps the ratio and linearity the same in each channel.

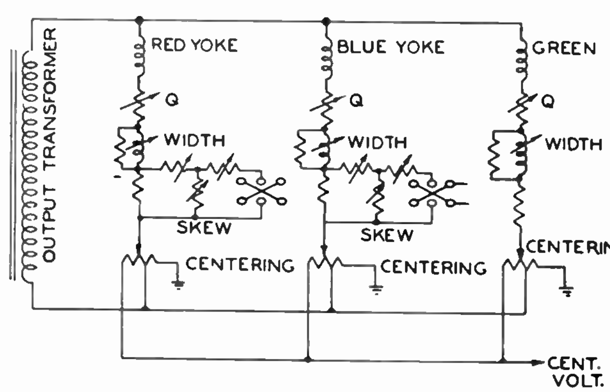
The "Skew" controls are also located on the rear panel of the camera. These controls, which are connected in the red and blue channels, introduce a small amount of sawtooth waveform at a vertical rate into the horizontal deflection yoke to center the horizontal scan by different amounts at the top and bottom of the raster. This serves to compensate for normal manufacturing tolerances in the axial placement of the yokes. This variation results in a slightly rhomboidal shaped raster, different in each channel. This amounts to only a degree or two and is not noticeable in monochrome cameras where only one signal is used. The need for skew adjustment is seen on the kinescope when the vertical lines of two superimposed channels are not parallel after the horizontal lines have been made parallel with yoke rotation.

Test Chart Lighting

It is already apparent to monochrome television broadcasters that good lighting techniques are of utmost importance in obtaining good pictures. This holds true for color operation, where requirements are even more stringent. A very important phase of aligning television cameras, often overlooked by the engineer, is that of lighting the test pattern. The amount of light is not important provided the level is at least high enough to bring the highlights a little above the "knee" of the image orthicon transfer characteristic when the remote iris is wide open. Of utmost importance, however, is the placement of lights.

An evenly lighted pattern with a minimum of surface reflectance may be obtained with two equal size scoops equidistantly placed at 45 degree angles to the chart. For angles less than 45 degrees, a large amount of surface or direct reflection may enter the camera lens. The image on the photocathode then contains excessive ambient light that gives a distorted gray scale and upsets the true black level. The scoops should also be at the same height as the chart. Direct light from all other scoops and spots should not be allowed to fall on the chart. If the pedestals are first matched with the lens capped, and if no surface reflectance is present, very little adjustment of the individual pedestals should be required to match the black levels of the test chart. If the "knees" and pedestals have been matched when viewing an improperly lighted test chart, the color balance will be distorted in both highlights and low lights when the scene is shifted to the studio set.

FIG. 13. Schematic diagram of horizontal scanning circuit showing location of Q and Skew controls.



Objective Lens Iris Setting

When more than one lens iris is contained in an optical system, the overall aperture and depth of field is defined by the lens that is stopped down to the greatest "f" number. Since the remotely controlled iris is in the relay lens, which has a speed of f-4, the objective lens should be set to f-4 so it will not limit the maximum overall aperture. Opening the objective lens greater than f-4 will only add flare light to the picture.

Image Orthicon Operation

The color image orthicon is designed especially for color work. The alignment techniques for this tube follow very closely in accordance with best monochrome practice using the type 5820 image orthicon; however, the nature of the color signal, composed of the mixed outputs of three image orthicons, requires a more precise degree of signal uniformity and freedom from spurious signals. Manufacturing tolerances have therefore been tightened for the color tube and each image orthicon is system-tested to rigid specifications in order to assure uniform characteristics of the tubes. This eliminates the necessity of buying image orthicons for the color camera in matched sets of three, and allows any tube to be replaced by another without replacing the entire set.

It is common monochrome practice to operate the image orthicon above the "knee" of its transfer characteristic since this offers a better signal-to-noise ratio and partially corrects gamma in the signal, also the redistribution effect of secondary electrons on the target preserves the fine detail in the highlights. For color operation however, the image orthicon must be free of any random redistribution that will distort the color information. Furthermore it must also be operated below the "knee" over a constant gamma range.

The capacity of the target assembly has been increased in the color version over that of the 5820 by reducing the screen-to-target spacing. This extends the contrast range and improves the signal-to-noise ratio below the "knee". The closer spacing allows the screen to collect more of the secondaries from the target. This eliminates random secondary redistribution of the target and eliminates "ghost" and "halo" effects. It has been found that the color tube is difficult to handle for large changes of light level reaching the photocathode, so the 5820 is still preferred for monochrome operation where the highlights are allowed to extend above the "knee".

An important consideration when initially aligning a color camera is that all image orthicons should be operated at about the same conditions. Targets should be maintained at two volts above cut-off, and the G-4 (Orth Focus) potentials set about equal.

Shading

Extreme care should be taken to obtain the best shading characteristics from the image orthicons rather than correcting later in the system with the shading signals provided in the processing amplifier. These shading signals superimposed on the video signal are fixed amplitude waveforms and therefore can correct properly at only one video amplitude level. At other video amplitude levels the same amount of shading signal is superimposed, but the shading component originating in the image orthicon may vary as a function of the video amplitude.

The shading component is due mainly to a change in the current amplification in the multiplier section as the return beam scans a small area of the first dynode. The effect of any variations of the secondary emission ratio over the first dynode will be amplified in the other dynode sections. Therefore, special care is taken in manufacturing the color tube to assure the most uniform and stable secondary emission characteristics of the first and second dynodes, and uniform collection of the secondary electrons.

The color camera requires careful adjustment for best shading because slight differences in the shading components from the three image orthicons will result in severe color distortion, especially in the low lights. This is seen as spurious changes of hue superimposed over the dark areas of the color picture.

The amplitude of the shading component is a function of the return beam and therefore is greatest in the dark areas where the return beam is maximum, and decreases toward the highlight areas where the return beam is decreased. All operation on the shading characteristics of the image orthicon should be made with the lens capped. This represents the worst case of shading, since the beam is then completely returned to the first dynode.

The shading generator in the processing amplifier inserts a constant waveshape into the video signal which adds the same amplitude to the dark areas as to the highlight areas, so that the shading generator signal does not completely cancel the shading component over the entire gray scale. For this reason the best shading possible should first be obtained out of the image orthicon with the shading generator cut off. The necessary shading generator signal should then be added to give the flatest waveform as seen on the CRO. This adjustment is also made with the lens capped, since in dark areas of the picture a given shading component represents a larger percentage of the signal than in the highlight areas.

G-5 Control

Reducing the potential on G-5 (Decelerator Grid) decreases the area scanned by the return beam on the first dynode. This potential should be set as high as possible in order to avoid burning the first dynode. G-5 also serves to cause the beam to approach the target perpendicularly at the edges. This eliminates "porthole-

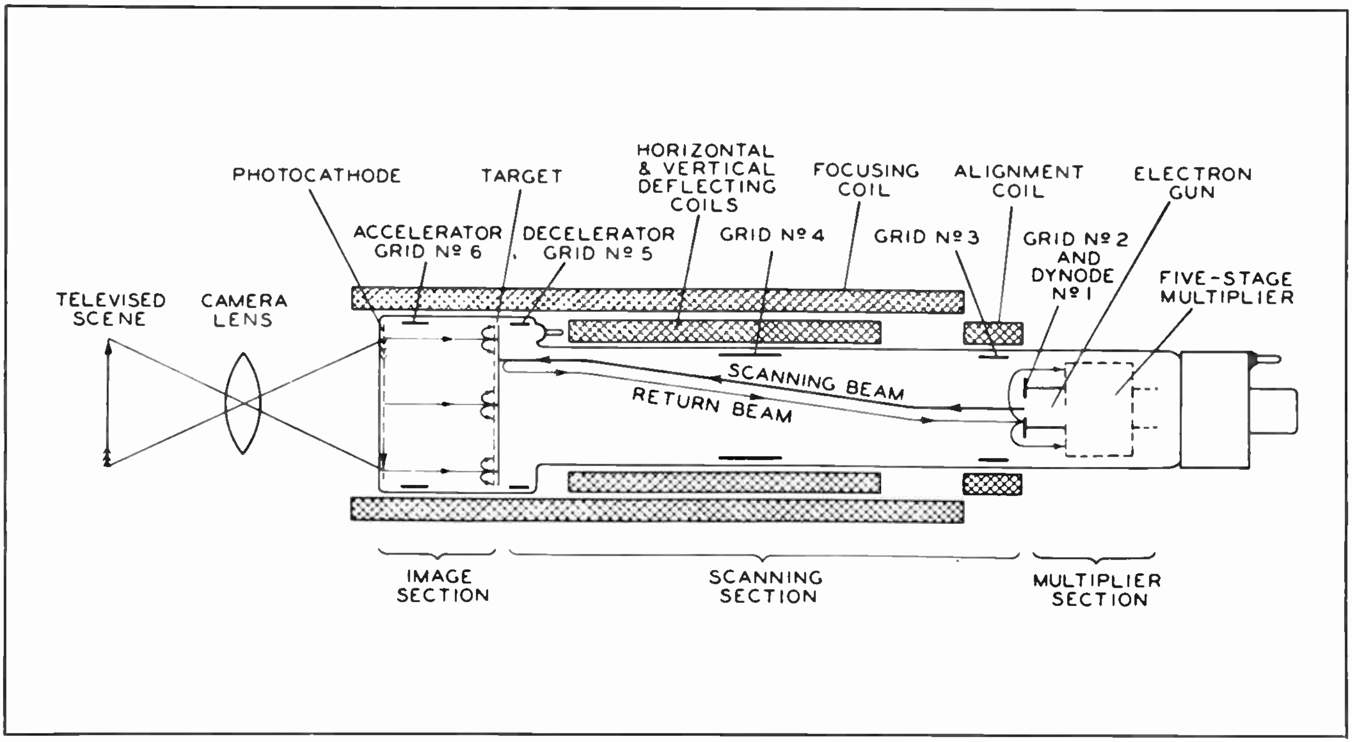


FIG. 14. Diagram showing elements of the image orthicon pickup tube.

ing" a dark ring around the edges. "Portholeing" is introduced as the G-5 potential is reduced. The proximity of G-5 to the target corners causes the potential on G-5 to influence the scanning geometry at the corners of the picture.

Because of the three effects mentioned above, G-5 should be run as far clockwise as possible, consistent with good shading. It is decreased to reduce any shading component in the corners due to variation in the secondary emission ratio over the first dynode. It is also decreased to scan the first dynode inside any burned areas which appear as "clouds" or white streaks when the lens is capped. If difficulty is experienced in registering the corners of the three image orthicons, it may be necessary to decrease the G-5 potential on one or both of the other image orthicons if the third G-5 has been reduced for shading considerations.

The area of the first dynode scanned by the return beam is also directly controlled by the deflection field. The centering and overall size controls may therefore be used to improve shading, but it is usually desirable to set these controls to scan as large an area of the target as possible.

Multiplier Focus

The potential on G-3 (Multi-Focus) influences the shape of the electrostatic field between the first and second dynodes. This field, in combination with the magnetic focus field, serves to collect the secondary electrons emitted from the first dynode and attract them toward the second dynode. It is essential for good shading characteristics that this field be uniform over the area scanned on the first dynode by the return beam. The G-3 potential will affect the peak video amplitude by collecting more or less of the total secondary electrons. In the case of the color camera the G-3 potential should be set for best shading rather than for maximum amplitude.

Beam Alignment and Landing

The alignment controls are initially set with the lens capped in order to cause the first dynode aperture spot to go in and out of focus without swirling when the Orth Focus Control is rocked back and forth slightly. This Orth Focus adjustment indicates that the beam is leaving the electron gun along the axis of the tube normal to the target. As the beam scans across the target, the decelerator grid (G-5) serves to keep the beam normal to the target over the entire raster; the variation in angular velocity of the beam as it approaches the target is therefore held to a minimum. The electrons drawn from the beam to the target sohuld then be entirely a function of the stored charge and not of the angular velocity.

The principle of the return beam being partially a function of the angle at which the beam approaches the target may be utilized by displacing the beam from scanning symmetrically about the tube axis. This displacement can compensate for any slight non-uniformity of target sensitivity or for slight angular assembly of the target. The need for correcting the beam landing is seen on the color monitor when the color balance in the highlights is not uniform over the entire raster. When viewing a resolution chart or a gray card, the amplitude of the video signal in the highlights as viewed on the CRO will slope to one side or the other at either a horizontal or vertical rate. This should not be corrected by the shading generator for reasons pointed out earlier. This slope may be corrected without affecting the shading in the low lights by displacing the alignment controls slightly from optimum.

Image Accelerator

The image accelerator (G-6) is set in the same manner as in monochrome operation; however, like the other controls, it is more critical for the color camera, because the result must be matched by all three image orthicons. G-6 should be set for minimum "S" distortion of horizonal lines when viewing the registration chart. "S" distortion can be more critically detected by superimposing a grating generator signal of horizontal bars or by panning the camera slowly back and forth. If "S" distortion of horizontal lines cannot be eliminated entirely in all three channels, the final criterion for setting the Image Accelerator should be for best registration of the horizontal lines.

Registration

Final registration adjustments should be made only after all image orthicons have been individually aligned for best picture. Besides those controls already mentioned that affect the geometry of the picture, there are several others that the operator may have a tendency to touch up that would cause misregistration. These are Orth Focus, Image Focus, and the alignment controls. These are adjusted in much the same manner as in monochrome camera operation. If any of these are changed after the camera has been registered, registration should be rechecked.

The best registration of the three images occurs when both the electrical and optical registration adjustments are individually set to optimum conditions. The operator should avoid using one adjustment to compensate for misalignment of another. It is difficult to set the front surface mirrors properly in the blue and red channels if the electrical images are not of approximately the same size and linearity, and likewise it is sometimes impossible to match the three scans if the mirrors are not aligned.

Centering

It is important to remember that it is always desirable to scan the largest possible area of proper aspect ratio within the target ring. After this is done the electrical centering controls are then held fixed, and the centering positioning of the red and blue picture to match the green is achieved with the front surface mirrors. The tilt adjustment of the mirrors (for vertical optical centering) should always be set before the mirror rotational adjustment (for horizontal optical centering, because a tilt of the mirror also produces some effective rotation of the image. Any image rotation introduced by tilting the mirrors may be corrected by rotating the deflection yokes.

Focus Tracking

The three yoke assemblies are positioned after the mirror adjustment to cause proper focus tracking. This should be done with the remote iris control set wide open (f-4) for minimum depth of field, or the most critical focus to be encountered. To be able to make optical focus from extreme close-in shots to infinity for all objective lenses it is necessary that the image stay in focus at both the focal plane of the field lens and the photocathode of the image orthicons. It is possible when viewing a distant object to position the yoke assemblies to obtain focus on the photocathodes without the image being in focus exactly at the focal plane of the field lens. However, under these conditions, a point may be reached as the camera is moved very close to the subject where it will become impossible to make optical focus.

Amount of Scan

The individual heights and widths should be matched, and the overall height and width set for proper size and aspect ratio. The proper amount of scan for new image orthicons is that which will just show the target corners when in the "Overscan" position. All corners should disappear when the overscan switch is thrown to "Normal." The overscan position does not apply maximum scan, but is designed to increase the pre-set amount of scan by about 15%. When looking for the target corners care should be taken not to confuse corners that may be inserted due to misalignment of the field lens mask, or due to excessive compression of the sponge rubber light shield bellows. As the image orthicons age it may be desirable to reduce the scan in order to obtain better shading characteristics.

After the sizes have been matched and the individual linearities adjusted (with the "Q" controls) for an approximate match over the entire raster the superimposed pictures will be in better condition to see the need for finer mirror adjustments. Again set the electrical centering controls to scan the center of each target and then make final adjustments on the front surface mirrors.

In order to see the amount and direction of electrical misregistration more clearly, the two superimposed pictures of the registration chart should be displaced slightly by electrical centering, because a difference in line separation is easier to detect than differences in overlapped lines. The individual height and width controls may then be operated to make the separation of the lines equal around the edges of the raster, and the Horizontal "Q" and Vertical "Q" used to separate the lines in the center by an amount equal to that at the edges. The horizontal lines should be made to be parallel with yoke rotation before paralleling the vertical lines with the Skew controls.

Color Balance

The *shapes* of the spectral responses in the color camera are fixed by dichroic mirrors and trimming fitters to conform to the color mixture curves for the primaries standardized by the FCC; however the relative *amplitudes* of the primary colors can be controlled by use of the individual gain controls and individual pedestals. The relative amplitude of each primary color signal to be transmitted is established by the fact that reference white must be transmitted with no color information, i.e., the subcarrier must vanish during the transmission of a neutral color. Since the colorplexer is designed to cancel out the color subcarrier when all three inputs are equal, the gains and pedestals on the camera should be set for equal outputs from all channels when viewing a neutral surface. Since a neutral object reflects light into the camera of the same spectral quality as the illuminant, it is apparent that the relative gains to which the three channels are adjusted will depend on the spectral quality of the illuminant being used. The pedestals are, of course, set for equal black level information. When gain and pedestal are properly set for highlights and lowlights respectively, maintenance of a proper gray scale in between these two levels depends on how well the transfer characteristics are matched.

The transfer characteristic of the kinescope is for all practical purposes assumed to be fixed; however, that of the image orthicon is a function of the potential above cut-off on the target. A potential of two volts above cut-off on the target gives the most constant gamma characteristics. The gamma corrector amplifiers are therefore designed to correct for image orthicons operated at two volts above cut-off on the target. The target test switch on the control panel is provided for setting the target at two volts above cut-off. When setting the target to cut-off with the switch in "test" position the pedestal should be raised and the brightness on the monitor increased so that the signal is not clipped. When all targets are operated at two volts above cut-off they all have the same gamma characteristics below the "knee." Therefore, in order to match the three transfer characteristics it is necessary then to match the "knees."

Matching Transfer Characteristics

If the iris is opened from a closed position when viewing the gray scale chart, three factors will determine which image orthicon reaches the "knee" first: the spectral quality of the illuminant; the relative light transmitting efficiencies of the three channels; and the relative image section sensitivities of the image orthicons. In order that all three image orthicons may be operated over the same portion of their transfer characteristics, neutral density filters are inserted in the "hottest" channels just ahead of the image orthicons. This reduces the peak highlights to a point on the transfer characteristic of the "hottest" channels to that of the least sensitive channel.

It is desirable to attenuate the incident light with the least possible amount of neutral density filters in order to keep the overall sensitivity of the camera as high as possible. The least sensitive image orthicon should be placed in the most sensitive channel, and vice-versa.

When looking for the "knee" care should be taken to have the beam sufficiently high that a fold-over due to the target not being completely discharged is not mistaken for a compression due to the "knee." Too much beam, of course, will add noise and shading to the signal, and the highlights will not be clearly defined. The dynode gains should be held so the highlights do not exceed about 0.3 volt on the master monitor CRO when the "input" signal is punched up on the processing amplifier. This is to be sure that no amplifiers are overloading.

A suggested method that will reduce the trial and error time required for selecting the proper neutral density filters when viewing the gray scale chart is as follows:

1. Consider only one channel at a time.
2. Set the iris so the highlight of one channel is at the "knee."
3. Set the dynode gain of that channel so the highlight falls at about 0.3 volt input to the processing amplifier.
4. Set the processing amplifier gain of that channel so the highlight falls right at the 0.7 volt calibration mark when the processing amplifier is on the "Output" position. (The 0.7 volt level then marks the "knee" for that channel regardless of where the iris is set, provided the pedestal is not changed.)
5. Repeat the above for each of the other two channels.
6. Set the iris so the highlight in the least sensitive channel falls at the "knee," or 0.7 volt output level.
7. Hold neutral density filters in front of the objective lens to determine the amount required for each of the more sensitive channels, so that highlights may be brought to the one volt level, the "knee" for that channel.
8. Remove the light shield and insert the neutral density filters into their proper channel.

Gain Controls

The importance of operating with an overall linear system, in order to faithfully reproduce colors over the entire luminance range, stresses the fact that the image orthicons must not be operated above the "knee" of their transfer characteristics. For the greatest contrast range and best signal-to-noise ratio, the brightest highlight should be allowed to fall just at the "knee" by operation of the remote iris control (Master Gain). Since the colorplexers are designed for a peak input signal of 0.7 volt, it would be desirable to have the "knee" represent 0.7 volt out of the processing amplifier. If the gains of each channel are adjusted for 0.7 volt out of the processing amplifier when the highlight is just at the "knee," the 0.7 volt calibration mark on the master monitor CRO will then serve as a reference for the position of the "knee."

Pedestals

The 0.7 volt level at the "knee" is set with the individual gain controls after the pedestals have all been adjusted to about a 5% set-up. If the pedestal is changed after the 0.7 volt output level has been set, the reference black will be changed from its 0.7 volt below the "knee" position, and the 0.7 volt calibration on the CRO will no longer represent the "knee." For this reason the gray-scale chart should have a contrast range similar to that of the scene to be televised, or about 30 : 1. Standard gray scale charts fulfill this requirement. In order to keep the "knee" at the 0.7 volt output position, the Master Pedestal should be touched as little as possible during operation.

It is often necessary to adjust the Master Pedestal for a more pleasing picture, however, such as in extreme close-ups where the darkest video level may actually be quite high; but it should be kept in mind that if the pedestal is lowered (blanking decreased) the "knee" will fall below the 0.7 volt level, and if the pedestal is raised (blanking increased) the "knee" will fall above the 0.7 volt level. During operation of the camera the iris is adjusted such that the highlight in the channel with the greatest peak video amplitude is held as high as possible, for best signal-to-noise, without exceeding either the "knee" or the 0.7 volt output level.

Final Color Balance

By observing the output of the colorplexer on a CRO when viewing the gray scale chart or the resolution chart, no subcarrier should be present (seen as a thickening of the lines) if the transfer characteristics of the three channels are perfectly matched and the colorplexer is perfectly balanced. The individual pedestals and gains on the processing amplifier should be touched up to cancel the subcarrier in the lowlights and highlights respectively. Another check for proper color balance is to switch the "Chroma" on the color monitor on and off while viewing the signal from the camera focused on the gray scale chart or the resolution chart. No change in the color balance of the monitor should take place if the camera chain is proper balanced.

Lighting and Subject Material

The most carefully aligned camera chain cannot give an accurate reproduction from a poorly lighted scene, or from a poor selection of subject material. The most important aspect of studio lighting and material selection peculiar to color television is to restrict the reflected light contrast of the scene to the contrast capabilities of the system. For an average scene being reproduced on the kinescope under typical viewing conditions the contrast between the brightest and darkest areas cannot exceed about 20 or 30 to 1. This is restricted at the high end due to the limited luminance capabilities of the kinescope and at the low end due to stray light and "spillover" in the kinescope and the ambient illumination.

Since the iris at the camera is adjusted so the brightest area in the scene is set at the "knee," or the maximum transmitted level, the areas with luminance values less than 1/20 the luminance of the brightest area will become de-saturated or be lost in the black level. Very bright areas allowed in the scene may therefore cause some critical colors, such as flesh tones, to be forced far down in the luminance range with the result of color distortion at the kinescope. If the iris is opened to improve the flesh tone reproduction, then the highlights will extend over the "knee," and the brightest colors will become de-saturated and some amplifiers will overload. For large dark areas in a scene where the contrast range exceeds 20:1 the shading component of the image orthicons becomes an appreciable amount of the signal, and the reproduced colors will be distorted in the low lights.

Flourescent lights should not be used where color fidelity is important. The spectral distribution is broken by excessive radiation over certain narrow bands of the spectrum.

The amount of light entering the camera lens depends, of course, on both the illumination on the subject and the reflectance value of the subject. All material to be used in the scene that has excessive reflectance and very low reflectance should be screened out before going on the air. A light gray shirt, for instance, will be reproduced as a white, when the iris is properly set, without forcing the other colors down in luminance value. The white areas in show cards that contain color should also be grayed down. Observation of the CRO waveform will give an indication of which subjects are exceeding the desired contrast range. The scene contrast may also be checked with a comparison type light meter such as the Luckiesh-Taylor Brightness Meter, or the McBeth Illuminometer.

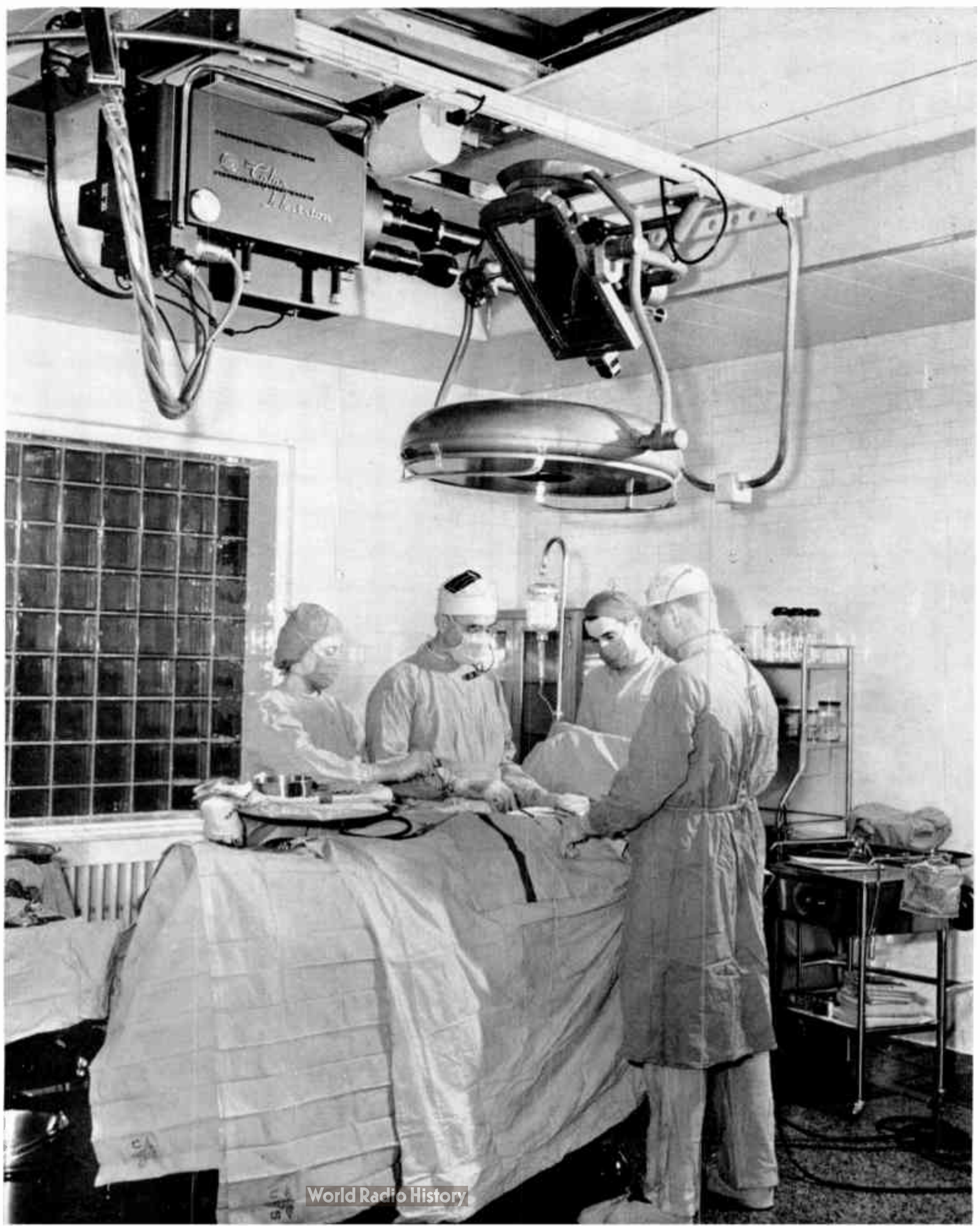
TK-45 3-Vidicon Color Camera

The RCA TK-45 Vidicon Color Camera is a compact and economical color camera chain employing the new Type 7038 Vidicon pickup tube.

The TK-45 is used primarily in hospital rooms to produce live color pictures of surgery for medical instruction, although it is useful in any application where adequate light can be made available. A light level of approximatetly 2500 foot-candles is required by the Vidicon color chain to produce high quality pictures. Possible industrial applications of the Vidicon color camera include observation of combustion efficiency in jet exhausts, open hearths and blast furnaces.

The Type 7038 Vidicon pickup tube has no side tip seal-off. This design feature permits use of smaller deflection components for the tube, and a significant overall reduction in camera size. Provision for remote control of the camera lens turret and optical focus mechanisms facilitates use of the camera in hazardous areas or in locations where it is impractical to have an operator. The camera can be mounted, without the viewfinder, at its top when suspended for hospital surgical applications as shown in Fig. 13, or it can be attached to a cradle head for standard pedestal mounting as can be seen in Fig. 14.

FIG. 15. TK-45 color camera suspended overhead and focused on the operating field by a special mirror.



Vidicon Color Camera Chain

Component units of the complete camera chain are shown in block diagram form in Fig. 16. The processing amplifiers, colorplexer, aperture compensator, automatic carrier balance, master monitor and power supplies are identical to those previously described for the image orthicon camera chain. The camera auxiliary, camera control, utility amplifier and shading amplifier are customarily mounted at the operating position in a console desk section adjacent to the master monitor; although provisions can be made for rack-mounting, if desired.

The processing amplifier inserts pedestal, adds gamma correction, generates shading signals, provides monitor and CRO switching, and delivers the correct video level to the colorplexer. The colorplexer, which is also described in another section, performs the necessary matrixing and modulation to provide a standard color signal. A modulation type shading generator is used, the gain of which varies in proportion to the shading waveform supplied by the processing amplifier. The utility amplifier is necessary in the chain to effectively cancel the vidicon dark current and provide more system gain. Gain of the amplifier is adjusted remotely by a set of push-buttons at the control position. The camera auxiliary unit provides regulated focus and alignment current for the camera subchassis.

As an accurate means for measuring vidicon signal current, a calibration pulse equal in amplitude to the recommended peak beam current of the vidicon, is injected into the preamplifier input by depressing a button at the camera operating position. This also provides an indication of the gain of the system. In addition to supplying a video signal to the control position, a second output is provided to a monitor amplifier in the camera. This amplifier with its associated circuitry provides the necessary mixing of signals and feeds them to the viewfinder for registration purposes. An external monitor also can be fed from this circuitry during the initial setup of the equipment. This is advantageous in installations where no viewfinder is used, and the equipment cannot be located near the operating position. The camera will operate properly with cable runs up to 500 feet.

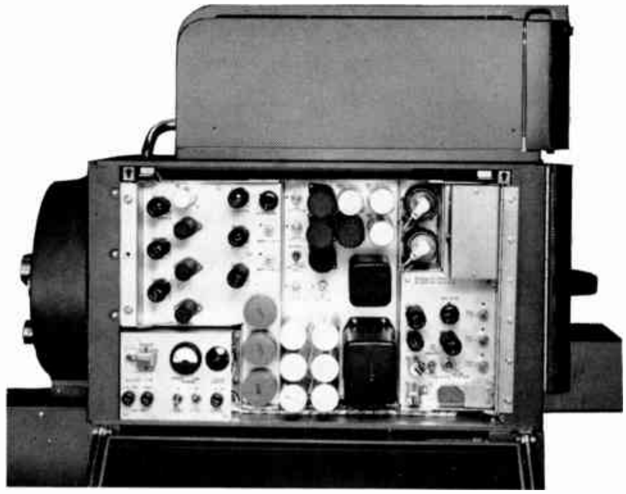


FIG. 17. Left side view of camera with hinged door lowered to show deflection chassis and associated components.

Camera

The TK-45 Camera contains the three vidicon pickup tubes with associated deflection and high voltage circuitry, a four-position lens turret, relay optical system and three video preamplifiers.

The deflection circuits are contained on recessed type chassis mounted vertically on the left side of the camera, as shown in Fig. 17. The three preamplifiers are mounted

FIG. 16. Functional block diagram of vidicon color camera chain.

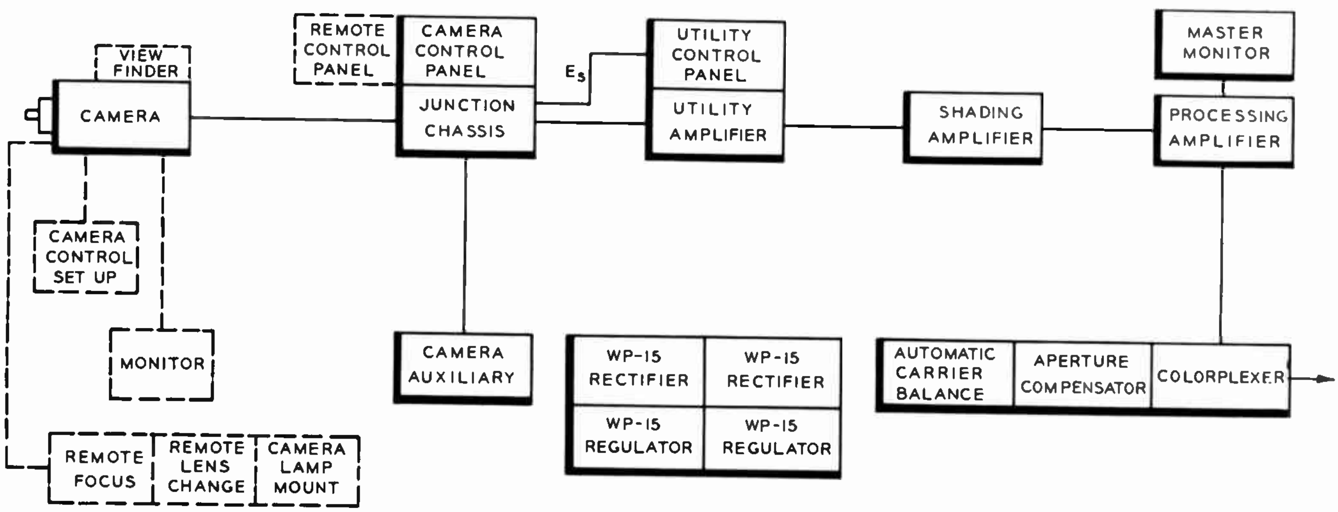


FIG. 18. Pedestal-mounted TK-45 vidicon color camera, shown equipped with remote-control lens change unit.

on the right side, as shown in Fig. 19. The preamplifiers are shock mounted to minimize microphonics, and hinged to provide withdrawal for ease of servicing. Each employs a low-noise cascode input stage to provide the best possible signal-to-noise ratio.

The camera control contains circuitry to operate the camera remotely. A feature of this unit is a plug-in control panel which can be taken physically to the camera for setup purposes and then returned to its normal operating position at the control desk.

Components of the relay optical system are arranged as shown in Fig. 20. The optical image formed in the field lens by the objective lens in use, is separated into red, green and blue components by the dichroics, shaped by trimming filters, and transferred to the photocathodes of the vidicons by the three relay lenses. The system features a dichroic film cemented between glass prisms. Use of these prisms simplifies cleaning, and eliminates inherent secondary reflection encountered when using dichroic-coated glass plates. As another point of interest, the front-surface mirrors previously used in the light path are included as part of the prism. Advantage is taken of the fact that almost total reflection takes place from a glass-to-air surface, set at 45 degrees to a light ray. No coating is used.

Since the vidicon has no seal-off tip on its side, the tube can be inserted in the yoke assembly from the rear. This has the advantage of keeping all mechanical adjustments associated with the vidicon faceplate securely locked in position. Complete support of the lens turret is provided by the front bearing to minimize bending and binding of the turret shaft. Ball bushings for longitudinal travel, and ball bearings for rotation, are used to reduce static friction of the system to a negligible amount under conditions of remote drive.

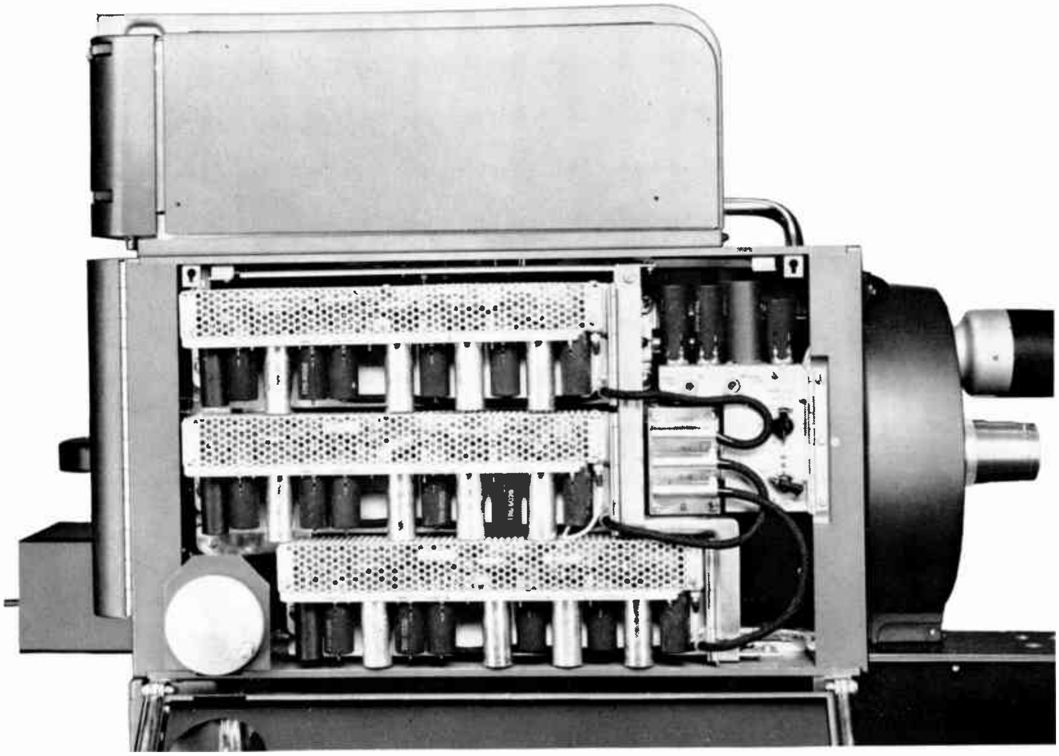
Remote Operation

When using the equipment in hazardous areas or in places where it is impractical to have a cameraman, provision has been made for controlling the turret rotation and the optical focus from a remote position.

A special control panel is located at the operating position for controlling the turret rotation, focus, and the pan and tilt of the mirror associated with the medical mounts.

The unit for remote lens change mounts under the front portion of the camera and is coupled by a toothed belt to the turret shaft. A geneva movement is utilized in this unit to minimize stresses in the lens mount where long focal lengths are required. The time between lens positions is two seconds. Lens selection is accomplished by pushing one of four pushbuttons located on the remote control panel. Local control is provided on the unit to simplify preliminary adjustment of the camera.

FIG. 19. Right side view of camera with door lowered to show hinged video preamplifier chassis.



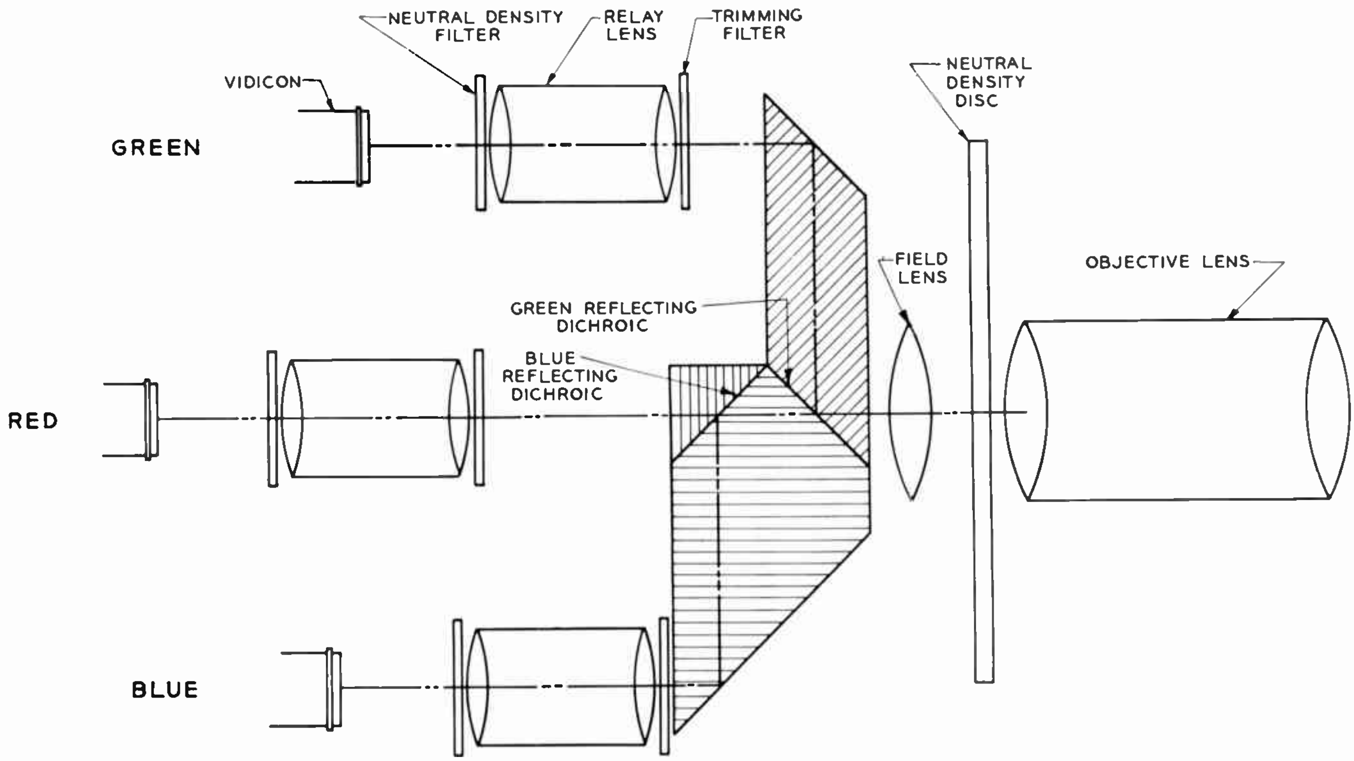
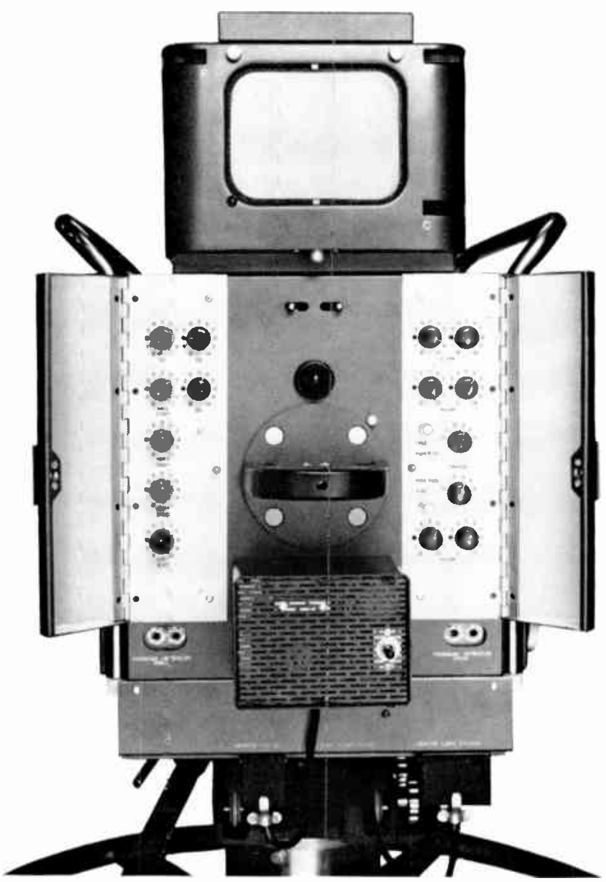


FIG. 20. Diagram of camera optical system.

FIG. 21. Rear view of camera showing vidicon controls, lens turret handle (center), and remote-control focus unit.



The remote focus unit is attached to the rear of the camera. This unit provides a full two and one-half inches of travel in ten seconds. Focusing is accomplished by operating a lever key located on the remote control panel. Local control is provided on the unit to simplify preliminary adjustment of the camera.

Surgical Installation

For surgical operating room applications a system of crosstracks is mounted to the ceiling. Suspended at opposite ends of a common boom are a camera and a lamp. A coaxial system of camera and operating lamp optical axes was chosen since with this method the camera automatically follows the positioning of the lamp with no mechanical interference problems. Best illumination is along the axis of a surgical lamp, which makes coaxial viewing with the camera ideal, especially where relatively small and deep operations are concerned. A mirror is suspended at a nominal angle of forty-five degrees over the center of the lamp through which a hole is provided so that the camera can view the operation. The lamp may be moved from its normal vertical position forty-five degrees in any direction except away from the camera where it is restricted to thirty degrees. The mirror assembly is coupled to the lamp in a manner that keeps the camera optical axis on the lamp optical axis for any position of the lamp. Remote control of pan and tilt of the mirror assembly is provided to allow the camera to explore within the illuminated area of the lamp.

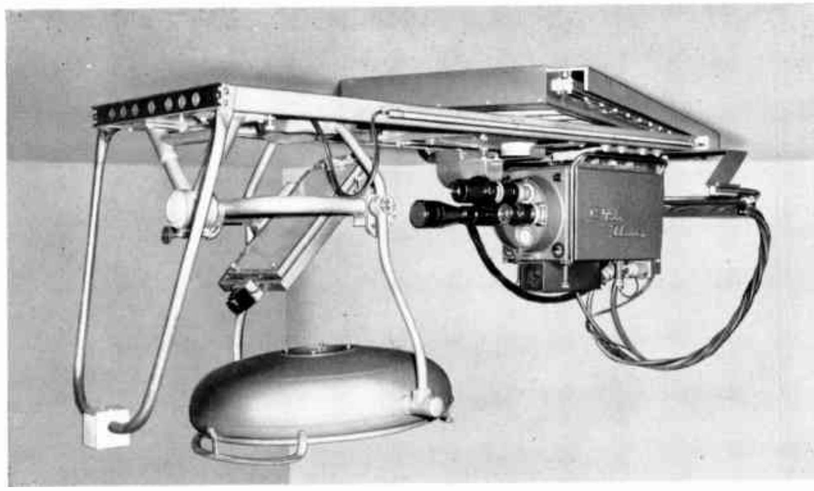


FIG. 22. Typical TK-45 camera overhead mounting for surgical use employs a system of cross-tracks with camera, lamp and mirror suspended.

Normally the camera is in front of the operating surgeon with the lamp positioned in such a manner as to supply light over his shoulder. This arrangement gives the camera the same field of view as the surgeon. Since the orientation of this field is very important to those who are viewing the picture, deflection reversal switches are provided on the camera so that during preliminary setup the desired orientation may be obtained. The camera lamp system can travel in both horizontal directions on the overhead tracks and can swivel a full 360°. The ceiling fixture for mounting the camera in an operating room is shown in Figure 22.

To obtain the small fields of view involved in the surgical application of this camera, lenses of considerable focal length must be used at relatively short throw distances. Since the light transmission capability of lenses used at low magnification is reduced, it is necessary to have more than the 1500 foot-candles of incident light to obtain the minimum light requirement on the vidicon photosurface. The need for extra illumination is aggravated by the difficulty of illuminating deep cavities. The approximate fields of view provided by the standard complement of lenses are:

Lens	*Field of View (inches)*
18 inch	2.9 x 3.8
13 inch	5.5 x 7.4
8½ inch	9.6 x 12.8

Vidicon Sensitivity

When low light levels are encountered, the sensitivity of the vidicon may be increased by raising the voltage across the photosurface which increases the lag or the apparent smearing of moving objects. Lag is probably most easily understood as the inability of the scanning beam to remove all of the energy stored in the photosurface on the first scan. Some energy remains to be removed on later scans after the subject has moved. The result is smearing of moving objects.

The surgical use of the camera is an example of an application where lag is not a serious problem since the scene being televised contains subject material which has relatively slow movement. Added sensitivity of the system may be gained by increasing the video gain of the system until the limit of the system sensitivity is determined by the resultant signal-to-noise ratio.

Another factor to be considered when raising the signal electrode voltage to increase the sensitivity is dark current. This is a current which flows through the photosurface of the vidicon in the absence of light and varies as a power function of the voltage impressed across the photosurface. In the film application of the vidicon where sufficient light is available and the signal electrode voltage is low, the dark current is a negligible portion of the signal. In the live pick-up application, the dark current can become an appreciable portion of the required video signal. Since this dark current exhibits itself as a false pedestal (black level shift) which is not normally the same in all three channels, a means for injecting an equal and opposite polarity signal is provided for cancellation.

Compensation for the variations in scene illumination or highlight reflectance is accomplished by the adjustment of a neutral variable density disk in the common light path. This method of keeping the video output signal of the camera chain at a constant level is preferred over other methods of adjusting the system gain electrically. The above method allows the setup of all electrical controls to the optimum point and effectively provides a method of varying scene illumination. Being in the common light path, there are no tracking problems. This disk is remotely controlled from the camera operating position.

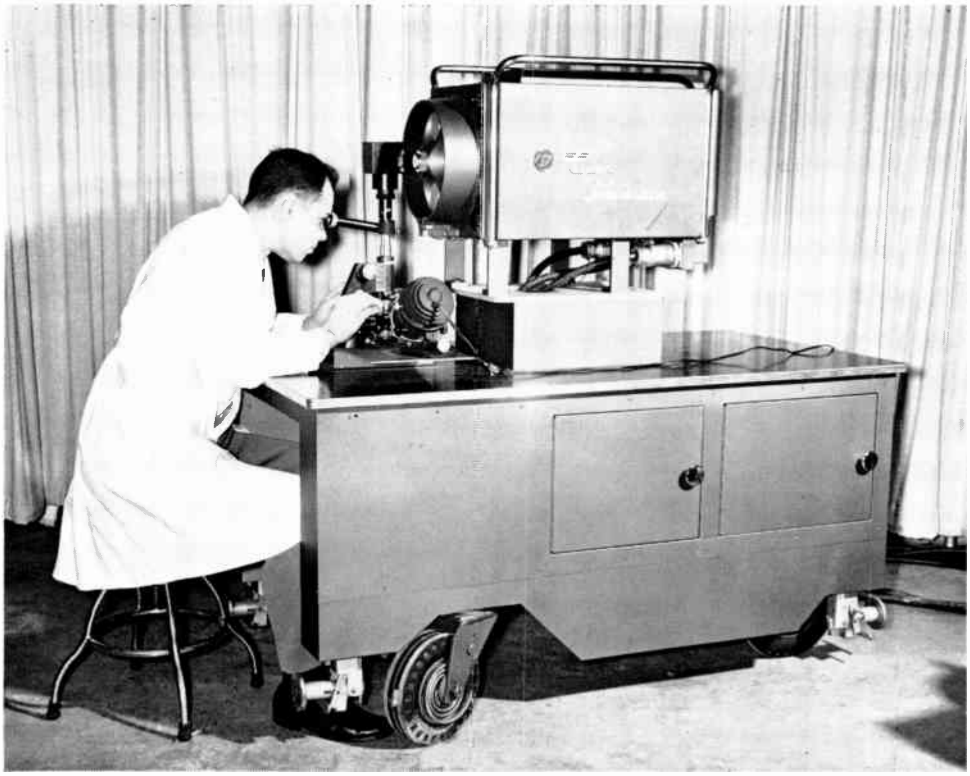


FIG. 23. The three-vidicon color camera used in conjunction with optical microscope for group demonstrations.

Color TV Microscopy

Color television has extended the usefulness of the ordinary optical mircoscope by permitting group observation of enlarged images in color. When the microscope is used in conjunction with the 3-vidicon color camera, images can be transmitted electrically to one or more viewing rooms and displayed on monitors, or projected onto a large screen for group observation. Thus, many observers can see simultaneously, in color and in the same enlarged detail, exactly what the microscopist sees using the microscope. The basic principles of color television microscopy are shown in the diagram of Fig. 24.

A television microscope assembly developed for use in color TV microscopy is illustrated in Fig. 23. A lathe-type bed, similar to that used as a machine tool, is mounted on the surface of a special microscope bench. On the bed are mounted keyed plates adapted to fit the bases of several standard types of microscopes used for ordinary microscopy, for dark field microscopy and for phase contrast work. Illuminators of several types are similarly aligned optically using the keyed base on the lathe bed. The television camera is suspended so as to insure alignment with the optical system of the microscope. The camera views essentially the same field as that displayed on the eyepiece of the microscope. The whole of this assembly is mounted on heavy-duty, rubber tired casters which allow it to be somewhat portable.

In order to ensure high quality, stable operation, provision has been made for the unit to be supported on retractable steel feet once it has been placed in a required area of operation. Thus, the television microscopy function can be quickly established in any one of several locations.

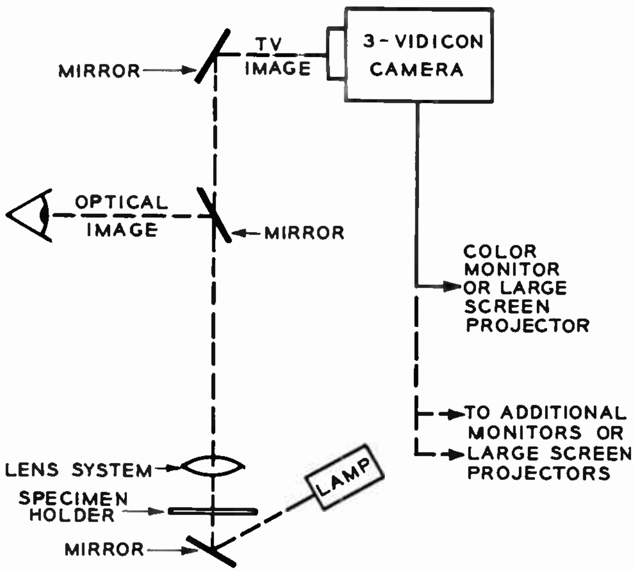


FIG. 24. Diagram showing basic principles of color television microscopy.

PART 6

Color Film Equipment

Modern color film equipment plays a significant role in the programming of most color stations. Beside presenting feature films, the film system is used in reproducing material for commercials, news announcements and station identification.

Program material might be in the form of slide transparencies, or opaques such as showcards and diagrams, or even actual product displays. It is reasonable to expect the film system to meet these requirements. In addition, the equipment should be capable of operating dependably day in and day out with only minor adjustment.

The three-vidicon system utilizing an intermittent projector was adopted by RCA in 1953 after a thorough test and evaluation of other methods that had been proposed. The advantages of the "3-V" system, which is contributing to the economy and quality of programming in scores of installations, are apparent when the inherent limitations of other methods are known.

Methods of Reproducing Color Film

A color television film system consists fundamentally of two parts: a *projector* which produces an optical image of the film, and a *camera* which converts the optical image into the red, green and blue electrical signals. Projectors can be divided into two classes, *intermittent* and *continuous;* and there are likewise two general classes of cameras, those employing *storage type* pickup tubes such as the vidicon, and those employing *non-storage* types such as the photocell.

The need for keeping the film stationary during the scanning of the raster can be met in different ways. Intermittent type projectors, which are used almost exclusively in the motion picture industry, employ an intermittent film transport mechanism in conjunction with a light shutter. Continuous projectors, on the other hand, utilize no intermittent mechanism but require a special optical system using rotating mirrors or prisms. Experience has shown that extreme accuracy is required in the manufacture of these mirrors and prisms, and that they are wasteful of light and difficult to keep clean.

The four systems obtained by combining the different types of projectors and cameras are diagrammed in Fig. 1.

Systems 1 and 2 differ basically from 3 and 4 in the source of light that is used. In 1 and 2, a high-intensity projection lamp provides adequate light for the densest films as well as for use of optical accessories in picking up opaques and product displays.

Systems 3 and 4 each employ a scanning spot of light produced by a kinescope. The amount of light obtainable is limited, and usually inadequate for the focal distances involved in making pickups from opaques and product displays.

Vidicon Performance Features

The 3-V system is capable of non-synchronous operation, and utilizes the inherent capabilities of the vidicon pickup tube which have been demonstrated through extensive use in monochrome systems.

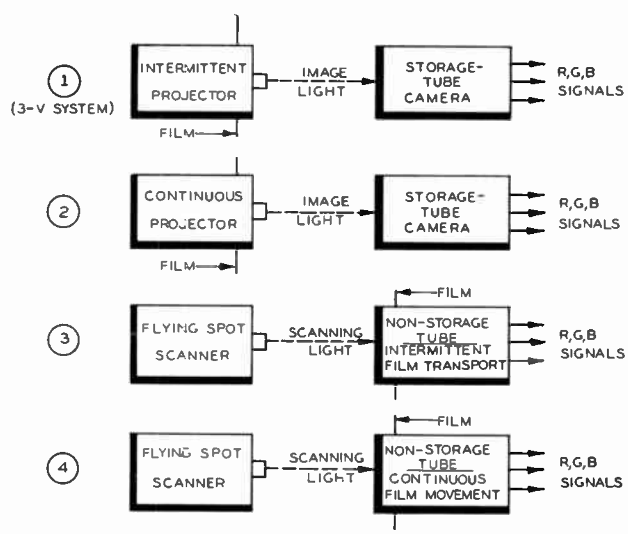


FIG. 1. Four basic systems for reproducing color film.

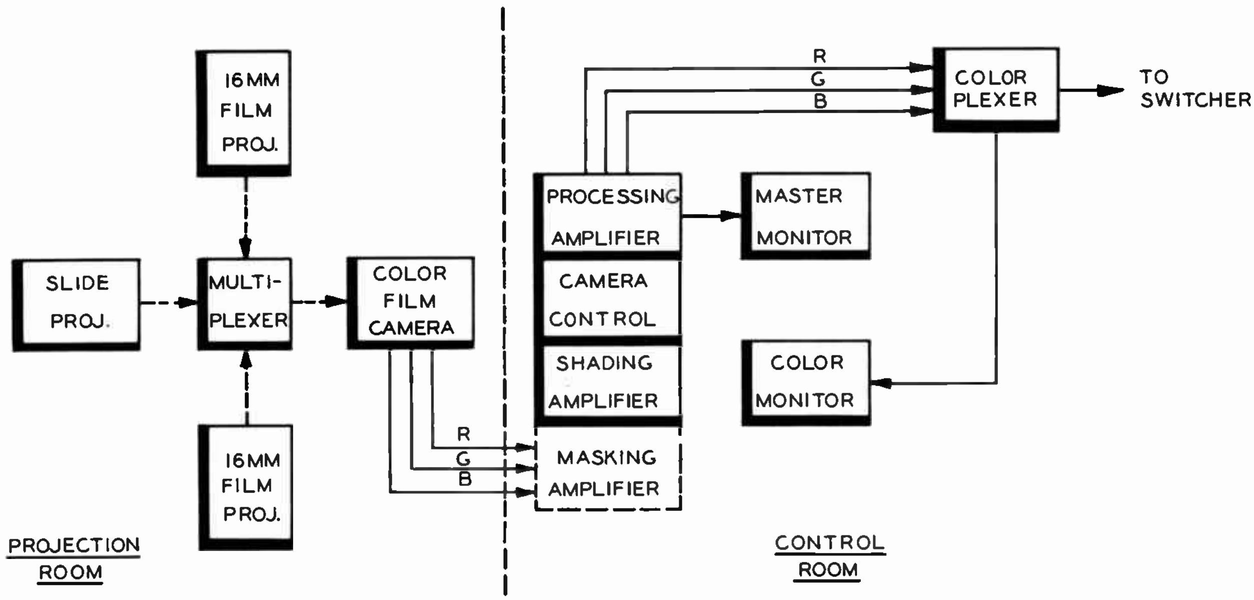


FIG. 2. Block diagram of TK-26 Color Film System.

For a number of years the iconoscope was the standard film pickup tube of the television industry. Although capable of excellent results, it is now being replaced by the vidicon because of the improved characteristics the vidicon offers for film reproduction.

Unlike the image orthicon and inconoscope tubes, which make use of photoemission, the vidicon uses photoconductivity, or the property by which certain materials change their conductivity when exposed to light. The construction of the tube is such that each picture element on the photocathode is in effect a small condenser with the photoconductive material acting as a leaky dielectric. Changes in the conductivity of this material, as determined by the amount of light focused on it, determine the rate of leakage. By means of a scanning beam, differences in conductivity are converted to a video signal.

The output of the tube is relatively high and no photomultipliers are required to bring the level any higher. For this reason, the output of the vidicon is virtually noise-free, the only noise in the output signal being that produced by the first video amplifier stage. By use of cascode amplifier circuits, this noise can be reduced to a very low value, and an excellent overall signal-to-noise ratio obtained.

The vidicon has other characteristics which make it ideal for film reproduction. Among these are: sensitivity which provides reserve for the densest of films; gamma or transfer characteristics with an approximate slope of 0.65, which simplifies the overall gradient correction problem; high inherent resolution which in effect can be even further increased by the use of aperture correction; well behaved black level; good storage characteristics which permit it to be used non-synchronously with long-application, intermittent type projectors; and absence of halos and other spurious effects.

Color Film System Components

Figure 2 is a block diagram of the TK-26 color film system. This basic system permits two 16mm film projectors and a slide projector to be operated through a multiplexer into a single TK-26 film camera.

The projection room equipment consisting of the film camera, projectors, multiplexer and slide projector is illustrated in Fig. 5. It requires an area of 50 square feet, or about the same floor space as monochrome film equipment. The camera can be operated with up to 200 feet of cable between it and the control equipment.

Control room equipment, consisting of the camera control, processing amplifier, shading amplifier, master monitor, can be mounted in standard 84″ racks; or, excepting the color monitor, in adjacent console sections as in Fig. 3 and 4 illustrates a space-saving installation combining the features of desk console and rack. The color monitor, processing amplifier and colorplexer are identical to those used with color camera equipment. These units are described in other sections of this manual.

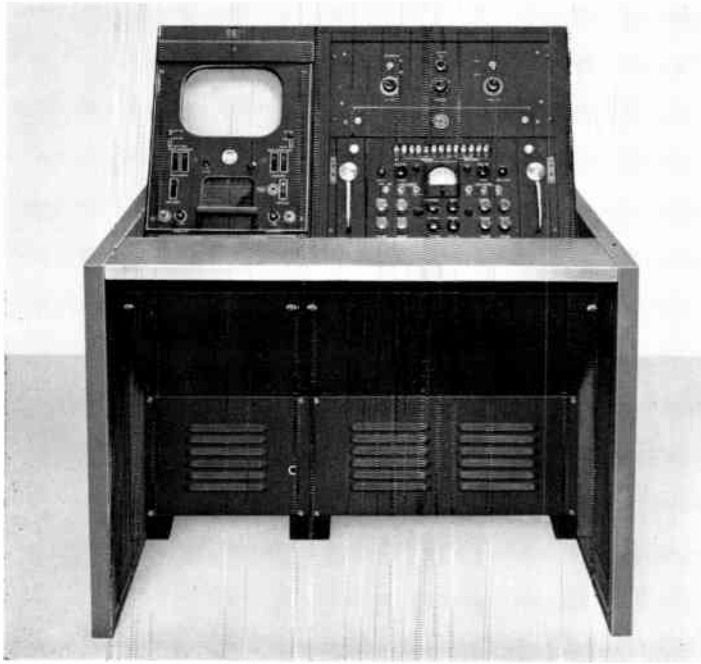


FIG. 3. Master monitor and processing amplifier mounted in a convenient desk console. Desk also contains camera control, not visible.

FIG. 4. Alternative mounting of master monitor, processing amplifier and camera control in 84-inch rack combined with accessory desk.

FIG. 5. Projection room equipment consists of film camera, two film projectors, multiplexer (center) and slide projector located on opposite side of multiplexer.

TK-26 Color Film Camera

The TK-26 color film camera consists of three identical vidicon cameras, a light-splitting optical system to provide the red, green and blue components of the color image, a camera auxiliary which supplies deflection and blanking voltages for the three cameras, and a local control panel which provides for complete setup of the film system at the camera location.

All components of the film camera are completely enclosed in a sturdy pedestal which can be anchored solidly to the floor. The three camera subchassis, each incorporating a preamplifier, are located together with the light splitting optical assembly in the upper portion of the pedestal. The camera auxiliary and local control panel are mounted in the lower portion of the pedestal, and are accessible through hinged doors on both sides.

Optical Assembly

The optical assembly mounts on the pedestal forward of the three vidicon cameras. It consists of a field lens, dichroic mirrors and filters, and a relay lens for each of the three cameras.

The relay lenses are mounted directly in front of the vidicons, and are used to provide adequate space for the dichroic mirrors mounted between them and the field lens. Provisions have been made to mount standard size neutral density filters in each light path where required so that the sensitivity of each channel can be adjusted to give the best signal-to-noise ratio.

FIG. 7. View of film camera pedestal showing the three camera chassis, control panel and camera auxiliary.

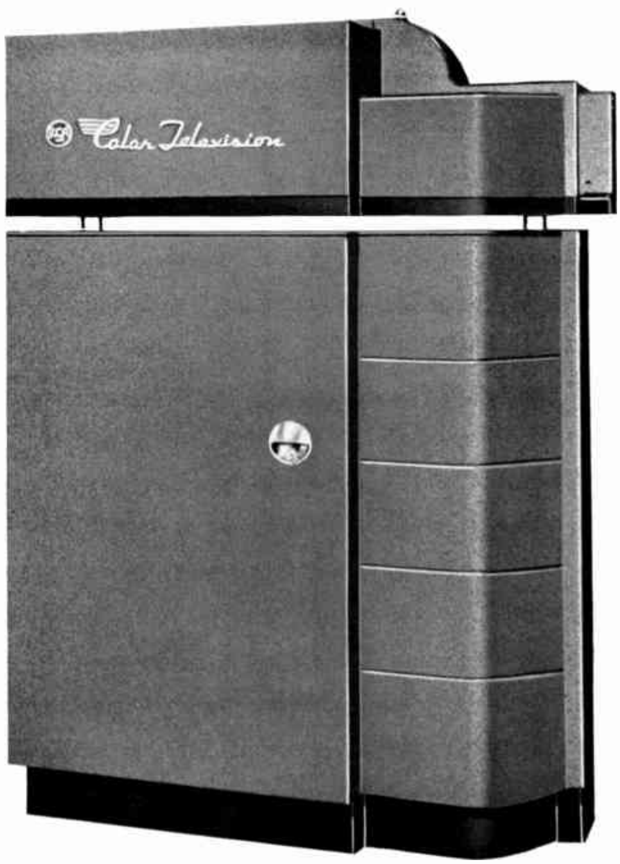


FIG. 6. TK-26 Color Film Camera.

Camera Auxiliary

The camera auxiliary contains circuitry to supply the horizontal and vertical deflection and blanking voltages to the three vidicons, as well as regulated focus and alignment current. Circuits are included to protect the vidicons from damage upon failure of the scan circuits. A monitor amplifier output provides a signal to a local film room monitor with pushbutton selection of red, green and blue, or superimposed images for setup, testing or monitoring.

The camera control panel permits complete local control for setup and servicing, eliminating back and forth travel from film room to control room positions. After setting up the camera, an operator can transfer control to the operation console by placing a "remote-local" switch in the "remote" position.

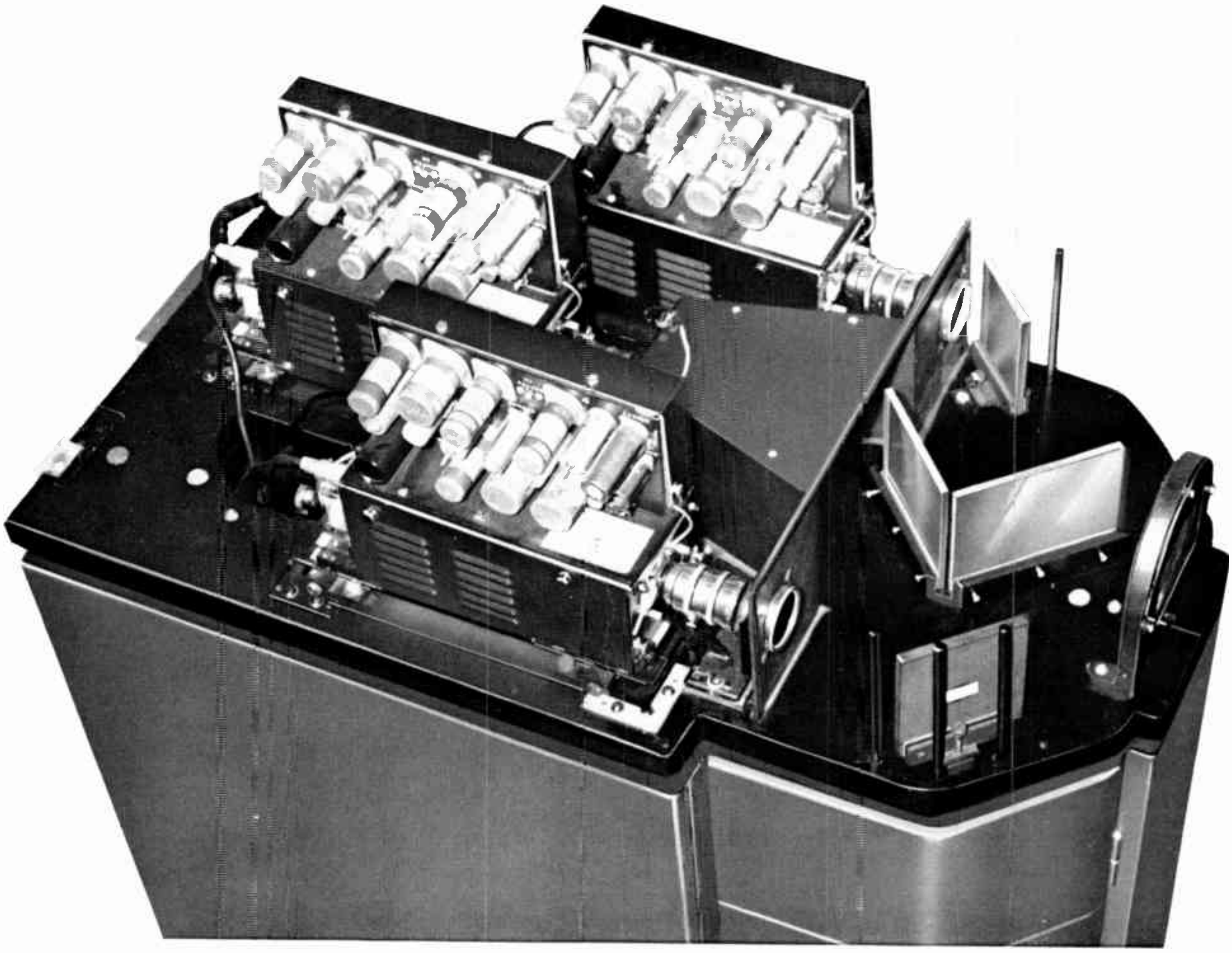


FIG. 8. R, G and B cameras employ separate preamplifiers and relay lens systems.

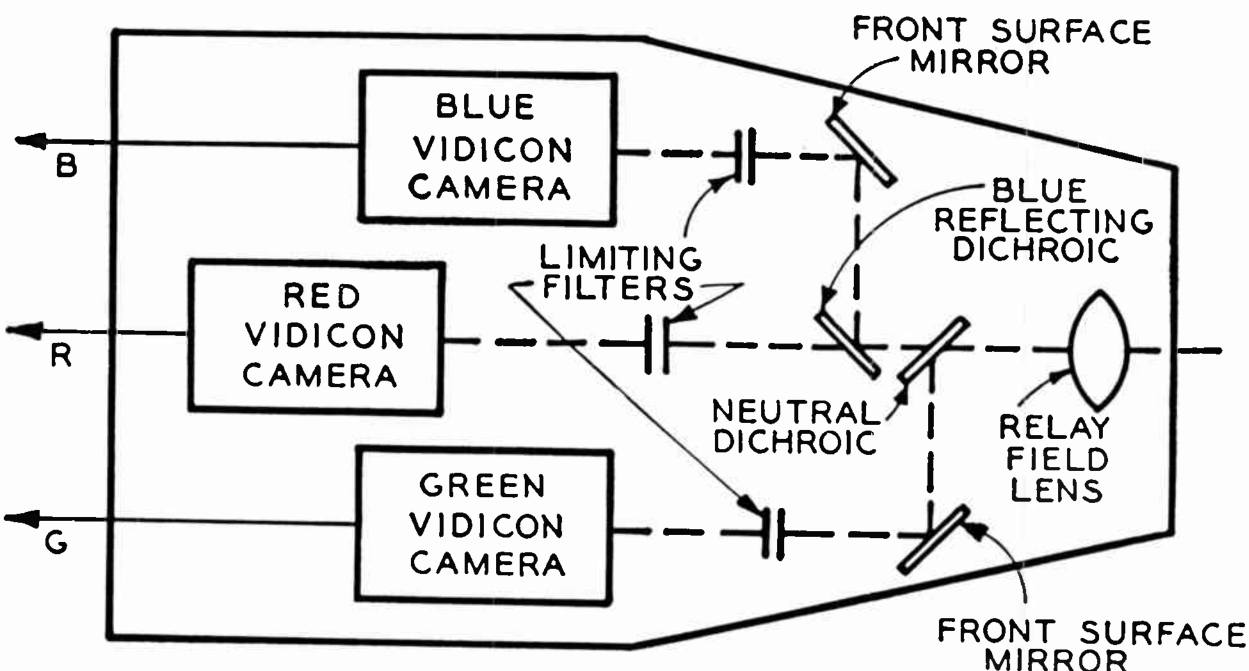


FIG. 9. Diagram showing optical paths provided by dichroic mirror assembly.

TP-15 Color Multiplexer

The TP-15 Color Multiplexer shown in Figs. 10 and 11 contains a special optical system designed to permit two vidicon film cameras (monochrome and color) to handle the images from any of four program sources, which might include two (16mm or 35mm) projectors and two slide or opaque projectors. Thus, the versatility of the equipment permits complete integration of color and monochrome in the program system.

One of the principal features of the TP-15 is the provision for projecting pictures into two television film cameras at the same time. This has the advantage of providing a preview picture from an upcoming program source, and permitting adjustment for proper level, while supplying a program signal from another source.

The multiplexer includes a main pedestal containing the mirror mechanism, and an auxiliary pedestal to mount a slide projector and a 1-V monochrome camera with associated optical system. Four motor-driven mirrors are used to permit selection of inputs and outputs. Figure 12 shows the arrangement whereby four inputs can be switched to any of two outputs. These and other possible combinations are diagrammed in Fig. 13. A few of the very useful combinations are described as follows:

1. Multiplex 2 motion picture projectors, 2 slide projectors, a 3-V camera and a 1-V camera.
2. Multiplex 2 motion picture projectors, 1 slide projector and 2 3-V film cameras. (The second 3-V camera is mounted in the normal position for the 1-V camera and slide projector pedestal.)

FIG. 10. TP-15 Multiplexer main pedestal (right) contains mirror assembly and control panel; auxiliary pedestal provides mounting for 1-V camera and slide projector.

3. Multiplex 2 motion picture projectors, 2 slide projectors and 2 1-V camera chains. (The second 1-V camera and slide projector are mounted on their pedestal in the normal 3-V camera position.)

The TP-15 may be operated from a local or remote control panel or both. This control panel (see Fig. 14) is equipped to start, stop or still-project any of the projectors and to operate the slide projectors. Dual channel controls are provided to enable the operator to select any of the picture sources for either of the camera positions. The Control Circuits are designed in such a manner that neither camera can take the picture away from the other camera accidentally. If it is desired to take the picture away intentionally, this can be done by use of the Interlock Defeat Switch located at either the local or remote control panel.

FIG. 11. TP-15 motor-driven mirrors which provide four optical inputs and two outputs.

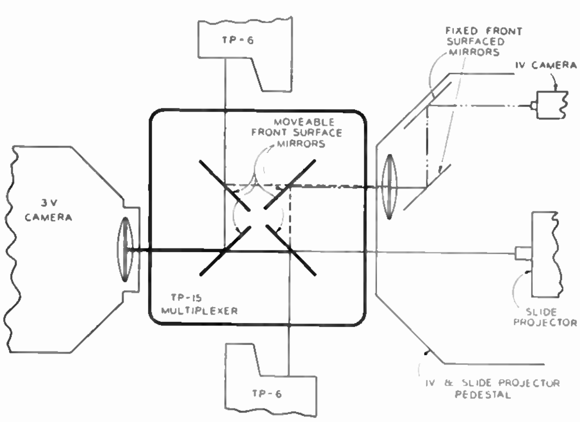


FIG. 12. Diagram showing possible light paths from two film projectors and a slide projector to 3-V and 1-V cameras.

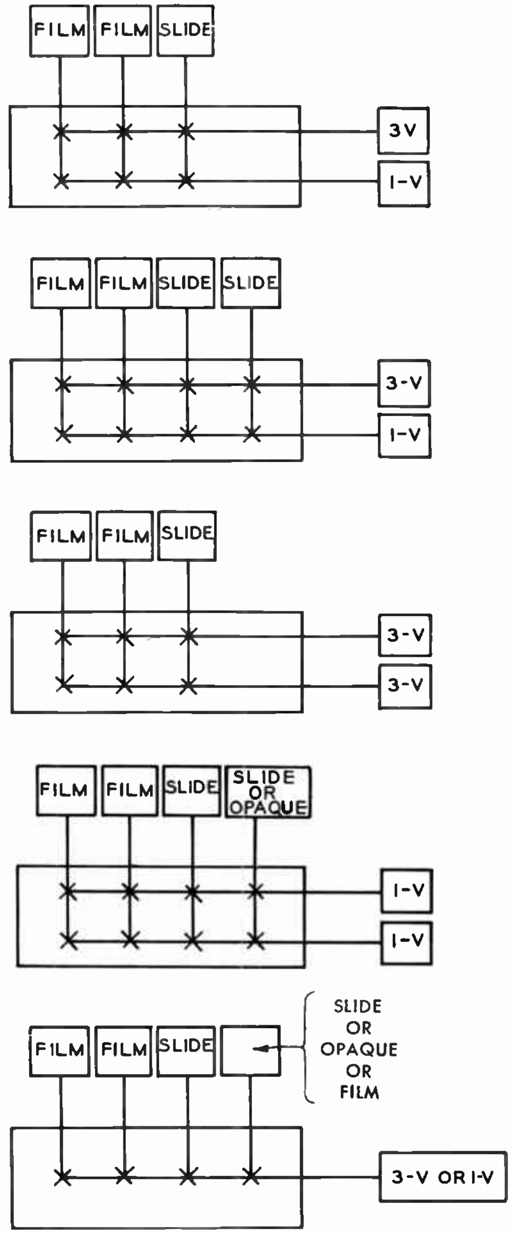


FIG. 13. Five possible combinations of color and monochrome cameras with film, slide, and opaque projectors using the TP-15 Multiplexer.

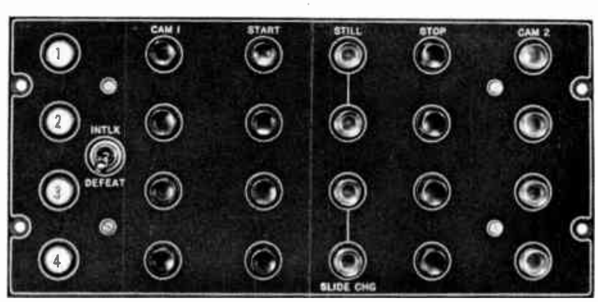


FIG. 14. Control panel for use at local or remote positions.

FIG. 15. TP-6 Professional 16mm Film Projector.

TP-6 Series Professional 16MM Projector

The model number TP-6 identifies a series of professional 16mm film projectors specifically designed to meet the exacting requirements for high quality film programming. Equipment comprises a projection unit, lens system, reels, support pedestal, preamplifier and associated power supplies.

The optical system consists of a spherical pyrex reflector, 1000-watt tungsten-filament lamp, condenser lens system, shutter and projection lens. It features an automatic lamp change assembly which houses two 1000-watt projection lamps in a rotatable mount. Lamp change takes place automatically and within one second after initial lamp failure, eliminating costly program interruptions.

The automatic projection lamp change mechanism consists of a turret arrangement which holds a 1000-watt lamp accurately in position. When a filament failure occurs, immediately a motor swings the turret around 180°, bringing a new projection lamp into place within one second. The filament is preheated while the new lamp is moved into place, thus avoiding thermal shock failures. (A pilot lamp indicates when the lamp has changed.)

Precision Optics—Light Control

Precision optics are used in both the light projection and sound sections of the projector. The highly efficient condenser lens system is of the relay type. A light spot approximately ⅜-inch in diameter is produced between the two sets of lenses. The shutter cuts the light at this point.

The TP-6 incorporates a heat absorbing glass and mirror between the two lenses in the front section to reduce the film gate temperature. Slide projectors used with this equipment should be equipped with the same type filter to insure color balance. A neutral density filter light intensity control is incorporated in the TP-6. It provides the facility to maintain constant signal level regardless of variations in film density. Two motors (one handles the shutter, the other drives sprockets and intermittent) permit still pictures to be shown.

A fast projection lens with a speed of f1.5 is provided for television applications. The focal length of the lens required varies with the type camera used. The projection lens on the TP-6 is a 2-inch lens fitted with an adjustable iris especially selected for use with the TP-12 Multiplexer and the TK-26 3-Vidicon Color Cameras. A 2½-inch lens, is specified for use with the TP-15 Multiplexer; or an (MI-26325) lens is required if the TP-15 Multiplexer incorporates one or more TP-16 Projectors in the film chain. On some TP-6 Projectors a 3.5-inch lens with an adjustable iris is employed. This lens is for use with the TP-11 Multiplexers and the TK-21 Vidicon Film Cameras. A rigid casting, mounted to the main frame, provides the support for the lens barrel.

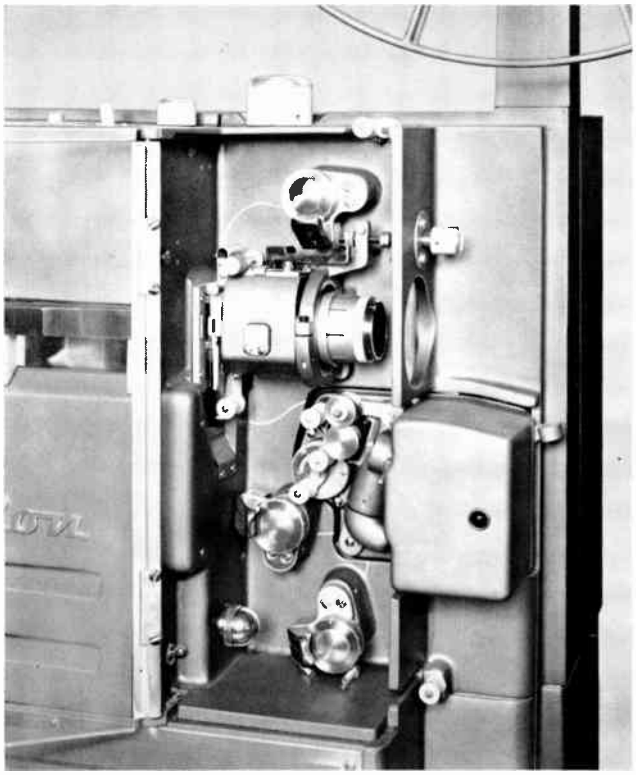


FIG. 16. Simplicity in the film path and space around the film gate result in easy threading of the projector.

The projector allows the use of a 30% application time shutter for 30% application storage permitted by image retentive qualities of vidicon tubes. Non-synchronous operation of projector equipment is required for use with color equipment since the color signal frequency is controlled by the crystal frequency of the sync generator.

Film Transport System

In the film transport system, sprockets are driven by precision helical gears from a shaft rotating at 3600 rpm. The shaft is attached through a flexible coupling to a vertically mounted synchronous motor. The motor has a permanent magnet rotor so that it will lock in at only one point. Motor phasing is adjustable by rotating the motor frame in its supports. A holdback sprocket is provided to prevent take-up reel disturbance from affecting the motion of the film at the sound drum.

A simple film path and generous space at the film gate result in easy threading of the projector. All parts in the film path are large and plenty of finger room is provided. A pressure adjustment permits compensation (during operation) for different types of film. The sprocket and intermittent mechanism may be turned by a knob at the top to check threading and advance film, one frame at a time. Still frame projection provides these features: (1) Is an aid in threading and set up. (2) Permits strip film projection. (3) Directors can preview film start. (4) Reduces "dead air" time. (5) Allows adjustment of camera equipment on a static scene. A lamp at the bottom supplies light for threading in darkened projection rooms. The clear plastic door prevents dust from accumulating on moving parts.

A high degree of picture stability and accurate film indexing is accomplished through the use of a specially designed "2-3 claw" intermittent. This is described on the next page.

4000-foot Reel Capacity

4000-foot capacity reels with a compensated professional "takeup" mechanism provide an enormous film capacity for continuous programming. Programs may be spliced together to save time and avoid errors. The 4000-foot reels accommodate enough film for one hour and fifty minutes of program time. Small reels, however, can also be used with equal facility. The supply reel shaft at the top of the projector has a friction brake with a broad, non-critical adjustment.

Sound Reproducing System

The sound reproducing system is shock mounted, and film motion at the sound drum is made uniform by the use of an accurately balanced flywheel and damping roller assembly. The sound pressure roller utilizes viscous drag to provide a tight loop around the sound drum. To decrease the sound stabilization time a flywheel starter is used. A brake action maintains the normal lower film loop to prevent the film rubbing against the optical system during starting and stopping periods.

The sound optical system consists of an exciter lamp, optical unit, and sound optical mirror—the same as the recording studio playback equipment (film phonograph). A special "in-out" focus is included to compensate for emulsion reversal. The aperture (slit width) is 0.0005 inches. Should the exciter lamp burn out during operating, a second exciter lamp can be shifted into place quickly by means of a lever.

Broadcast quality sound is assured from the "plug-in" type preamplifiers, flat to 10 kc. Two other response curves are available. Average flutter content is 0.15% RMS, and distortion 0.5% or less. Stabilization time is 4 seconds measured by a flutter bridge on a steady tone. To the ear, stabilization time is 2 seconds on any sound but a steady tone.

Power Supplies

Power for the preamplifier and bias for the phototube is supplied by a separate power supply. This unit is mounted in the pedestal of the projector and has sufficient capacity for both the optical and magnetic preamplifiers for the TP-6 Series Projectors. A d-c voltage for the exciter lamp is provided by another power supply which can also be accommodated in the pedestal of the projector or in a 19-inch rack.

Advantages of the TP-6 Professional Projector

Improved Intermittent Design

The TP-6 Projector achieves a high quality of operation through specifications restricting "jump and weave" —much tighter than those required for standard type projectors.

A 34% steadier picture is obtained through the use of a three-toothed claw, which permits positive pulldown of film (even though the film may contain some broken sprocket holes.) The top tooth of this claw has a sapphire insert to insure long life. An intermittent mechanism permits the claw to move straight up and down. This enables the claw to engage the film to its maximum extent, whereas the two-toothed claw movement of the standard projector describes an arc in its motion to engage the film. As a result, the two teeth moving in an arc provide a less steady picture and a greater chance of losing loops. Pulldown periods are staggered, thus avoiding the dangers of ordinary movements which require special acceleration attachments.

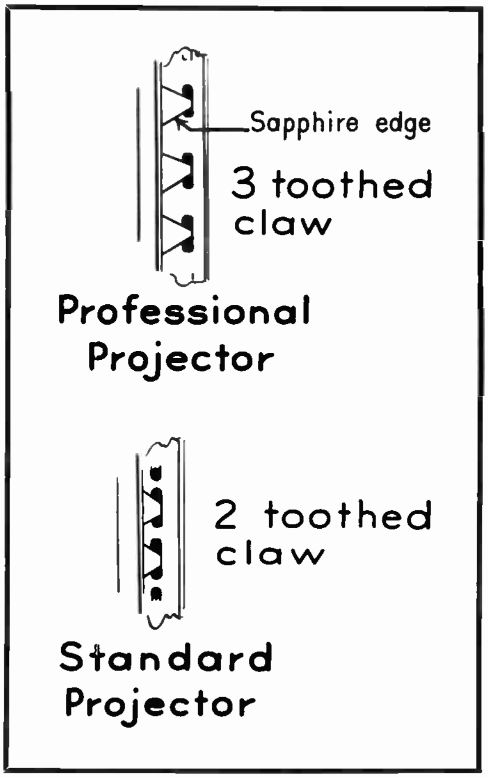
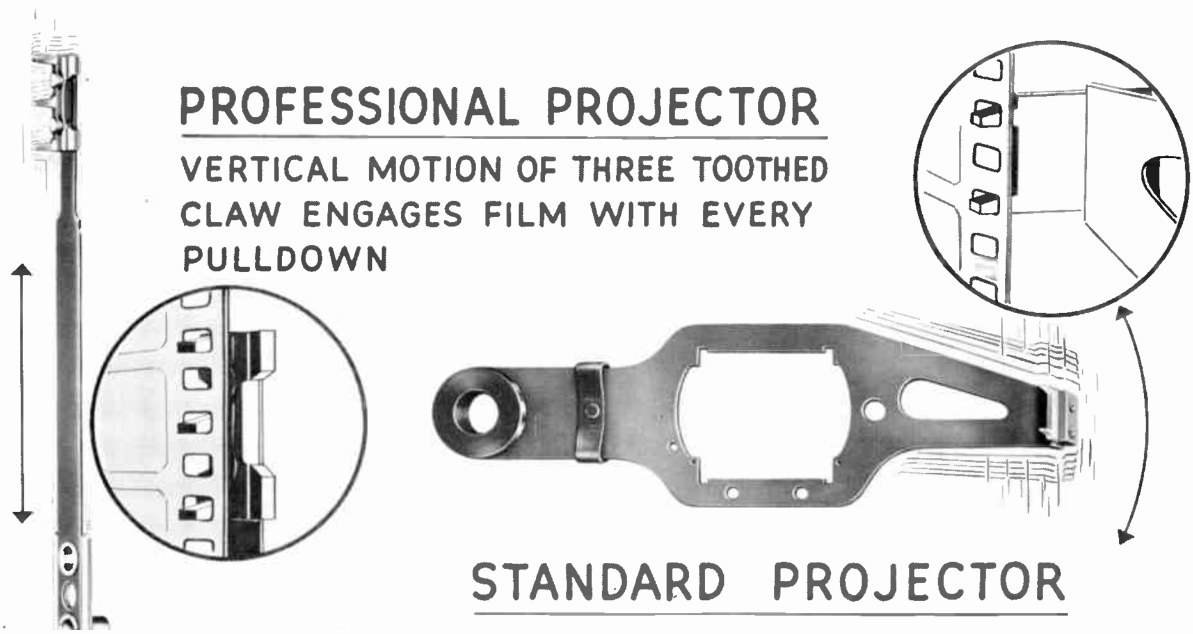


FIG. 18. Sapphire insert on claw of professional projector assures long life.

FIG. 17. Three-tooth claw gives steadier pictures, permits positive pulldown even though film may contain broken sprocket holes.



Claw pulldown on the TP-6 requires fewer precision parts than sprocket-type mechanisms. The claw pulldown has only two mating parts affecting the accuracy of the position of the film as compared with the sprocket-type pulldown where approximately eight moving parts are required. In the latter case, extremely tight tolerances are required in order to be sure that the film always stops in precisely the right spot. The claw-type intermittent can be serviced in the field, while the sprocket-type must be returned to the factory for servicing.

The TP-6 intermittent is designed for long, quiet, maintenance-free operation. Theatrical type framing is used for the picture so that the position of the film is moved, rather than the aperture. The framing knob is on top where it can be conveniently reached from either side of the projector—a feature important in television programming.

Additional features of the intermittent mechanism include: a claw pulldown which permits ease of restoring lost loop; interchangeable parts for ease of servicing in the field; an intermittent movement which provides "two-three' pulldown for non-synchronous operation; as well as intermittent parts which operate in oil for longer life.

Quality Optical System

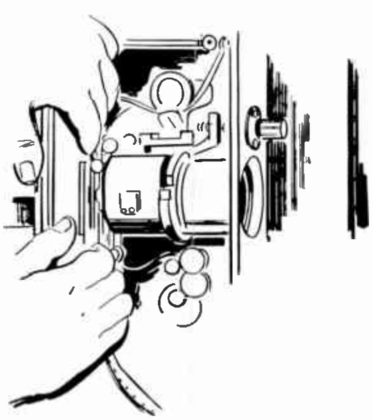
The TP-6 optical system provides professional quality of film projection because of high resolution and good contrast in the projection lens. The lens is mounted in a rigid casting attached to the main frame; hence it need not move during the threading operation. Once focus is set, the lens will not have to be disturbed. In comparison, the lens and lens mount of the standard projector must be moved out of position during the threading operation. This requires a movable lens mount; hence stability of focus is questionable. The condenser lens system is of the relay type, producing a light spot of about 3/8 inch diameter between the two sets of condenser lenses. Sufficient distance between the first and second condenser lens system allows the insertion of the neutral density type light control disc for controlling system gain of vidicon film camera.

The TP-6 further improves the quality of film operation by providing still frame projection which (1) aids in threading and setup; (2) allows preview of film start by directors; (3) reduces "dead air" time; and (4) facilitates adjustment of film camera on static scenes.

Broadcast Quality Audio

Extensive design effort went into the sound system in order to provide broadcast quality frequency response and wow and flutter specifications. Rapid sound stabilization, an important operational requirement, is achieved —being less than three seconds for speech in the TP-6

PROFESSIONAL PROJECTOR



STANDARD PROJECTOR

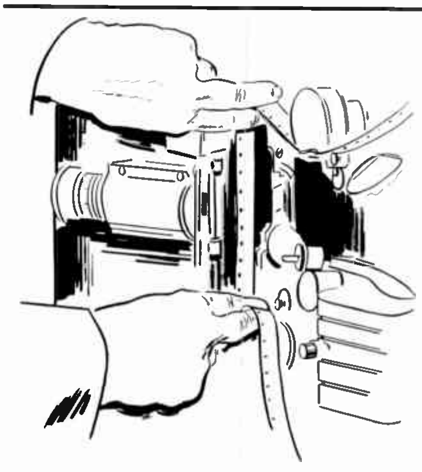


FIG. 19. Lens mount on professional projector is stationary; it need not be swung out of position for threading. Focus need not be disturbed.

Table 1

COMPARISON OF FREQUENCY RESPONSE, FLUTTER AND WOW SPECIFICATIONS

	TP-6 Professional Projector	Standard Projector
Frequency Response (in db)	50-7000 cycles .... ±1 10,000 cycles .... ±1	4000 cycles .... ±2 5000 cycles .... down 4
Flutter and Wow (in percent)	Average .... .15 Peak .... .25	Average .... .25 Peak .... .40

Projector. The complete sound optical assembly is shock mounted and isolated from the rest of the projector mechanism. Improved wow and flutter are accomplished by an additional take-up sprocket which isolates the film motion of the take-up reel from the film sound path.

Table I shows the frequency response, also wow and flutter, of the TP-6 Professional Projector as compared to a standard projector. Further improvements in sound quality may be obtained by the use of magnetically striped film, which can be accommodated in the TP-6 Projector.

Use of 16mm magnetically striped film is increasing because raw film stock with a magnetic stripe and "taking" cameras equipped with magnetic record and reproduction equipment. are becoming more readily available. The advantages of magnetically striped film are superior sound quality and flexible sound programming. For example, sound can be added to filmed news shows; then in the foreign market, the local language can be substituted. An easily installed modification kit for the TP-6 includes a sound reproduce head and mount, the parts to adapt the head to the TP-6 film sound area. a pre-amplifier to accommodate both optical and magnetic sound, and a power supply.

Automatic Lamp Change

Since projection lamp failures might interrupt revenue-producing commercials, automatic projection lamp change is one of the most important cost saving features of the projector. Two lamps are mounted in a rotating mechanism, as shown in Fig. 20, and their positions are instan-

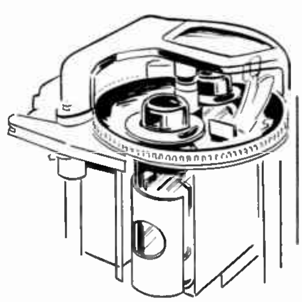


FIG. 20. Rotating lamp mechanism instantly changes to spare projection lamp should "run" lamp fail. Pilot light indicates lamps are changed.

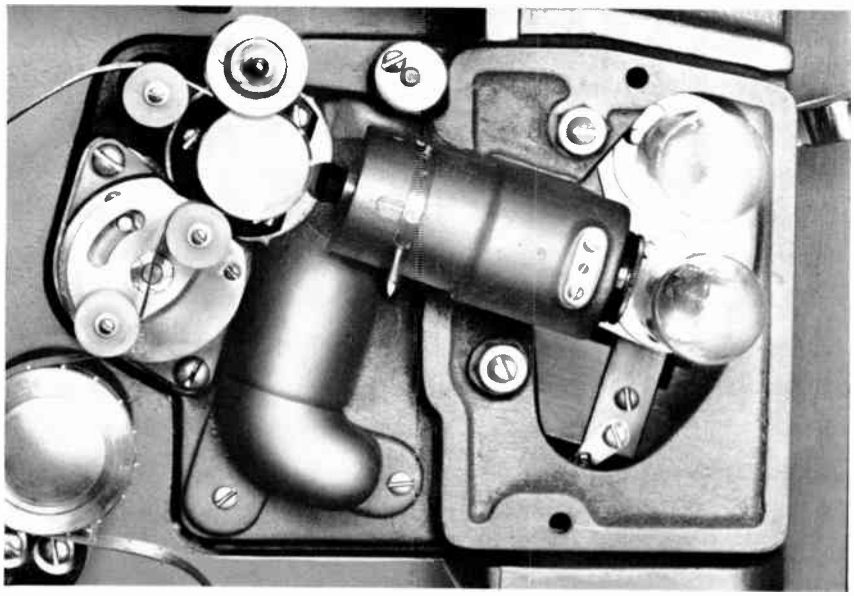
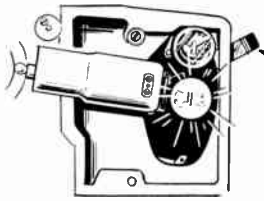


FIG. 21. Spare sound exciter lamp can be put into use instantly by operating the lever shown.



taneously changed upon failure of the "run" lamp. When the spare lamp moves into the projection position, an additional set of contacts preheats the lamp as it goes by; and when the lamp reaches the projection position, it meets heavy current contacts. The entire operation, from the failure of one lamp to the automatic replacement of a new lamp, takes place in approximately one second. The effect, when viewed on the monitor screen, is negligible since it can occur during a film scene change. Because this automatic change of lamps takes place in such a short time and might be overlooked, a pilot lamp is provided which indicates when a change has been made. The faulty lamp can be replaced through a door in the cover, even when the machine is operating.

Since projection lamps may be operated to extinction, cost savings of thirty-five to fifty cents per hour may be realized. A spare sound exciter lamp is also available in the projector. The spare lamp can be instantly placed in operation by pressing a lever. This feature also prevents loss of commercial or program time due to exciter lamp failure. The TP-6 Projector is designed in subassembly form to permit ease and rapid method of servicing and maintenance. Each of these subassemblies can be moved in and out of place with a minimum of effort.

FIG. 22. Lamp change mechanism is easily accessible for convenient replacement of inoperative lamps.

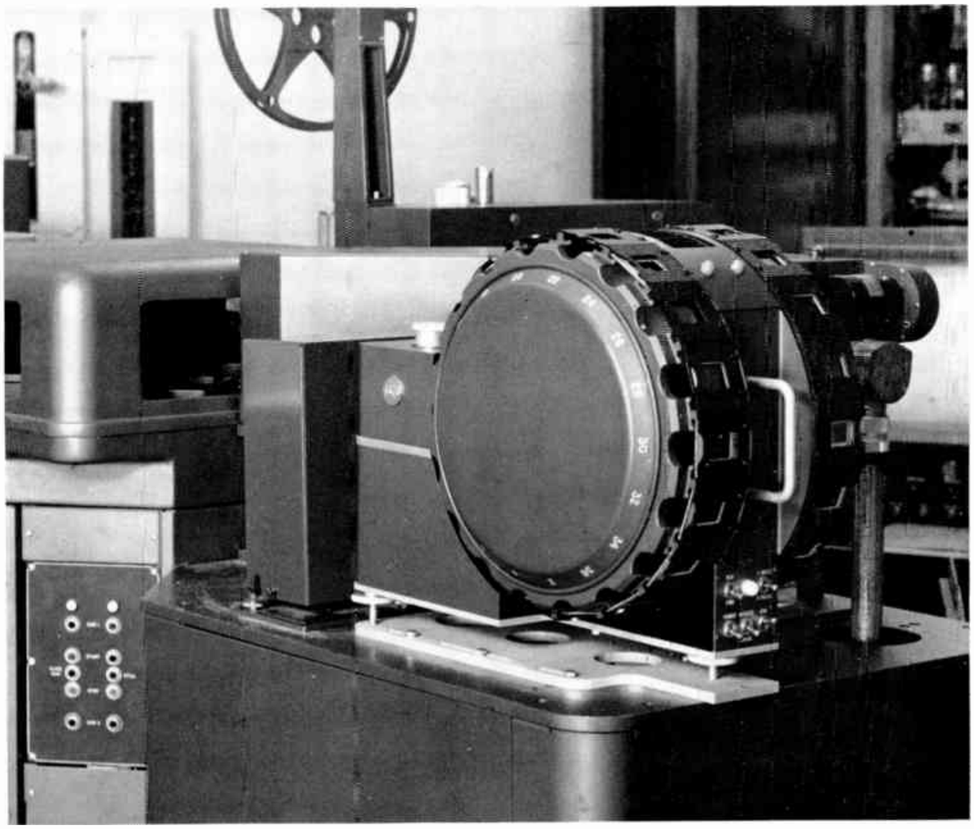


FIG. 23. TP-7 Professional Slide Projector shown mounted on pedestal facing TP-15 Multiplexer.

TP-7 Professional Slide Projector

The TP-7 Professional Slide Projector provides a ready means of projecting standard 2 x 2-inch slide transparencies into monochrome or color TV film cameras. The optical resolution and detail contrast are sufficient for any TV pickup application. The machine has adequate light output for 3-V color film pickup systems, and it provides uniform brightness over the entire field of the projected image.

The TP-7 is semi-automatic in operation, projecting the slides in a sequential manner on signal from a local or remote location. Dual drums provide a slide capacity of 36 (18 per drum), and the slide change time is practically instantaneous. The slides advance either forward or backward. The operator may gain access to the slides in the two magazines for inspection or rescheduling during operation of the projector. It is possible to hold a slide in one channel while showing a series of slides in the other channel. An emergency projection lamp is available for quick manual change.

Dual condenser lens systems form two optical channels. A drum type magazine associated with each optical channel provides storage for the slides for projection without any dark period as the projector drums are rotated. Instantaneous slide change results from changing successive slides first from one drum then from the other drum.

One projection lamp is used in conjunction with the two sets of condenser optics each of which form an optical channel. Light is collected from both sides of the lamp filament by these optics and directed to each of the two slide gates (one per channel) which are offset from but symmetrically located with respect to the projection axis. Three fixed and one movable front surfaced mirrors located between the slide gates and the single projection lens multiplex each of the channel axis into the centrally located projection lens. Split second movement of this mirror in or out of the optical path switches from one slide channel to the other. A relay type condenser system with four lens elements per channel is used.

This optical arrangement is the nucleus of the design of the TP-7. It provides the means of meeting all objectives associated with the optics. Two channels are available to provide the desired continuity of programming. Internal multiplexing of the two channels into one projection lens permits the on axis projection required on field lens systems. One projection lamp eliminates the possible introduction of color unbalance between the two channels with unmatched lamps. Use of a fully reflective moving mirror in the multiplex systems eliminates the need for dichroic or half silvered mirrors which introduce color unbalance with the inherent spectral selectivity. A 300 watt medium pre-focused base down lamp provides approximately 450 foot candles on a 3.35 x 4.46 inch screen. This is sufficient light for a 3-Vidicon color film camera. Uniformity of screen illumination exceeds 90% in open gate search measurements.

Separate drive motors are used for each drum so as the slide from one drum is being projected the other drum advances to a new slide projection. Precision indexing of each slide position on the drum is accomplished by suitable detents.

Forced air cooling is provided so that the slides operate cool, even for extended exposure. A centrifugal type blower located under the optical plate shares this space with the moving mirror mechanism. Ample air flow is provided to maintain cool operation with a 500 watt lamp.

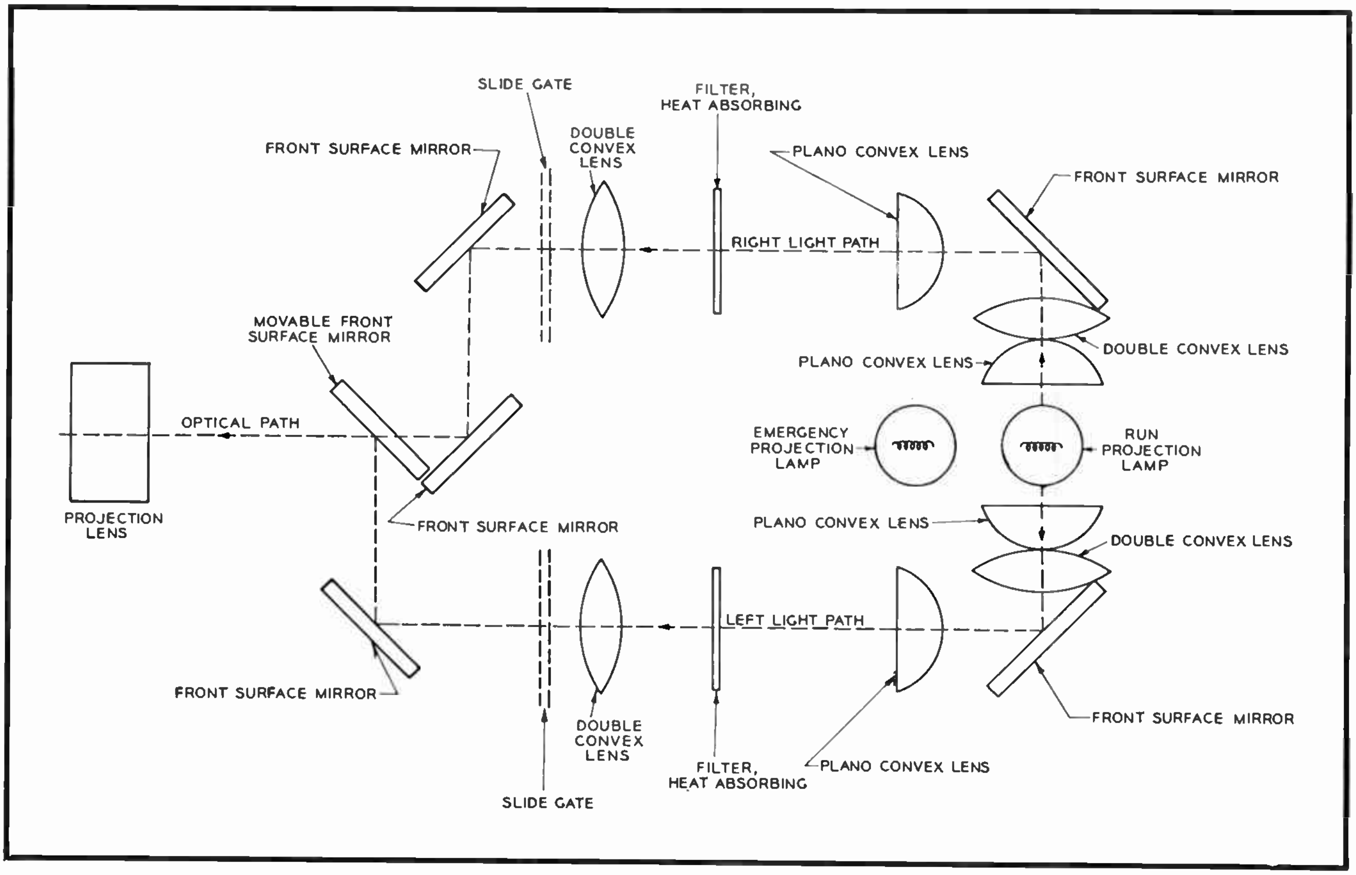
The TP-7 is sturdily constructed for years of use. The main framework of the projector consists of basic plate, a horizontal bottom plate, two parallel vertical plates and an optical plate casting. The base plate's function is to provide a means of attaching the projector to its supports. Slots are provided for hold-down bolts. The projector bottom plate is coupled to the base plate through three adjustable leveling legs. These legs have knobs for ease in making adjustments and have locking provisions to eliminate all play between components.

Unitized construction of the TP-7 Professional Slide Projector provides easy accessibility for cleaning or servicing. The top front cover which protects the multiplexer mirrors from dust may be removed thus giving access to all optical components on the optical plate. For access to the condenser optics, the drum covers or drums can be removed; while access to the arm is possible through the openings in the drum associated with the slide wells. Bottom covers and lamphouse are also removable so that access to every component is possible. Dowel pins and other devices reassure automatic alignment on reassembly.

Operating controls for the TP-7 are located at the rear of the projector. The projector also can be controlled from a remote control panel.

A reversible shaded pole gear-head motor coupled to the mirror through a restricted type of geneva movement

FIG. 24. Diagram of optical system of the TP-7 Slide Projector. Single lamp source shown eliminates color balance problems.



provides the means for rapid movement of the mirror into and out of the optical paths. The mirror and its mount are pivoted on a shaft which is perpendicular to the reflective surface. This permits mirror motion only in the plane established by this surface. Although the drive motor rotor has low inertia, a friction type override clutch between the crank and the motor reduces shock when the crank strikes its limit stops. Lever type sensing switches are operated by the crank near each end of its travel. The crank is detented in these positions to prevent spring back when the motor is de-energized and to maintain proper pressure on the sensing switches. Actual mirror motion time is less than 1/5 second, yet the comparatively gentle accelerating and decelerating forces inherent in the geneva mechanism gives smooth quiet operation.

Soft illumination of all slides in the top and rear portions of the drums is provided in this projector. This permits visual observation of picture area when loading the slides. It also permits visual checks on orientation, loading sequence, etc. of the slides in the drum at any time without removing them from the drum. Since the drums may be readily rotated by hand, a complete check on every slide in the drum can be accomplished quickly.

A control box, separate from the TP-7 Slide Projector, may be mounted in a rack or the base of the multiplexer. This box contains all the relays used in the control circuits as well as the larger capacitors associated with the drive motor. All control circuits operate on 24 volts d-c. Interconnection between it and the projector requires a 24-conductor cable which is terminated in the projector on two barrier type terminal boards and at the control box by a Jones plug. Separate jacks are supplied on the box for the two power inputs and for two types of remote outputs.

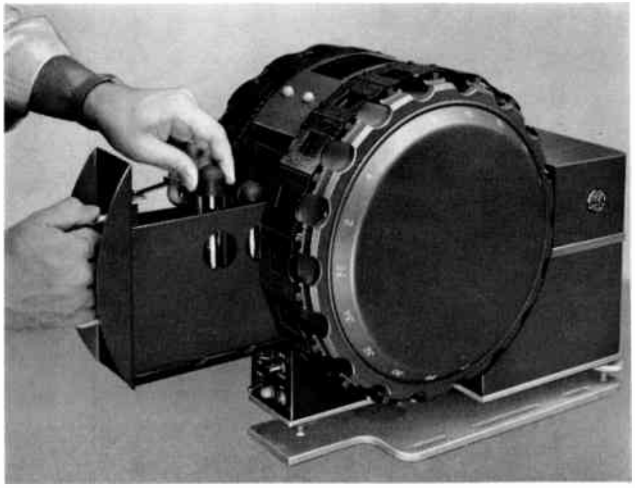


FIG. 25. Projection and emergency lamps are easily accessible for replacement. A stop prevents the drawer from being accidentally withdrawn from the projector.

Designed to Meet Broadcast Requirements

Many years of field experience aided by a carefully evaluated field survey of representative TV stations provide the technical background for the following features of basic importance to the TV broadcaster:

1. *High Slide Capacity*

   The TP-7 stores and handles 36 slides, 18 on each drum.

2. *Quick Lamp Change*

   A built-in stand-by lamp can be quickly placed in operation to minimize lost time due to lamp failure.

3. *Easy Loading*

   The slide holders register the slides precisely and are conveniently accessible around the periphery of the drums. The drums can be rotated manually in either direction at any time except during a slide change cycle.

4. *Slide Check Viewing*

   Rear illumination of slides around the drums is provided for ready visual checking.

5. *Rapid Slide Sequencing*

   Slides can be shown at a rate of approximately one per second.

6. *Slide-to-Slide Fast Dissolve*

   The transition from one slide to another is accomplished in approximately 1/5 second.

7. *Durability*

   Rugged construction and optical rigidity are provided by the use of castings. Long life is assured by extensive use of ball bearings and nylon for wear surfaces.

8. *Accessibility*

   Optical surfaces are readily accessible for cleaning without the use of tools. Projection lamps can be readily replaced.

9. *Versatile Control*

   Remote and/or local control of drum operation in forward or reverse directions as well as holding either drum while advancing the other is provided.

10. *High Quality Optics*

    The single light source and front surface mirrors, which are used throughout, assure color balance between channels. The slide illumination reaches a new high in uniformity.

11. *Interchangeability*

    Compact design permits the TP-7 to be installed and used with all vidicon film equipment systems described in this manual.

FIG. 26. Opaque Pickup Assembly mounted facing TP-15 Multiplexer.

Opaque Pickup Assembly

The opaque pickup assembly is an extension lens system designed for use with either color or monochrome film cameras to enable televising of opaque subjects such as art work, signs, maps, diagrams, comic strips or color magazine pages as well as all kinds of product displays—live or action—in the simplest possible manner. The opaque assembly can be directed into any of the three regular multiplexer inputs (either TP-15 or TP-12) and can be self-mounted or can be affixed to the auxiliary pedestal of the TP-15 multiplexer.

Action Pickups

This relatively inexpensive and simple lens assembly can pick up either color opaques or products located in a limited display area. These products can be moved, liquids poured and the products demonstrated. Without physical or circuit modifications, the TK-26A Color Film Camera can reproduce opaques and limited live commercials thus extending the revenue-producing power of the 3-V film equipment. News flashes, news photos, temperature and time announcements may also be telecast in addition to commercials. It is equally well adapted for use with monochrome film cameras.

Live color commercials and opaques are relatively easy to prepare and can be changed, reworked, retouched or altered quickly to meet the demand of the sponsor, eliminating the time and expense involved in preparation of 2 by 2 inch slides. The area available for opaque or live objects may be varied from 4½ by 6 inches minimum

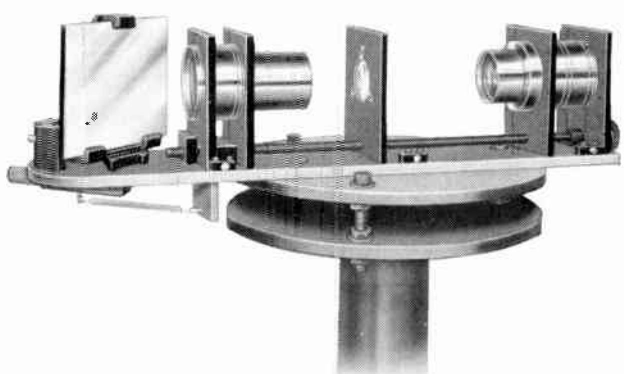


FIG. 27. Optical system of Opaque Pickup Assembly as seen with cover removed.

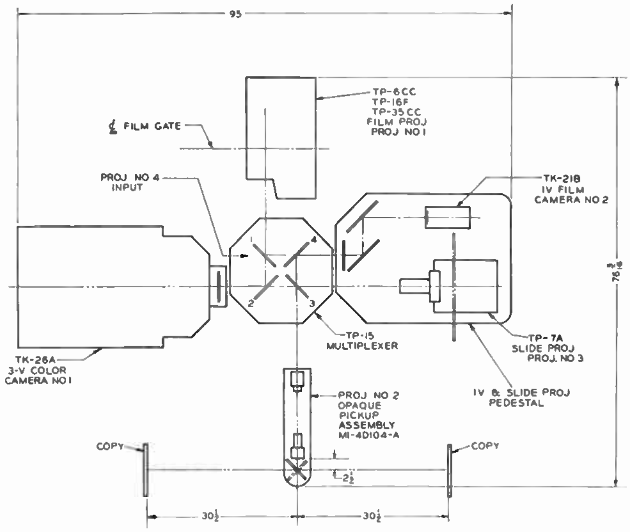


FIG. 28. In this floor plan, the Opaque Pickup Assembly is mounted on a separate pedestal in order to utilize two copy areas.

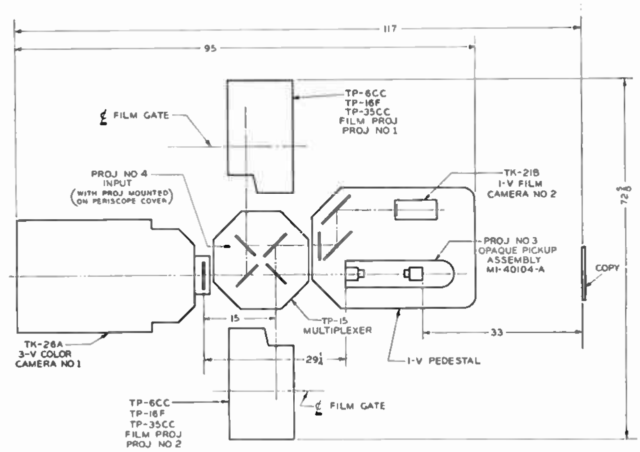


FIG. 29. Floor plan showing Opaque Pickup Assembly mounted on pedestal beside the 1·V Film Camera.

to 9 by 12 inches maximum. An area of 7½ by 10 inches is the average design size. A swiveled mirror makes it possible to pick-up either of two subject areas for televising in the open in fully lighted rooms. There is no need for light covers or strobe lights. The vidicon cameras provide inherently good resolution and quality color equal in every way to that attained with studio type color cameras.

The opaque pickup assembly devised for limited live commercials and opaques consists of an extension lens system mounted on a base plate assembly that in turn mounts on a supporting pedestal with flange base supporting assembly. The lens system may be focused by means of a manual focus knob, and a swiveled mirror is provided for selection of either of two subject areas. Convenient adjustments are included for leveling and alignment of the equipment after it has been installed. The entire assembly has been carefully planned to assure rugged construction and to withstand constant hard usage. Bolts for leveling are included in the base plate.

Optical System—Lighting

The optical system begins with a 3½-inch Wollensak Cinema Raptar projector lens with a speed of f1.9 which is focused on the object to be reproduced either directly or by means of the intermediate mirror. A double convex field lens of 63mm focal length is placed at the back-focus image-plane distance. The 1.3 diagonal real image at this plane is then viewed by a Wollensak Cinema Raptar 6-inch relay lens with a speed of 2.3 which produces a new real image at the film camera field lens. All the lenses were chosen for their high quality and freedom from vignetting effects. The system maintains a good depth of focus. Close-ups or distant pick-ups can be focused by moving the 3½-inch lens in its mount by a manually operated focusing knob.

A collimated light source such as a 1-kw slide projector with f2.3 lenses illuminating the 7½ x 10 opaque area is a convenient accessory for lighting purposes. For illumination of a live or action display, several 500-watt photo-flood lamps may be used. A total of 12,000 foot candles of light is required. Vidicons are capable of accommodating extreme highlights with no halo or edge effects in the TV picture. The high lighting level intentionally recommended for use with the Opaque Pickup Assembly and vidicon cameras reduces the lag with motion to a negligible amount, thus making possible the use of "action" shots.

Floor Plan Arrangements

The assembly may be utilized with several types of camera installations. The floor plans reveal a typical arrangement with the opaque pickup mounted on its own pedestal, or mounted beside the 1-V Film Camera. Other set-ups may be realized with the equipment, and final location of the equipment will be determined by individual station requirements. In any installation, the total length of the light path from the copy to the end of the 3½-inch lens barrel should be approximately 30 inches. The total distance from the end of the 6-inch lens barrel to the camera field lens should be approximately 29¼ inches. The optical center-line of the projector must be 48 inches above floor level to conform to the requirements of the RCA Multiplexer, projectors and cameras. The image must be reflected an even number of times to avoid reversal of the copy from left to right.

Adjustment of Color Film Systems for Best Performance

Optical Alignment[1]

The TK-26 Color Film Camera provides accurate fixed alignment of the color-splitting dichroics. The front surface mirrors are aligned when the equipment is installed. The removal and replacing of mirrors for cleaning will not disturb this alignment, if care is exercised to avoid reversing dichroic mirrors when replacing them after cleaning. (The mirror alignment procedure is covered in detail in the instruction book.)

The vidicon camera lenses are mounted rigidly in a fixed position and are mechanically independent of the vidicon camera mounting. The three camera-lens positions are accurately located on the 3-V bedplate for the proper magnification (0.625 inch diagonal image on the vidicon tube). The camera lens focus is set at infinity. Lens focus setting and lens position should not be changed after installation.

Optical focus of each vidicon camera is obtained by moving the camera back or forth on a precision mount with respect to its lens by means of an adjusting screw. See Fig. 30. It is important to point out that the procedures on optical alignment outlined in the instruction book should be followed carefully. Field experience has shown that most of the difficulties encountered in set up of the equipment have been due to lack of appreciation of the role of optical alignment.

The high points of the general optical alignment procedure follow: First, stop down the slide-projector lens iris and the camera lens iris to minimum aperture. The spot of light from the projector lens iris can then be seen and centered on the iris of the camera lens. Now remove the color trimming filters directly ahead of the camera lenses so the light spot on the lens iris will be more clearly defined. The field lens (5.5 inch diagonal aperture) mask should be installed permanently. This mask can be used for convenient check on visual image size and alignment. The slide-projector position should be adjusted to align the spot of light formed by the projector lens iris in the center of the red channel camera lens iris when the field lens image is centered in and fills the field lens mask aperture. The field-lens image must also be in focus at the field lens. See Fig. 31. The projector lens iris must be *open* when adjusting the centering, size and focusing of the projector image in the field lens, and *closed* when centering the light spot on the camera lens iris. The projector should first be aligned to optimum using the red channel camera lens and field lens as the reference This avoids any error in possible misalignment of reflecting mirrors for the blue and green channels.

[1] The fundamental recommendations made for optical alignment included in the instruction book should be studied thoroughly and carried out before turning to these specialized procedures applying to color.

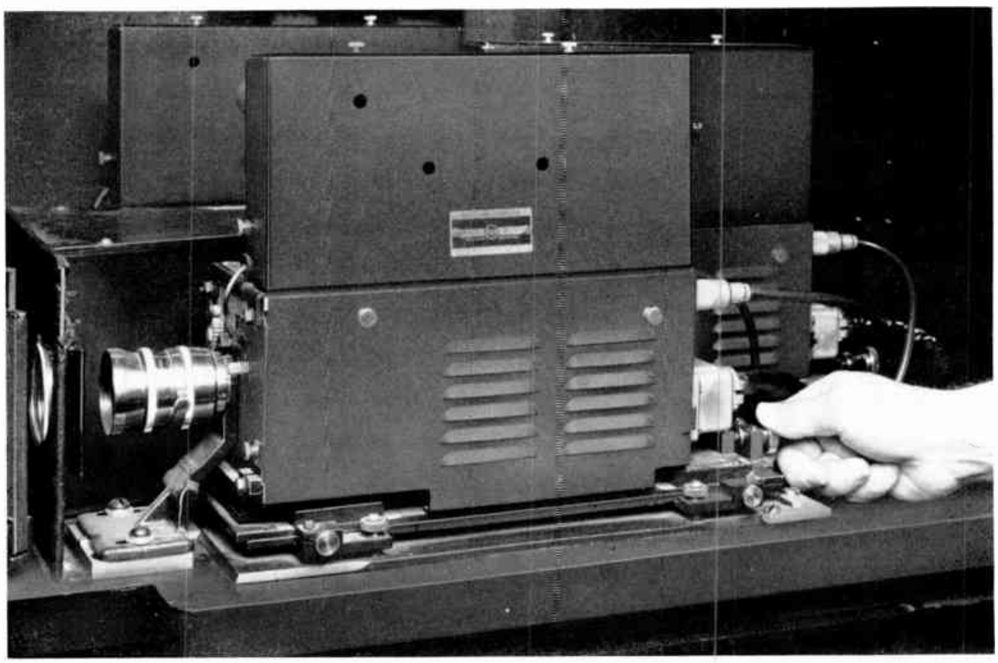


FIG. 30. Optical focus of each vidicon camera can be obtained mechanically by moving the camera on a precision mount with the adjustment screw shown above.

Now, with the red optical channel aligned, inspect the centering of the light spot on the iris of the blue and green camera lenses. The spot of light from the stopped down slide projector lens iris should fall in the center of the red, blue, and green camera lens irises. Off-center spots on the blue or green channel lens irises indicate mirror misalignment errors in the channels. Correct any misaligned mirror and optically align all projectors to give identical results.

After the alignment procedure, *the camera lens irises must all be opened to maximum aperture.* The cone of light from the field lens is intended to fill the camera lens aperture. Stopping down the lens will result in vignetting or porthole shading of the output signal.

Projector lens irises should always be at maximum aperture when focusing images.

Vidicon Cameras

The three vidicon cameras (see Fig. 32) comprising the TK-26 Color Camera are identical and can be interchanged if so desired. Each vidicon camera is equipped with mechanical adjustments for aligning the vidicon with respect to the optical image. The individual camera positions are keyed to permit rapid removal for vidicon replacement or service and later replacement without disturbing camera alignment; thus, only minor adjustment is necessary to re-register the vidicon images. The mechanical mountings and alignment controls of the camera should be tightened after adjustment, because free motion might result in loss of image registration if the installation is accidentally bumped or jarred.

The vidicon camera amplifier has a feedback output stage. A cascode amplifier input stage gives excellent signal-to-noise ratio. The amplifier output level is 0.5 volt peak-to-peak. Low camera filament voltage may result in poor signal-to-noise ratio. The filament voltage should be measured at the WE417A input stage tube socket, and should be maintained between 6 and 6.3 volts. Frequency response compensation for the vidicon load capacitance (high peaking) is accomplished entirely in the camera.

TK-26 Video Level Control

A brief summary of various operational methods of video level control is given here:

1. Varying the amplifier gain only will result in variable signal-to-noise ratio, overloaded video amplifier, the possibility of undischarged vidicon target, and decreased resolution caused by the need for excess signal electrode current capabilities. This method is highly unsatisfactory.
2. Varying the vidicon signal electrode voltage may result in (a) constantly varying electrical image shading, (b) will shift the black reference level. This method is operationally unsatisfactory.

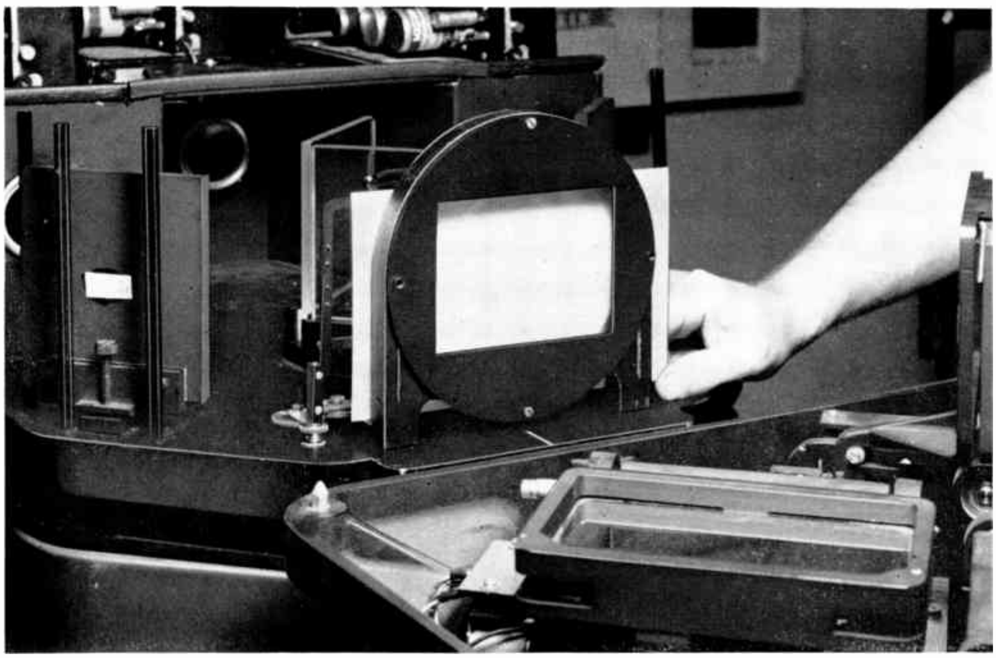


FIG. 31. Field lens image is focused at field lens using a white card. Image is focused at both front and rear of this lens, and final focus can be compensated so that it falls at the center of the lens.

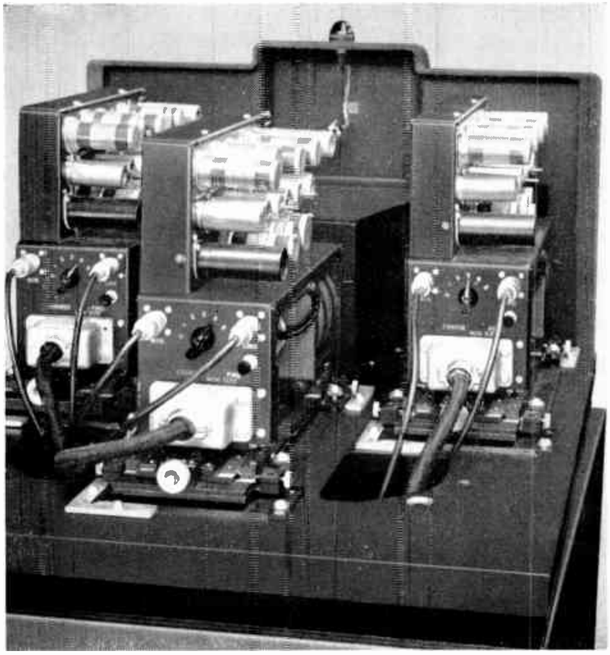


FIG. 32. The three vidicon cameras are identical and can be interchanged as desired.

3. Varying the intensity of the incandescent lamp source over the required range by varying the filament voltage varies the color temperature of the light. This method of light control is very good for monochrome but results in noticeable color balance variation when used with color film or slide equipment.

4. Varying the source of light with a variable neutral density disk (Fig. 33) is an ideal method of video level control. This system permits all equipment adjustments to remain fixed at the optimum value.

The TK-26 was originally supplied to broadcasters with a reactance dimmer for varying the projector filament voltage to control the video signal level. The variable neutral density disk control under development was not available for delivery at that time. Modification kits have since been made available to convert from reactance dimmer to neutral density disk control.

Preliminary Vidicon Adjustment

The electrical adjustment procedure for the vidicon camera is discussed in detail in the instruction book, which should be the *primary* reference. The techniques can be summarized as follows:

1. Select a *test* condition of 25 volts on the vidicon signal electrode.
2. Adjust the "open gate" projector light output to obtain 0.25 microamp signal current, allowing adequate reserve to handle dense film.
3. Overscan vidicon horizontally and vertically sufficiently to see the target perimeter of the tubes.
4. Center the target perimeters of all tubes using electrical centering controls.
5. Use registration chart slide in projector and center image on vidicon face using *mechanical* centering controls, maintaining faceplate perpendicular to optical axis.
6. Adjust vidicon horizontal and vertical deflection amplitudes to get proper size of slide display on monitor (filling field lens aperture mask).
7. Check optical focus for optimum value, using knurled screw drive at back of each camera, with projector lens wide open.
8. Align electron beam of vidicon to obtain swirl around center of raster as wall focus is varied. Some compromises may be required in terms of shading, flicker and registration.
9. Make behavior of all color channels as symmetrical as possible.
10. Adjust signal electrode voltage so that *dark current* (Vidicon beam "on" and light "off") is less than one half of one scale division on the beam current meter—less that 0.01 microamp. Check meter zero with beam "off."

Linearity Adjustments

The TK-26 is capable of achieving deflection linearity to within 2 per cent. The procedure for adjusting deflection linearity is covered in the instruction book for the

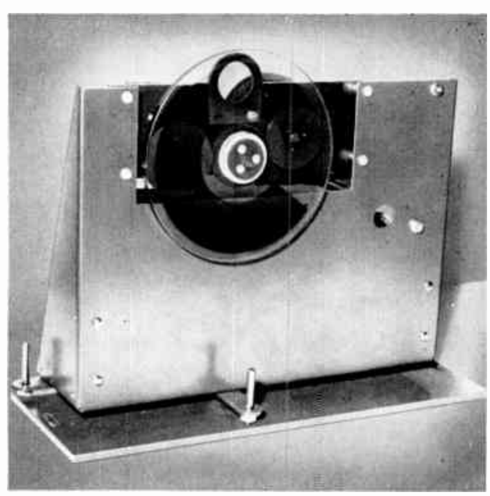


FIG. 33. A variable netural density disk used in front of the projectors is the ideal method for video level control.

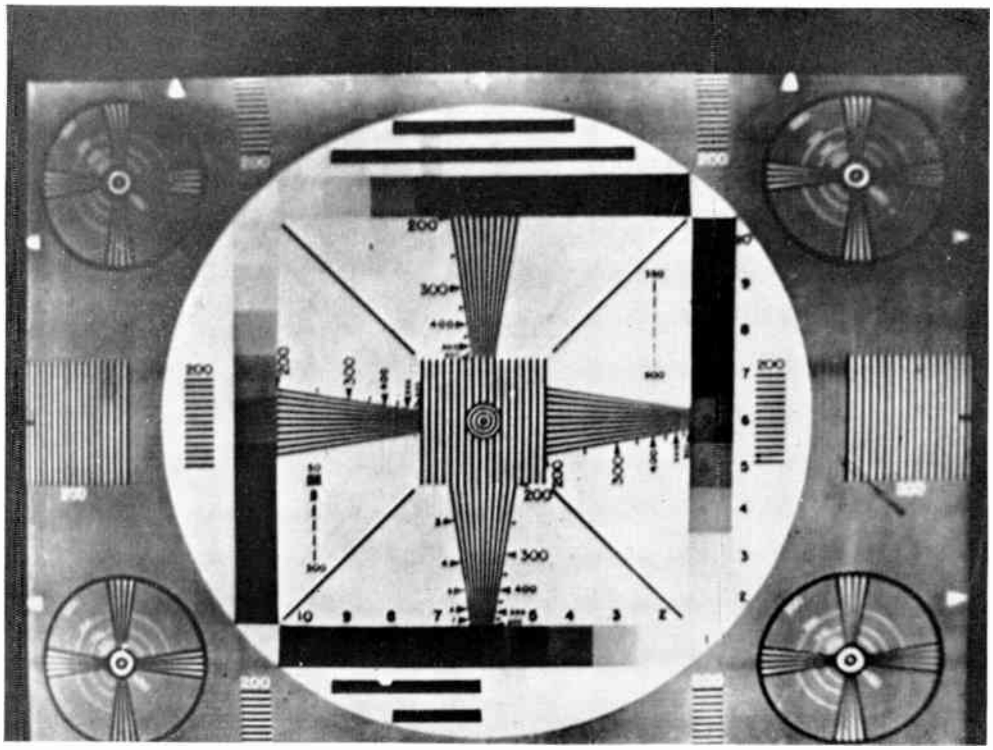


FIG. 34. Photograph of a monitor screen showing registration of a typical, well-adjusted TK-26 film system.

equipment. Some differential linearity difficulties have been traced to aging circuit components. Differential linearity problems are apparent when it is impossible to register two images in the center and at both extremes at the same time. A modification kit has been made available to correct this condition.

Choice of Signal Electrode Voltage

The optimum signal electrode voltage for a vidicon is the one giving the flattest field output signal with a dark current of less than 0.01 microamp. However, one must be sure that the illumination on the faceplate is uniform to begin with, in order that the signal display is representative of the vidicon tube characteristic only. It is important to point out that similarity of output in the three tubes is more important than *absolute flatness*. A slight amount of similar shading in all three tubes will produce a much more pleasing display than absolute flatness in two channels and a departure in the third.

Image Registration Techniques

The registration of vidicon images is covered in detail in the equipment instruction book. The following comments will help the operator to do the work with greater precision and less effort:

1. Optical and electrical focus should be adjusted before precise registration is attempted. The vidicon image rotates slightly as the beam is focused electrically.
2. Always adjust projector lens iris to *maximum* aperture before focusing.
3. Vidicon beam-splitting may occur if beam current in excess of 0.3 microamp is used in discharging the signal-electrode. Beam-splitting under normal operating conditions is indicative of a *defective* vidicon; one whose thermionic cathode emission characteristic has deteriorated or one whose G2 voltage has too low a value. Beam-splitting, when observed using the registration slide, appears as double lines in certain portions of the image.
4. Image geometrical distortion can result either from excess vidicon beam current or the use of excess vidicon alignment coil current. Photograph taken from a monitor, showing registration of a typical well-adjuster TK-26 film system, is shown in Fig. 34.
5. Varying or trimming individual vidicon beam focus by varying wall focus control after registration will rotate the image slightly and may cause some misregistry.

Vidicon Shading Procedures

Shading is introduced into the three video signal channels to make possible a much higher degree of uniformity or flatness of field than can be obtained by relying only on the characteristics in commercial vidicons. Shading is *purely a set up control procedure which is never varied during program operation.*

Even the highest quality present-[illegible] vidicons show some departures from flat output signal such as porthole, flare, or tilt—both horizontally and vertically—when the light on the tube is perfectly uniform. These departures are "well-behaved" and can be corrected rather completely by suitably introducing a small amount of parabolic or sawtooth shading to the original output at horizontal and vertical scanning rates.

The set up procedure for shading is very straightforward. The vidicons are exposed to "open-gate" white light at normal, full operating level, and each vidicon signal is in turn compensated with the required shading waveform input to produce the flattest, or most nearly identical field for all three signals. Under these conditions the color monitor display for 'ideal" adjustment will give a completely white field. If shading compensation is removed, the field will show areas of color where the characteristics of the three vidicons are not matched. For example, if red and blue outputs are perfectly matched at all points in the raster, and green output is matched with red and blue everywhere except at the edges, the raster will be white with *green* edges when the green vidicon output has *edge flare* or *excess green signal.* It will have *magenta edges* when the green vidicon output has *porthole* characteristic or *deficiency* in green signal amplitude at the edges, because magenta is red plus blue minus green. By examination of the "white" raster display itself one can determine directly what corrections are necessary, and can use the final display itself as a precision tool for fine balance of shading of the raster field.

Axis Shading and Modulation Shading

In motion-picture techniques, the 'fade-to-black" is widely used for many artistic and psychological reasons and is therefore common to all monochrome and color films. In live TV programs switching at full level is widely used and "fades-to-black" are comparatively rare. This has direct bearing on requirements for shading and how it must be carried out. In the discussion about producing a flat white field, no mention was made about how the shading or "compensating signal" is introduced. However, it is quite apparent that axis or "additive" shading, once introduced, is independent of the signal amplitude. Thus, even though a perfectly flat field is set up at full white, a "fade-to-black" with *no* vidicon output signal, will contain *the full amplitude* of the *shading signal* introduced. Thus, axis shading produces *maximum error in raster color contamination* at "fade-to-black," exactly when motion picture recording practices demand *zero* error.

Since the vidicon as used for film reproduction has essentially *constant* black level, a modulation *shading circuit technique* was developed for use with 3V systems. In this process the *video* gain of a "modulating" amplifier is changed in a bridge circuit in accordance with the shading waveform requirements. Thus, the circuit *maintains complete compensation* at "white" or set up condition and *also introduces no distortion at black level.* It is difficult, if not impossible to use axis-shading operationally in film reproduction.

Vidicon Shading Procedures

The TK-26 equipment was originally delivered with additive or "axis-shading" of the video signal. A modification has been made available to convert from axis shading to modulation shading of video signal in the TK-26.

The modulation shading modification uses the same source of horizontal and vertical parabola and sawtooth correction signals from the process amplifier as the original axis shading circuits.

The modulation shading amplifier (see Fig. 35) is provided with R, B, and G channel *modulation balance* controls. The balance should be checked at regular intervals to insure freedom from drift errors. (*next page*)

FIG. 35. The modulation shading amplifier is mounted beneath the desk section of the processing amplifier.

FIG. 36. The video amplifier in the processing amplifier contains a plug-in gamma compensation unit (left side of chassis) with a 0.7 gradient correction.

The shading signals are inserted and removed from the shading modulation circuits by the shading "in-out" switch on the processing amplifier control panel. The shading modulation equipment is provided with three switches to bypass the red, green, and blue video signals from the modulation circuits in case of technical difficulties. The adjustment and maintenance procedures for shading amplifiers are covered in the equipment instruction book.

Gamma Compensation

In addition to an amplifier gamma of unity, the TK-26 is equipped with a plug-in gamma compensation unit (Fig. 36) having a gradient correction of 0.7, which can be switched in-or-out at the control panel. This with the vidicon gamma of 0.65 gives an over-all transfer characteristic slope of 0.65 or 0.45. It will be found that the additional gamma correction is desirable for best reproduction of film, but the 0.65 slope will produce higher color saturation, particularly with cartoon abstracts.

Color Temperature Balance of Projectors

In a typical color installation any one of three or more film or slide projectors can be selected to operate with a TK-26 film chain, using the TP-12 or TP-15 multiplexer arrangement. For good control of film or slide reproduction the "color" temperatures of all sources should be the same. In general, this means that the operating temperature of all tungsten filament incandescent sources should be identical. If there are substantial differences, identical color subjects placed in each of these projectors will be reproduced with different color balance in projectors differing from the standard. With too low a filament voltage the red output rises rapidly as compared to blue, and the image reproduction will be too red.

It is *not* necessary to operate a projection lamp at its *top rated* voltage. To obtain longer life, it may be operated at lower voltages, which are sufficient to give adequate light reserve for dense film and adequate signal-to-noise in the blue channel (which will show light deficiency first as the lamp is operated at lower or "redder" color temperature). The color system itself can be "white-balanced" for almost any useful projection lamp voltage.

It is possible in some cases to detect substantial differences in color temperatures between the two outputs of a TP-3 Slide Projector. This is due to small color-selective departures from complete optical symmetry in the neutral density light-splitting mirrors and other transmission elements. A color temperature balancing kit for minimizing this discrepancy has been made available.

General Hints for Final Adjustment Procedure

1. Signal electrode voltage for each vidicon is chosen for flattest field at a low dark current.

2. The slide projector is used for "open-gate" light source, with light level set to give 0.25 microamp signal current, with signal electrode fully discharged. Light level control should be set to give adequate reserve for dense film.

3. A beam current meter should first be "zero-balanced" with no light on vidicons for red, blue, and green vidicon channels. With "open-gate" illumination source all vidicons will probably have different signal-current values.

4. Select the channel with *lowest* signal current and raise the light level to obtain 0.25 microamp signal under conditions of "open gate", 100 per cent light transmission. This gives standardized "ideal" operating condition on the vidicon.

5. "Pad" the light level on the other two vidicons using appropriate neutral density filters until they also have 0.25 microamp signal. This gives identical operating parameters in all three channels.

6. *Do not attempt to pad by stopping down a camera lens iris* as serious vignetting and optical shading errors will be produced.

7. "Dark current" is current which flows through the photoconductive layer of the vidicon *when no light is on the vidicon.* Zero-balance the beam-metering circuits with beam off and light off. Measure dark current with beam *on* and light *off*. Dark current with present TK-26 techniques should be negligible compared to signal currents. It should be maintained at very low values, below 0.01 microamp, for minimum smearing of motion and minimum scene retention.

8. Insert a resolution chart test slide in slide projector and open projector iris to maximum opening. Verify image focus position within field lens, using a white card placed alternately before and behind field lens positions as in Fig. 31; next, check the optical focus of each vidicon cameras as seen on display monitor pattern; then stop the iris down by two stops.

9. Verify individual vidicon R, G, B, electrical focus. *Since there is a small amount of image rotation as the wall focus voltage is varied* through its correct value, one should not be surprised to find that a *perfectly registered picture* can be degraded in registry merely by "trimming" the red, green, and blue electrical wall-focus voltages at slightly different values from those originally selected. It is good practice to use the green channel as a reference for resolution and registration and register and focus the red and blue channels with respect to it.

10. Once optimum registry and resolution have been obtained, the system should stay in focus and regis-

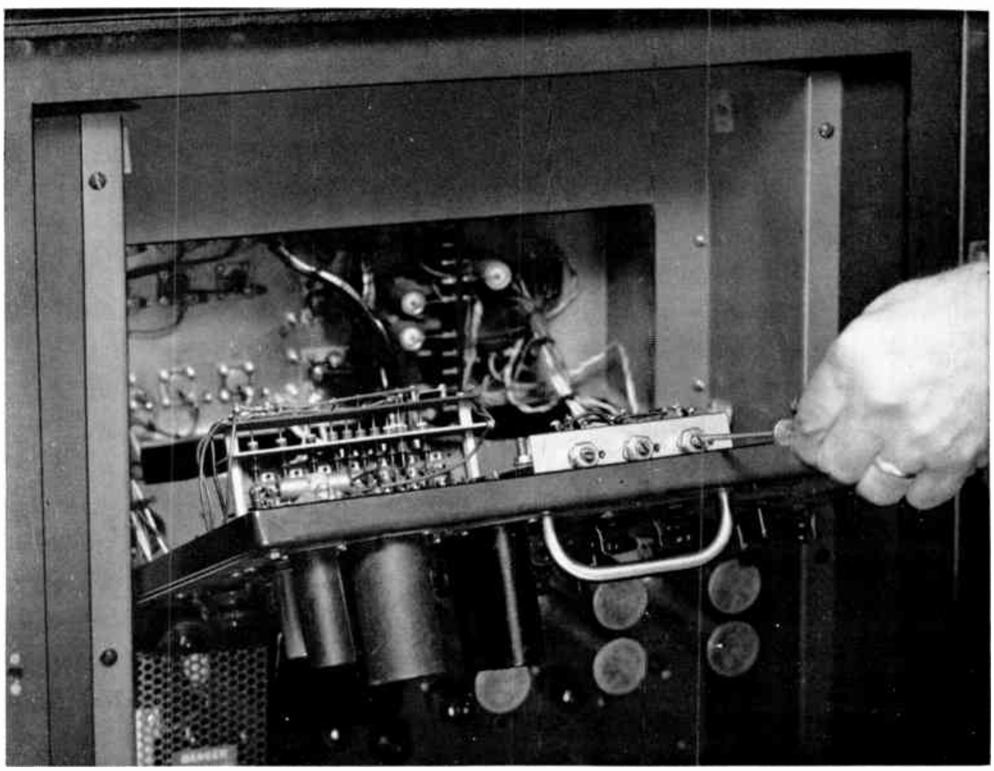


FIG. 37. Vidicon screen voltage controls are screwdriver adjustments located behind handle of local control panel.

try over long periods, although minor long-term variations in regulated currents and voltages will require compensation.

11. Experience indicates that modulation shading compensation based on about 70 per cent peak white signal produces better pictures than that based on full white raster.
12. Shading variations between projectors can be caused by: (a) misalignment of projector, (b) misalignment of condenser lenses, and (c) misalignment of projector lamp or reflector. Stopping down projector irises may result in peculiar banding caused by the increased depth of focus of the system and consequent imaging of the lamp filament in the raster.

Vidicon Flicker

Occasionally a pickup tube such as the vidicon or image orthicon will exhibit "flicker" in a small portion of the scanned area. Oscilloscope observation shows that the signal is generated in the region *only during alternate fields* and gives rise to a 30 cycle "flicker" component. While the mechanism of "flicker" generation is not completely understood, it is connected with the shape of the scanning spot and with the thermionic cathode activation. It can be produced in some cases by excess beam current; therefore, *use only enough beam to just discharge the highest scene highlights.*

In severe cases of flicker, it will be found that lowering the vidicon screen (G2) voltage from its nominal 280 volt value is effective for suppression. The vidicon screen voltage controls are located directly behind the handle of the "local" control panel on the TK-26 camera pedestal (see Fig. 37). Operate the screen voltage control at the *maximum position at which no flicker is evident. Too low a G2 screen voltage* may make it *impossible to obtain sufficient* peak beam current to discharge the highest scene highlights.

Color Balance Adjustments

A standardized procedure for white balance adjustment and black level check of the TK-26 is recommended. The logarithmic step-wedge slide (Fig. 38) is used in the projector and a standard 100 per cent signal level at average light level is produced. The red, blue, and green channels are made equal by adjustment of video gain. Then decrease light to produce 5 per cent signal level and balance the three black levels. Alternate between 100 per cent and 5 per cent, trimming the gain and pedestal settings respectively *until black and white levels match in all three channels.* The use of 0.7 gamma, or "black stretch" at the 5 per cent level will aid in accurate setting of black levels.

Stability of the TK-26

The red, blue, and green images will remain registered over long periods of time. However, it is good practice to check registration two or three times a day. Drift in registration and image size is generally traceable to poor and variable contact resistance in potentiometers, while differential linearity errors in scanning are generally due to "aged" components.

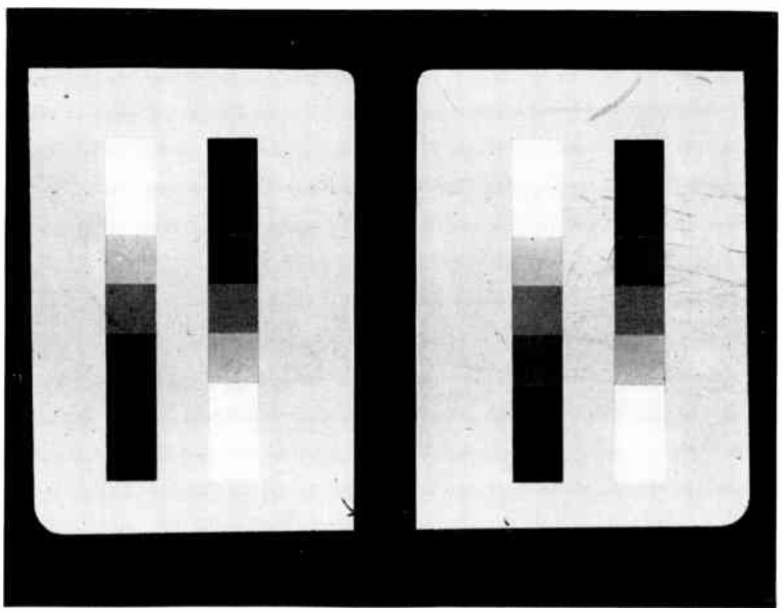


FIG. 38. A 2 x 2 inch logarithmic step-wedge test slide made from two frames of SMPTE 35mm gray-scale test film.

Opaque Pickup

The 3V film equipment can readily be equipped with an auxiliary lens system which will produce excellent pictures from opaque art and live commercial subjects. An increase in optical efficiency by more than a factor of 2, using a green dichroic instead of the original 50/50 neutral density mirror is possible. A modification kit can be purchased.

Electronic Color Masking

A masking amplifier has been developed for use with the 3-V system. It is intended for use in controlling the saturation of the reproduced color pictures, in correcting the hue of skin tones due to color film errors, and for compensation of system colorimetric limitations.[2]

Masking is not to be considered as a magic device to correct poor film. It is a vernier which can be used to make good film and slide reproduction better.

Evaluation of Color Performance

One of the most accurate methods of evaluating color TV performance at present is direct comparison with duplicate film or slides projected on a screen adjacent to the color receiver or monitor. When the film chain is correctly adjusted and operated the results are startlingly close to each other. However, the viewing conditions must be arranged to fulfill several fundamental requirements.

The color temperature of the average color receiver screen is 6500 degrees K (illuminant "C"). The usual slide or film projector operates at a color temperature of 3000 degrees K. In order that it match the color receiver it is necessary to insert a Wratten 78AA filter in the optical path to raise the color temperature to the illuminant "C" level. The projector image brightness should also be reduced by iris or neutral density filters to the same level as that of the color receiver.

Color Test Slides

It is important to remember that even the best color slides available today will fade quite rapidly if exposed to high light and high temperature. For this reason it is advisable to hold an extra set of standard slides in reserve as a primary comparison source.

Monochrome Operation of TK-26

In many broadcast installations the 3V film equipment is used both for color and monochrome reproduction of slides and film. While there are many possible arrangements of TK-26 components for monochrome, the use of one camera for monochrome operation eliminates the necessity for all registration and shading match. The basic approach is generally to alternate between red, blue, and green camera heads in order to get approximately the same

[2] "Electronic Masking for Improved TV Reproduction of Color Film," RCA BROADCAST NEWS, Vol. 90, August, 1956.

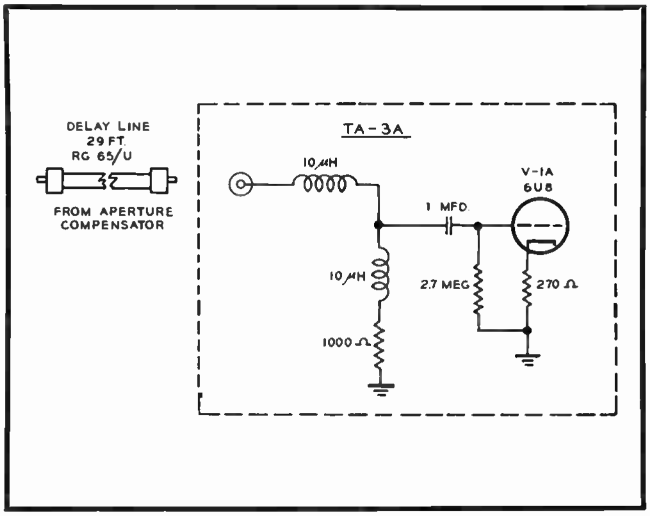


FIG. 39. Circuit diagram of a system widely used for monochrome operation of the TK-26 Cameras. Red, green and blue output terminals are looped through the inputs of a switcher and terminated in the colorplexer.

hours use from each vidicon. In this case it is preferable to remove the heater voltage from the unused cameras and preamplifiers by easily installed switches. This eliminates cathode emission slump which can be caused by operating with heater voltages alone. Deflection and focus field voltages are always applied to all cameras. An alternation schedule of one camera per week has been found to be generally convenient.

The system of monochrome operation used by most stations is one using the red, green, and blue output terminals looped through the inputs of a switcher and terminated in the colorplexer. This system requires an aperture compensator (MI-40414), a delay line (29 feet of RG-65/U) and a TA-3 distribution amplifier. A gain of 2 times in the TA-3 is necessary to compensate for the losses in delay line and aperture corrector. The RG-65/U delay line termination into the TA-3 is shown in Fig. 39.

The video signal from either the red, blue, or green camera can be selected for monochrome operation, and equal operating time can be scheduled on the vidicons.

The vidicon cameras not in use can be placed on stand-by by switching off filaments. The filament voltage should be measured on the camera in operation when the other two camera filaments are off. This test is made when installing filament switches to be certain the filament voltage does not exceed 6.3 volts.

The foregoing discussion has outlined the most important considerations in getting top performance from the TK-26 3-Vidicon Film Chain. The specific suggestions and recommendations presented here will help provide improved stability and best possible performance with a minimum expenditure of effort in day-to-day operation.

PART 7

TM-21 Color Monitor

The "state of the art" in compatible color television has been advanced by the introduction of the RCA TM-21 Color Monitor. This newly designed color display device is capable of producing high-quality pictures, stable enough to hold adjustments over long periods of time, and rugged enough to stand up under rigorous operating conditions. The TM-21 has been designed "from the ground up" to meet the requirements of broadcast stations and closed-circuit color television plants. It is expected to find many applications as an adjunct to color camera chains, as a general-purpose monitoring instrument, and as a high-quality display device in "prestige" applications, such as clients' booths and reception rooms.

Stable Design Enhances Monitoring Applications

One of the most important applications for a color monitor is in control rooms where operators face the problems of setting up and matching color cameras. Because of its high quality and stability, the TM-21 is unusually well qualified for this service. Compared to other monitoring devices the TM-21 offers the following benefits:

(1) It provides a better check of registration during actual programming than the black-and-white master monitor.

(2) Because of its own excellent deflection linearity (within 1% in both directions), a good check of camera deflection linearity is possible.

(3) Provision for underscanning, to show the corners of the picture, permits better checking of camera framing, camera lens aberrations, and camera deflection transients. Underscanning also makes cue marks in the picture corners readily visible.

(4) A highly stabilized method of black-level setting permits better evaluation of camera shading characteristics and clearly indicates the effects of camera pedestal adjustments.

(5) Precision decoder circuits and highly linear output amplifiers produce a picture of improved color fidelity, so that camera color fidelity can be more accurately evaluated.

(6) The improved picture sharpness facilitates checking of camera focus.

(7) Ease of set-up and circuit stability reduce operating cost, because very little operator time is required to keep the monitor operating.

(8) Excellent accessibility for servicing reduces both the maintenance cost and down-time in the event of tube or component failures.

Another important application for the TM-21 is at master control or transmitter monitoring points where the color picture must serve as final indication of the quality of signals being received or transmitted. In this application, the stability of the monitor is particularly significant, because it is important that operators be

FIG. 1. TM-21 Color Control Monitor. Only operating controls normally exposed are brightness, contrast and on-off switch.

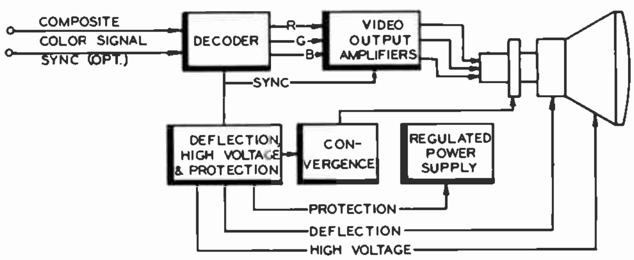


FIG. 2. Overall block diagram, showing the five major chassis in the TM-21.

certain whether observed picture faults are due to the monitor or to the signal itself. When master control or transmitter operators are given a monitor in which they have confidence, they can do a much better job of taking or recommending corrective action when substandard signal conditions are detected.

In general-purpose monitoring applications, the provision for automatically removing the subcarrier trap in the monochrome channel when a monochrome picture is displayed is of special significance. Most compatible color displays are limited in horizontal resolution to about 275 lines because of the necessity for attenuating the color subcarrier at 3.58 megacycles before it reaches the kinescope. This limitation is not serious when the monitor or receiver is producing a color picture, because the addition of color more than compensates for the loss in resolution. When producing monochrome pictures, however, a 275-line limit is quite obvious in comparison with wide-band monochrome displays. The TM-21 has avoided this limitation through its cross connection of the subcarrier trap with the color killer; hence, monochrome pictures are displayed with the full resolution capabilities of the color kinescope, about 450 lines. The TM-21 will do a very satisfactory job of displaying both color and monochrome pictures in many situations where it has heretofore been necessary to provide both a monochrome and a color monitor.

Another application for the TM-21 is in "prestige" situations where it is important that pictures of the highest possible quality be presented. Both the professional appearance of the monitor and its excellent picture are definite assets in such places as clients' booths and reception rooms where the best possible impression on customers or on the public is desired. Stability is important in these situations, too, because the monitor must often operate for long periods with no operator attention.

Serves as System Standard

The TM-21 is the first instrument designed to serve both as a color picture display device and as a piece of test equipment. With respect to circuit design, most previous color monitors have been approximately equivalent to color receivers with the tuner, intermediate-frequency amplifier, and sound sections removed. Most of these devices have been designed with mechanical packaging making them suitable for use in broadcast plants, and have proved generally useful for color display purposes. These previous monitors have not been particularly useful as "standards of reference," however, because they have lacked the stability to suit them for this service. In the TM-21, great pains have been taken to overcome the limitations of conventional receiver designs in order to produce pictures which are limited only by transmission standards, and capabilities of the color kinescope. Stability has been provided by extensive use of feedback and other stabilization techniques, and the mechanical design represents a new high in operating convenience and serviceability.

The Importance of Stability

Before reviewing in some detail the design highlights of the TM-21, it is appropriate to comment briefly on the significance of stability in color monitors. It is not enough to make a color monitor merely capable of *producing* a high-quality color picture—it must be capable of *maintaining* such a picture over long operating periods without frequent readjustments to compensate for circuit drifts. While great progress has been made in reducing color television to a science, there is still enough "art" mixed in with the science to make it necessary that many adjustments in cameras and transmitting apparatus be made on the basis of what they do to the color picture. Unless the operators who make such adjustments are provided with a highly stable color monitor, they can never be quite sure whether some of the effects they see in the monitor picture result from the signal or the display device (monitor).

Of course, stability in an electronic device is a result of careful design. In the TM-21, for example, a high degree of stability has been achieved by the combination of three design approaches: (a) simplification of the basic circuit configuration to reduce to a minimum the possible sources of drift, (b) frequent use of inverse feedback, and (c) generous reserve factors in cases where feedback is not practical.

Circuitry Designed About Five Main Chassis

The monitor has a professional appearance with an over-all size determined primarily by the 21-inch color kinescope. Cabinet dimensions are 27 inches wide, 33 inches high, and 28 inches deep. The only operating controls normally exposed are: brightness, contrast, and the power off-on switch. The main power fuses are also accessible on the front panel. Internally, the monitor consists of five main chassis mounted on a sturdy frame, decoder, output amplifiers, deflection and high voltage, convergence, and power supply. The relationship between these chassis is shown in Fig. 2. The functions of the five chassis are described briefly as follows:

(1) The *decoder* processes the composite color signal to derive red, green, and blue signals suitable for controlling the color kinescope. It also contains

a sync separator and a sync interlock circuit which permits optional use of external synchronizing pulses.

(2) The *output amplifiers* increase the amplitudes of the signals from the decoder to the levels needed to drive the electron guns of the kinescope. They also provide for the restoration of the DC components of the signals.

(3) The *deflection and high-voltage chassis* is controlled by pulses supplied from the decoder chassis. It provides sawtooth currents for the deflection yoke of the color kinescope, plus a source of regulated power at 25 kilovolts for the kinescope ultor. The protection circuits, which prevent kinescope damage from certain types of failure or improper operation, are located within this unit.

(4) The *convergence chassis* develops second-order deflection currents, which are applied to the convergence yoke on the color kinescope for the purpose of adjusting the shapes of the red, green, and blue rasters so that they may be properly registered in all parts of the picture.

(5) The *power supply* provides regulated +B power for the other chassis.

Mechanical Design Features
Ready Access to All Components

Figure 3 shows how the chassis are mounted within the main frame. Excellent serviceability is achieved by mounting four of the chassis (with the exception of the convergence chassis) vertically with the tubes projecting inward. This design makes it possible to replace any tube from the top or rear of the monitor. Ready access to all small components and wiring is gained by simply removing the side covers.

The same design configuration also provides good separation of heat sources from temperature-sensitive components, so that adequate cooling is possible with natural convection currents. The mounting frame is made of sturdy aluminum angles, and is constructed so that the

FIG. 3. Rear-quarter view of TM-21 with side and top covers removed, showing how the chassis are mounted within the main frame.

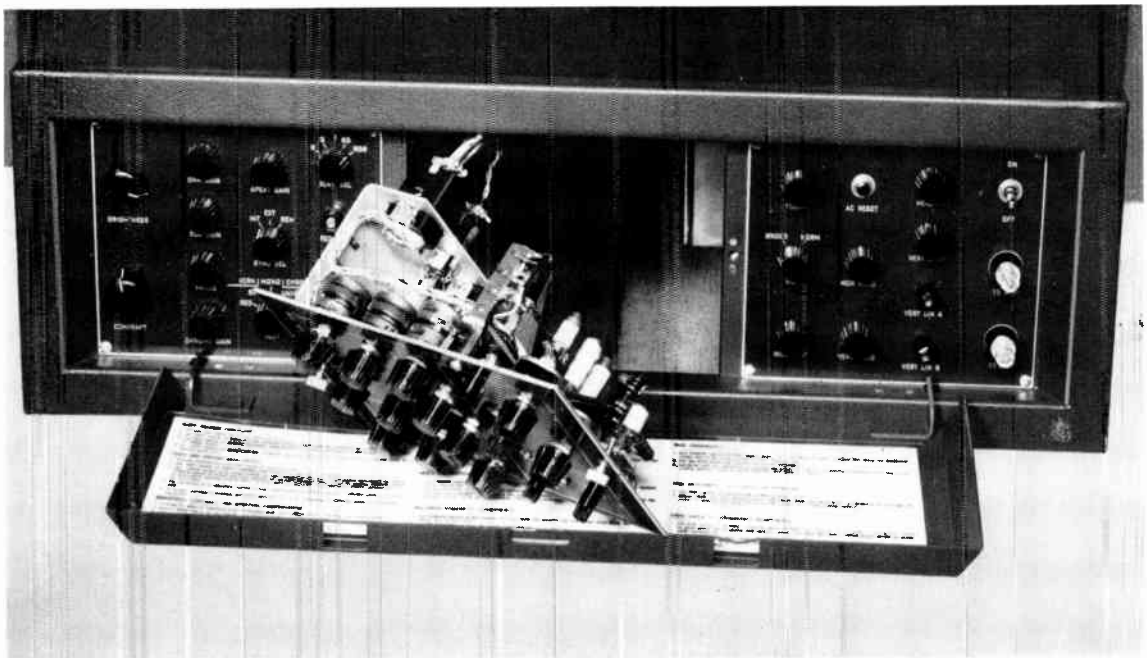


FIG. 4. Front view of the TM-21, with convergence chassis withdrawn for easy servicing.

monitor may be placed on any of its six surfaces without damage. However, it is unnecessary to gain access to the bottom of the monitor for any normal service functions.

As shown in Fig. 3, the deflection and high-voltage chassis is mounted at the lower left, with the power supply immediately above it. The decoder is at the lower right, mounted below the output amplifiers.

The convergence chassis, not shown in Fig. 3, is mounted as a subassembly just behind the middle portion of the front panel. This chassis, which contains only passive components, can be withdrawn from the front for servicing, see Fig. 4.

Another outstanding feature of TM-21's mechanical design is the arrangement for mounting the kinescope. The decorative bezel surrounding the picture area may be readily removed to provide convenient access to a group of screw-driver slots in the periphery of the mask assembly, (see Fig. 5). These screw-driver adjustments control the equalizing magnets which assure uniformity of color rendition in all areas of the screen. With the bezel removed, the safety glass is easily taken out so the kinescope faceplate can be cleaned. A front-panel, high-voltage interlock protects the operator during this procedure. The metal cone of the kinescope is enclosed by a polyethylene boot, which serves as a high-voltage insulator, as a filter capacitor for the high-voltage power supply (since a conductive coating on the outside of the boot is grounded) and as a mechanical support which is clamped against the front panel. The upper section of the front panel is hinged at the bottom, so that it can be dropped forward to permit convenient replacement of the kinescope as illustrated in Fig. 6.

FIG. 5. Decorative bezel surrounding the picture area is removed for access to the equalizing magnets and the safety glass.

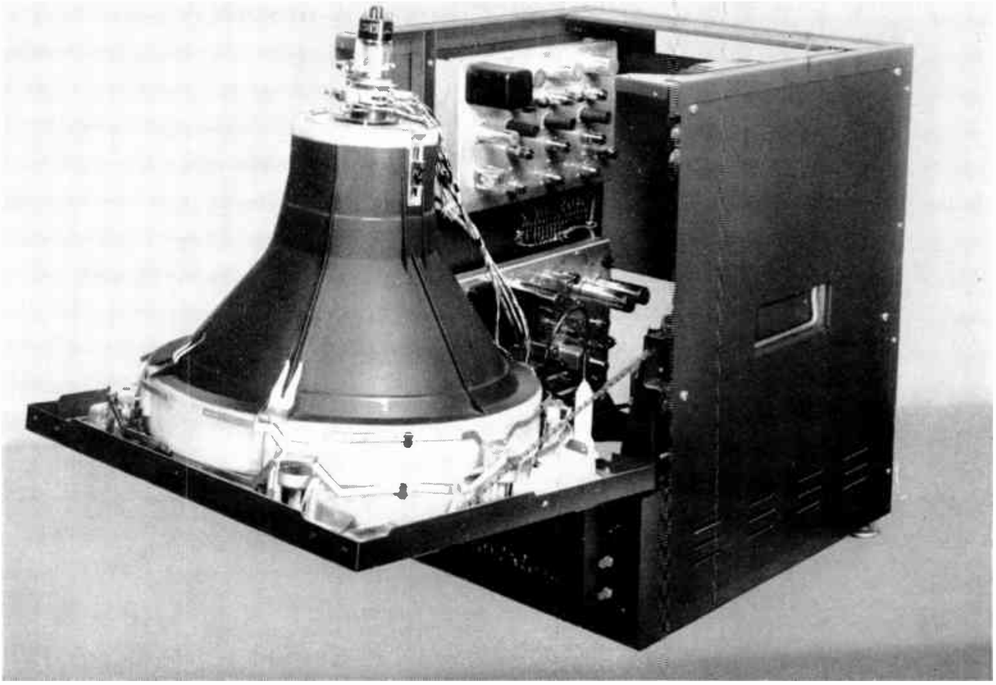


FIG. 6. Monitor front panel is readily swung down for quick removal of kinescope.

Decoder Chassis Differs From Receiver Design

The area in which the monitor differs most significantly from conventional receiver designs is the decoder. A photograph of this chassis is shown in Fig. 7; a block diagram in Fig. 8. Many of the drift problems in conventional receiver or monitor designs fall in this section, because it is necessary that separate but parallel signal channels be used for many of the processing functions. For example, in a receiver the high-frequency portion of the signal must be processed in channels containing demodulators and filters, while the low-frequency portion is passed through delay equalizing networks and an aperture compensator. Drift problems can arise unless such separate but parallel stages are highly stabilized with respect to both gain and phase characteristics. In the TM-21 decoder, the drift problem has been kept under control by reducing the number of stages required in the parallel paths, by eliminating the need for gain in these paths, and by stabilizing each of the individual stages.

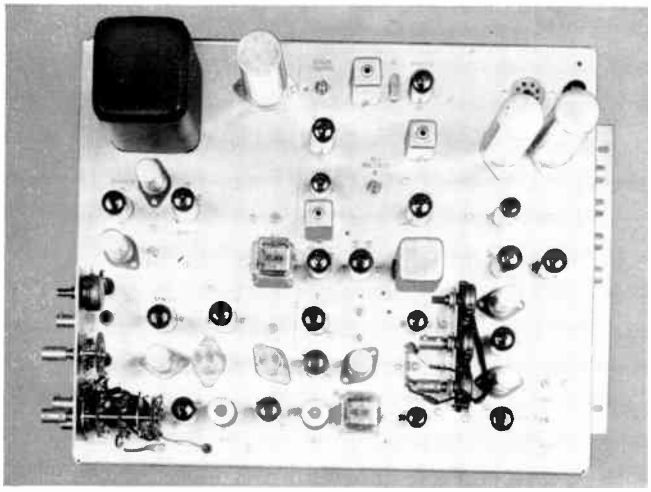


FIG. 7. Decoder circuits are housed on a single chassis.

Video Driver Handles All Signal Components Simultaneously

The heart of the decoder design is a stabilized "video driver" stage which drives the monochrome channel and the burst-controlled oscillator from its plate circuit, and the two chrominance demodulators from its cathode. The DC component is restored at this stage by means of a feedback-stabilized clamp. One of the gating stages involved in this feedback clamp has been made to serve as a burst separator as well, thus eliminating a separate tube for this function. In the video driver the plate signal current is inherently equal to the cathode signal current, so there is no possibility of changes in tube characteristics (thus eliminating any possbility of gain variations in the plate circuit relative to the cathode circuit).

Prior to the video driver stage, the input signal is raised to a relatively high level (about 12 volts, peak-to-peak) by an amplifier equipped with a nonselective or

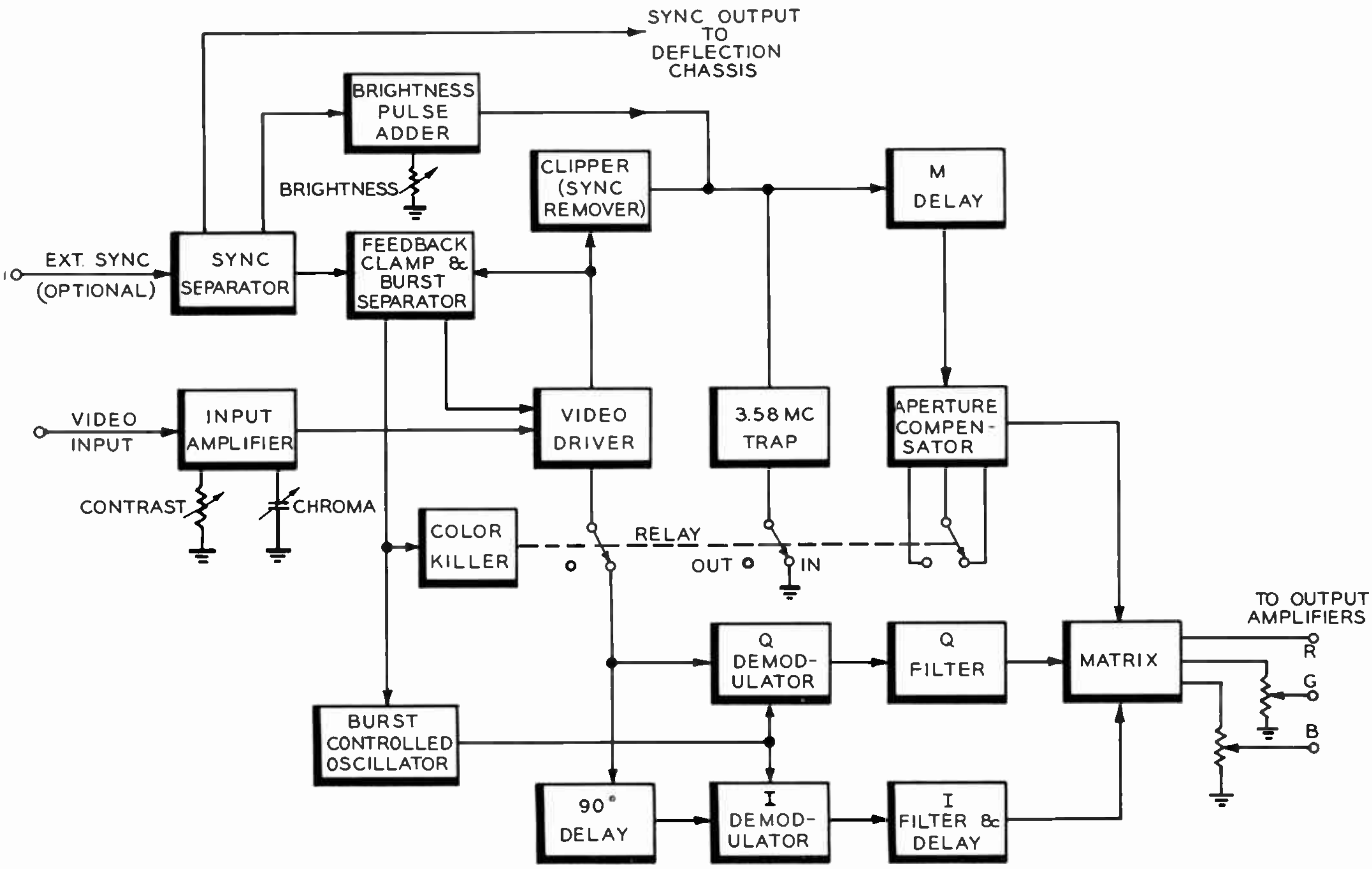


FIG. 8. Simplified block diagram of the TM-21 decoder.

wide-band gain control. By using this high level at the driver stage virtually all of the voltage gain required in the entire decoder is supplied by an amplifier which handles all signal components simultaneously. This technique eliminates the problem of matching the gains of several individual amplifiers. In the stages which follow the video driver, (which must necessarily be split into separate channels), it is possible to sacrifice voltage gain for the sake of stability and still deliver signals at about a 1-volt level at the output of the decoder. The amount of degeneration (or feedback) that it has been possible to incorporate in the TM-21 by following this approach has made practical the elimination of several conventional gain controls (normally provided in decoders to compensate for circuit variations).

Burst Controlled Oscillator Features Single Output

One of the channels following the video driver stage is the burst-controlled oscillator, consisting of a crystal-controlled 3.58 mc oscillator shunted by a reactance tube whose control voltage is derived from a phase detector. This detector compares the oscillator output with the separated bursts provided by the video driver. Special attention has been given to drift problems in this oscillator, so that the phase of its output remains stable relative to the phase of the chrominance signal delivered from the cathode side of the video driver.

In conventional decoder designs, the burst-controlled oscillator normally delivers two subcarrier outputs, (90 degrees apart in phase), to the chrominance demodulators. A popular method of deriving the two outputs is to use a pair of tuned circuits, one tuned above resonance and the other below resonance to achieve the required 90 degree phase shift. In the TM-21 decoder, however, a potential phase stability problem has been avoided by providing only a single output from the oscillator. This output is tied directly to both demodulators, so that there can be no relative phase drift between them. The required 90 degrees phase shift is provided in the *video* channel by passing the input signal to the I demodulator through a precision delay line equivalent to 90 degrees at 3.58 megacycles. The delay line is manufactured with a tolerance of only ±1 degree; hence it is possible to eliminate the conventional 90 degree or quadrature phase control. The presence of the delay line in the I video channel poses no problem, because it is very simple to take it into account when adjusting the total delay of the I channel relative to the narrow-band Q channel.

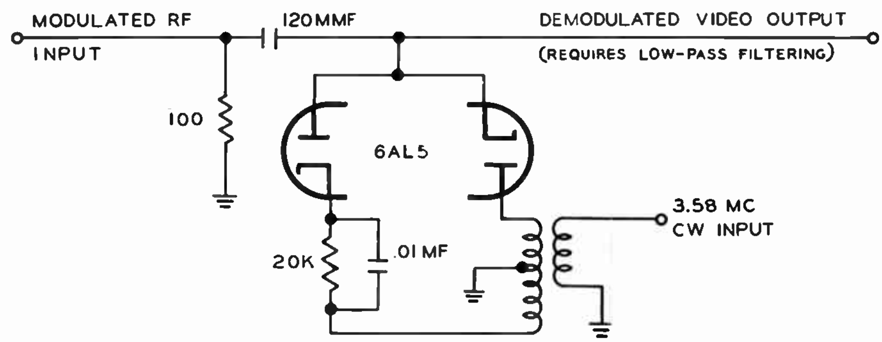


FIG. 9. Simplified schematic of a clamp-type diode demodulator used in the TM-21.

Stabilized Diode Demodulators Eliminate Drift

The demodulators themselves are a stabilized diode type, as shown by the simplied schematic, Fig. 9. In essence, the circuit is a fast-acting clamp. The diodes are closed periodically at a 3.58 MC rate, and their effect on the signal is to connect the output side of the 120 mmf capacitor to ground through the center tap of the 3.58 MC transformer. The charge stored in the 0.01 mf capacitor through the rectifying action of the diodes serves to make the diodes conductive only during the extreme peaks of the subcarrier cycle. Because the clamp is closed only momentarily, the output side of the 120 mmf capacitor is normally free to follow the variations in the input signal. The average output level, however, is a function of the input level at the instants when the diode conduction occurs, as illustrated by the waveform sketches in Fig. 10. This average level is affected by both the amplitude and the phase of the incoming chrominance signal, and represents the desired demodulated signal.

The major advantages of this demodulator circuit are: (1) it has no video gain drift problem, since it behaves in principle like a fast-acting switch, (2) it is insensitive to the level of the CW subcarrier signal, provided the CW signal is always of higher amplitude than the modulated RF signal.

High Resolution Pictures From Monochrome Channel

There are several unusual features in the monochrome channel of the decoder, driven from the plate side of the video driver. A clipper in the plate circuit removes both the sync and burst components of the input signal. In the blanking interval thus cleared, there is provision for adding a "brightness control pulse" of adjustable amplitude. This pulse is derived from separated sync and makes possible a considerable simplification in the adjustment of the monitor for proper gray scale balance. Since the pulse is introduced in the monochrome channel ahead of the matrixing operation, it is automatically supplied in the proper proportions to the red, green, and blue channels which are separated at the output of the matrix. As will be explained in more detail later, the brightness pulse serves as a reference level to which the signals are clamped in the DC restoration process at the kinescope guns.

In all compatible color display devices it is necessary to provide attenuation in the monochrome channel to prevent the subcarrier components of the signal from reaching the kinescope by this path. In the TM-21, this need is met by a simple trap circuit. When the monitor is operated from a monochrome signal (i.e., one without color sync bursts), the "color killer" not only disables the chrominance channels to avoid crosstalk effects, but also removes the trap from the monochrome channel permitting substantially higher resolution. This feature is of considerable value in situations where the monitor is used for viewing both monochrome and color pictures.

A delay line is needed in the monochrome channel to compensate for the greater delay of the I and Q channels. Following this delay line, an aperture compensator of a linear-phase-shift type provides an adjustable boost

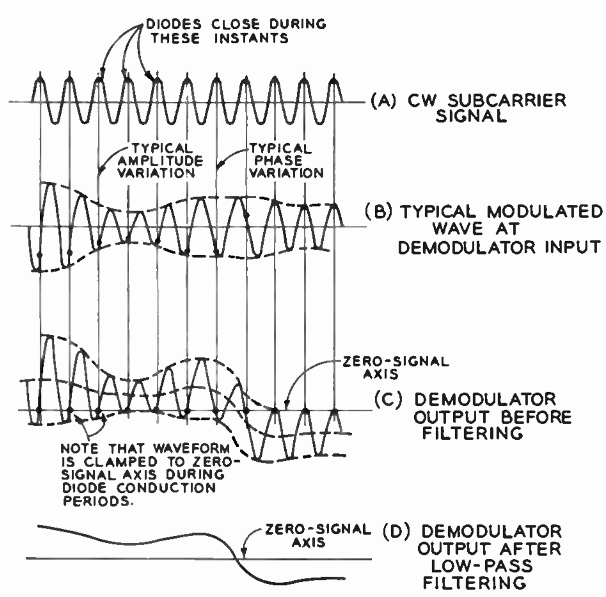


FIG. 10. Waveform sketches illustrating operation of the clamp-type demodulators used in the TM-21.

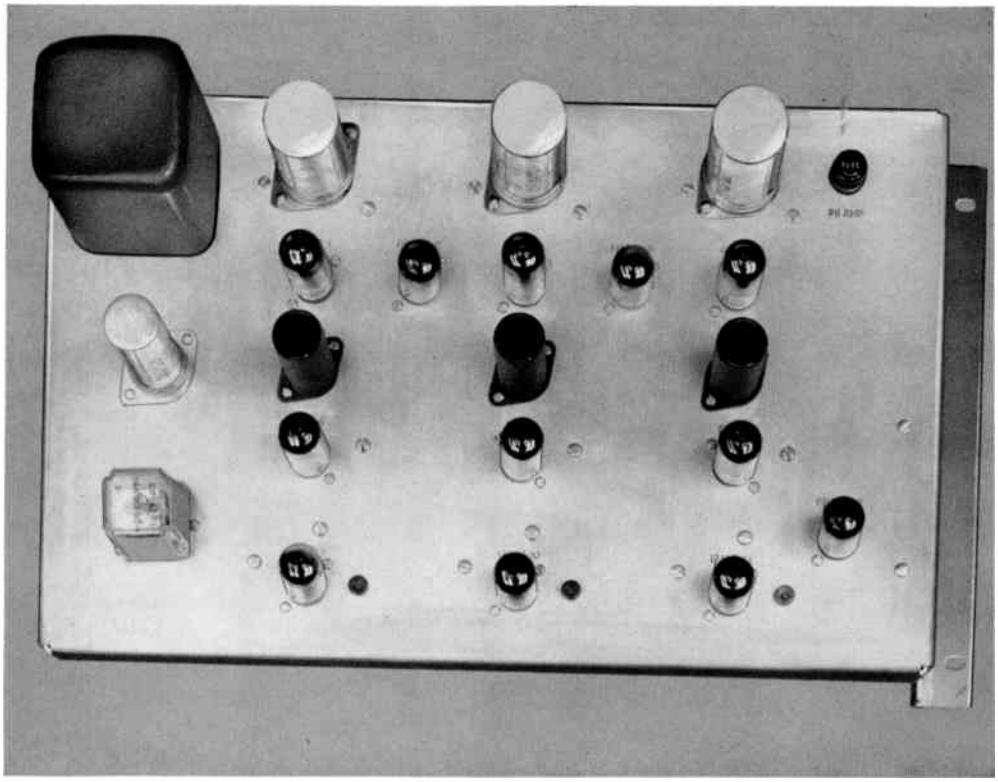


FIG. 11. Output amplifier circuits are housed on a single chassis.

for the higher frequency components of the signal to compensate for the finite spot size of the kinescope beams. The aperture compensator is also tied to the color killer through a relay, so that the shape of the high-boost response curve is altered automatically when the monitor is operated from monochrome signals. This automatic shift in aperture compensation further enhances the sharpness of monochrome pictures.

Gain Controls Eliminated in Matrix Section

In the matrix section of the decoder, the M, I, and Q signal components are cross-mixed in the proper proportions to form red, green, and blue signals. The matrix circuit used in the TM-21 is of a new design, requiring only one phase inverter, which is highly stabilized by degeneration. The relative gains of M, I, and Q signals entering the matrix are so thoroughly stabilized that no gain controls are required. To provide for situations where it is desired to use the monitor with a substandard signal having improper amplitude of the chrominance signal relative to the monochrome signal, a "chroma" or saturation control of limited range is provided in the form of a frequency-response trimmer on the input amplifier. In the normal operating condition, (selected by a front-panel set-up switch, to be described later), this chroma control is disabled, and the monitor display may be accepted as a good indication of the actual quality of the signal applied to its input. Gain controls external to the matrix are used for adjusting the amplitudes of the green and blue signals relative to the red. These controls are needed to compensate for component differences in the subsequent output amplifiers and for differences in the relataive efficiencies of the three phosphors.

The decoder chassis also contains the sync separator, which provides pulses for controlling the deflection circuits as well as some of the keying functions in the decoder. There is an optional input for external sync for use in situations where the monitor is operated from noncomposite signals. An interlock circuit permits remote selection of internal or external sync in applications where both composite and noncomposite signals are encountered.

Output Amplifiers Feature Excellent Amplitude Linearity, Frequency Response and Gain Stability

The amplifiers which raise the decoder output signals to the levels necessary to operate the color kinescope are mounted on the chassis shown in Fig. 11. In order to maintain the proportionality of the red, green, and blue signals necessary for good color fidelity, the individual amplifiers must have excellent amplitude linearity, frequency response, and gain stability.

The operation of one of the three nominally identical channels on the output amplifier chassis is illustrated in Fig. 12. A current feedback loop from the output stage to the input stage accomplishes the following:

(1) The gain is stabilized against line voltage variations, tube aging, and especially, loss in transconductance in the output stage.

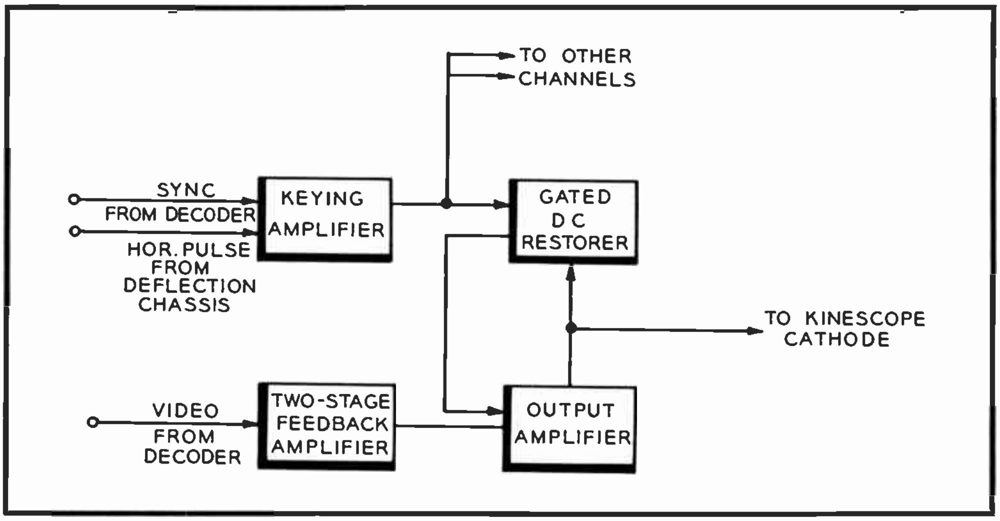


FIG. 12. Simplified block diagram of one output amplifier channel.

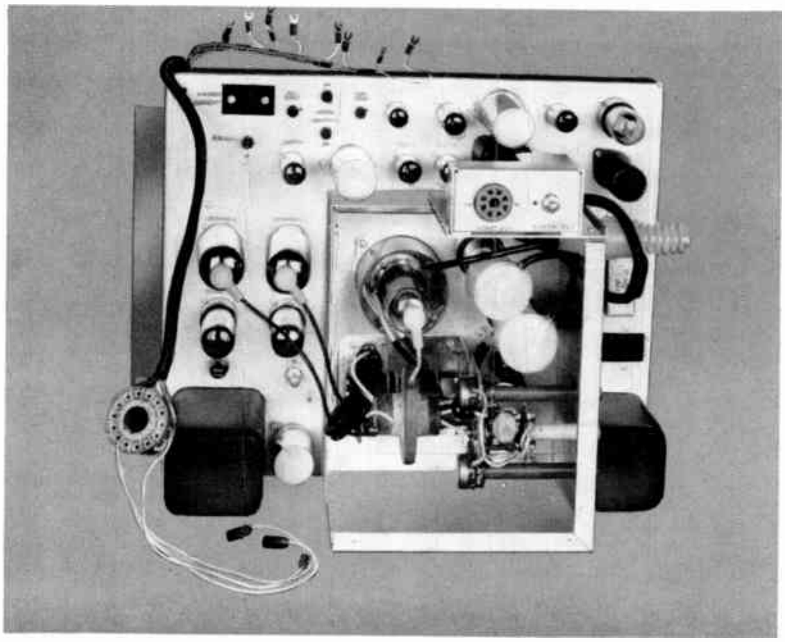
(2) Excellent amplitude linearity is maintained (less than 2 per cent differential gain).

(3) Uniform frequency response, in excess of 6 megacycles, is maintained up to the output tube plate circuit. The passive circuitry, which direct-couples each output stage to its respective kinescope cathode, is a series-shunt compensated network that maintains uniform response to about 5.5 MC.

Instead of conventional diode-type DC restorers, the TM-21 employs gated clamps around the final amplifier stages. The three individual clamps are operated from a single reference voltage in such a way that the DC plate voltages for the three output amplifiers are identical. The different grid bias conditions required to maintain this condition are automatically established by the clamp circuits, which sample the ouputs at the plates but apply their correction voltages to the grids.

The gated DC restorers are normally operated by separated sync pulses, so that the clamping occurs during the transmission of the special brightness pulse inserted by the decoder. In the event that the sync pulses to the monitor are interrupted, control of the clamping operation is automatically taken over by horizontal pulses derived from the deflection chassis. This prevents pro-

FIG. 13. Deflection and high-voltage chassis.



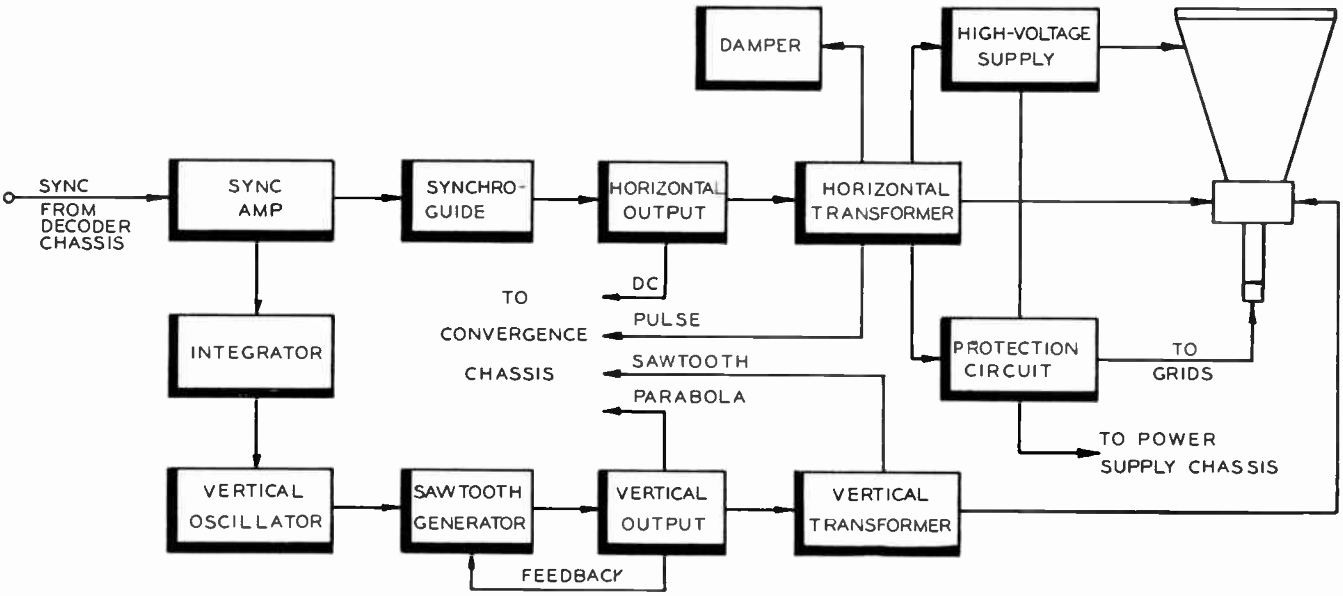


FIG. 14. Block diagram of deflection, high-voltage, and protection circuits.

longed operation under improper bias conditions. When the monitor is operated under no-signal conditions, the brightness pulse is absent, but the monitor operates safely with a gray screen of about 20 per cent maximum luminance.

Deflection Circuits are Feedback Stabilized

While the deflection circuits in the TM-21 are based on conventional principles, they include a number of design refinements that are worth pointing out. The circuits are mounted on the chassis, shown in Fig. 13, and their operation is illustrated by the block diagram, Fig. 14.

The vertical deflection circuit is stabilized by a feedback connection between the output stage and the sawtooth generator. This arrangement not only makes the circuit highly immune to variations in supply voltages and tube characteristics, but also permits the vertical size (or height) to be adjusted over wide limits without disturbing the scanning linearity.

The horizontal deflection oscillator and sawtooth generator is a refined version of the conventional synchroguide circuit, offering a good combination of stability, noise immunity, and optimum phasing of the horizontal retrace period. Added stability is incorporated in the horizontal output circuit to provide generous reserve factors. While typical receiver designs use a single horizontal output tube to deflect the 21-inch color kinescope, the TM-21 employs a pair of 6CD6-GA's in parallel to perform this function, and a pair of 6AU4GTA's to serve as dampers. An unusual type of bifilar winding is used in both the horizontal and vertical output transformers to facilitate the introduction of centering current without requiring bulky isolation chokes around the centering potentiometers.

A unique and significant feature of the TM-21 deflection chassis is the provision of an operational "size" switch for switching rapidly from a normal rounded-side picture to a reduced-sized picture that permits observation of the corners. This switch operates on both the horizontal and vertical circuits simultaneously.

High Voltage Chassis Includes Protection Circuits

The high voltage supply for the kinescope ultor is of the conventional "kickback" type, conservatively designed to deliver all the high-voltage power that the kinescope can safely utilize (1.25 ma at 25 kv). A pair of shunt regulator tubes maintain good regulation under all operating conditions.

Because of the reserve power and signal voltages available to operate the color kinescope near the upper limits of its performance capabilities, special attention has been given to the design of protection circuits to guard against damage to the kinescope in the event of certain failures or improper operating conditions. If the beam current becomes excessive, resulting from improper operating voltages or excessive video drive, the bias on the kinescope grids is automatically shifted to a safe value to prevent damage to the shadow mask. In the event of horizontal deflection failure, extreme overdrive, or a short-circuit in the high voltage system, the protection circuit not only cuts off the kinescope guns but also disconnects the main +B supply on the power supply chassis. The protection circuit itself is designed to be "fail safe," so that failure in any of its components will turn the monitor off.

Convergence Circuits Designed for Easy Set-Up

The convergence chassis, shown previously in Fig. 4, contains purely passive circuits for modifying certain waveforms derived from the deflection chassis before applying them to the convergence yoke surrounding the kinescope gun structures. The word "convergence," as applied to color-display devices, refers to the process of adjusting the positions of the red, green, and blue beams so that the respective images are registered in all parts of the screen. Because the effective distance between the guns and the screen assembly varies with the deflection angle, it is necessary to control the convergence with dynamic waveforms containing both horizontal-frequency and vertical-frequency components. The basic waveforms consist of a parabola and a sawtooth at each frequency, but these must be mixed in different proportions for each gun.

In the TM-21, unusually good performance with respect to convergence is made possible by the conservative design of the deflection circuits, which provide good waveforms to start with. As indicated in Fig. 14, both the output tubes and the output transformers serve as signal sources for the convergence circuits. Stability and ease of operation were given strong emphasis in the design of the convergence section of the TM-21. An examination of the convergence control panel, shown in Fig. 15, will show how the operation of this section of the monitor has been greatly simplified. Two features of the convergence circuit design which particularly facilitate a straightforward set-up procedure are: (1) the controls are arranged so that the red and green rasters may be adjusted as a pair, relative to each other, after which the blue raster may be brought into registration relative to the red-green pair, and (2) every control has been made to direct some type of movement in either the horizontal or vertical direction, not along the 120-degrees axes that prove to be quite confusing in conventional convergence arrangements.

The large number of convergence controls needed for a tricolor tube (16 in the case of the TM-21) need not seem too formidable if each one performs some readily-understood function. Those used in the TM-21 are so designated and arranged on the control panel that it is easy to visualize them as trimming adjustments for the deflection circuits. There are only five basic types of controls (see Fig. 15) and these are readily understood. The *position* controls are only trim adjustments for the centering function, while *size* and *linearity* carry the same connotation as in conventional deflection systems. The *tilt* and *bow* controls produce these effects on the lines of the grating pattern commonly used to facilitate convergence adjustments. The *bow* control affects the curvature of the lines, while the *tilt* controls are used to make them parallel.

Note that the controls are logically grouped in two ways. The *vertical*, *static*, and *horizontal* adjustments are located in separate columns. The upper controls in each column adjust the red and green rasters relative to each other, while the lower controls adjust the blue raster relative to the red-green pair. A screen selector switch just to the left of the convergence control panel makes it possible to view any of the rasters separately, or to view only the red-green pair.

Three-in-One Regulated Power Supply

The power supply for a piece of electronic equipment is often taken for granted as a circuit of obvious function and little significance. In the case of the TM-21, however, the power supply plays a vital role in helping the other sections of the monitor do their jobs properly. The purpose of a regulated supply is to eliminate the

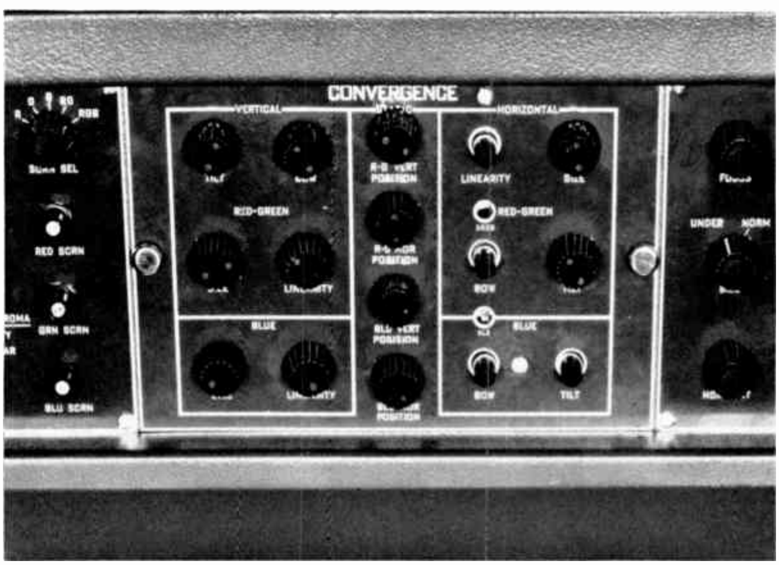


FIG. 15. Convergence control panels used in monitor set-up procedures.

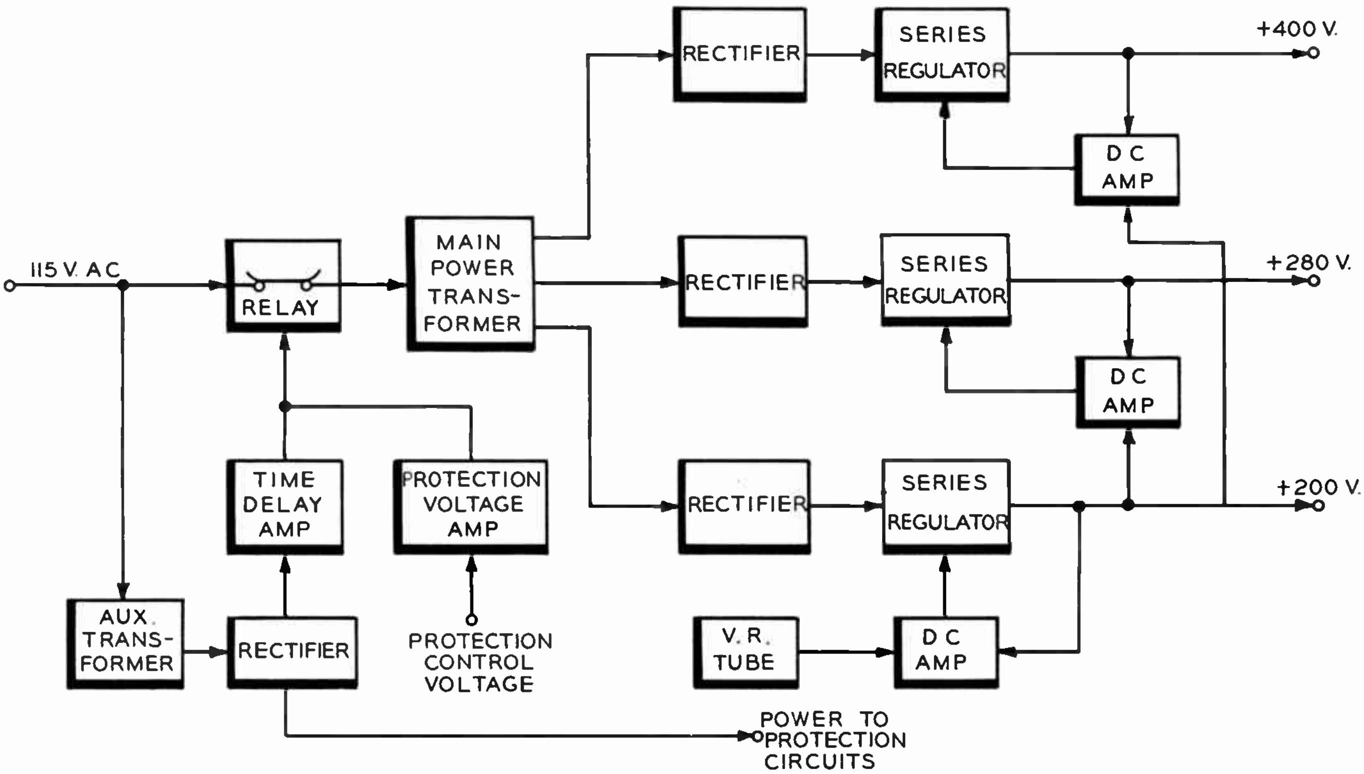


FIG. 16. Block diagram of three-in-one power supply.

interactions and cross-coupling between circuits that occur if supplies of appreciable source impedance are used. Also, the stabilization of the output voltages against line voltage changes preserves the performance designed into the other circuits.

The block diagram, Fig. 16, indicates that the TM-21 supply is actually three power supplies in one. It provides the optimum regulated voltage for each section: +400 volts for the deflection circuits, +200 volts for the video output amplifiers, and +280 volts for most of the other circuits. Since the load requirements were definitely known in each case, an optimum degree of regulation is incorporated without costly over design. As shown in Fig. 16, a common transformer serves all three supplies, but they have separate rectifiers and series regulators. All three are tied to a common voltage-reference system, so that calibrating the +200 volt section automatically sets the others to their proper values. The use of precision resistors in this common voltage reference system eliminates the need for several controls that would otherwise be required.

The use of cool and efficient germanium rectifiers makes it desirable to delay the application of plate voltage to the series regulator tubes until their heaters have had an opportunity to reach the proper operating temperature. The main power transformer is energized through a relay which is controlled by an amplifier deriving its power from a small auxiliary transformer and a vacuum-tube rectifier. Delay is provided by the warm-up cycles of the auxiliary rectifier and the amplifier itself. Time constants give the proper delay when the monitor is turned off and on again quickly. The same auxiliary power source also supplies current to the protection circuit in the deflection unit. The protection control voltage also operates through the same relay as the time delay amplifier to disconnect the power supply automatically in the event of a failure in the horizontal deflection or high-voltage circuits.

The power supply is mounted on a separate chassis, similar in mechanical design to those used for the other sections of the monitor, see Fig. 17. Note that a number of fuses are provided to protect individual sections of the circuit. All fuse-holders are of an indicating type, so it is easy to determine which fuse has blown in the event of trouble.

Rapid Set-Up Procedure

Strictly speaking, a television monitor should not require "operation" because its function in a television system is to serve as a tool for an operator. His main job is to operate a camera, to check the quality of signals, or to select the proper signals for a television program. On the block diagram of a complete television system, the monitors are properly shown as appendages, not as main links in the equipment chains. It is desirable, therefore, to make a monitor so stable that its operation

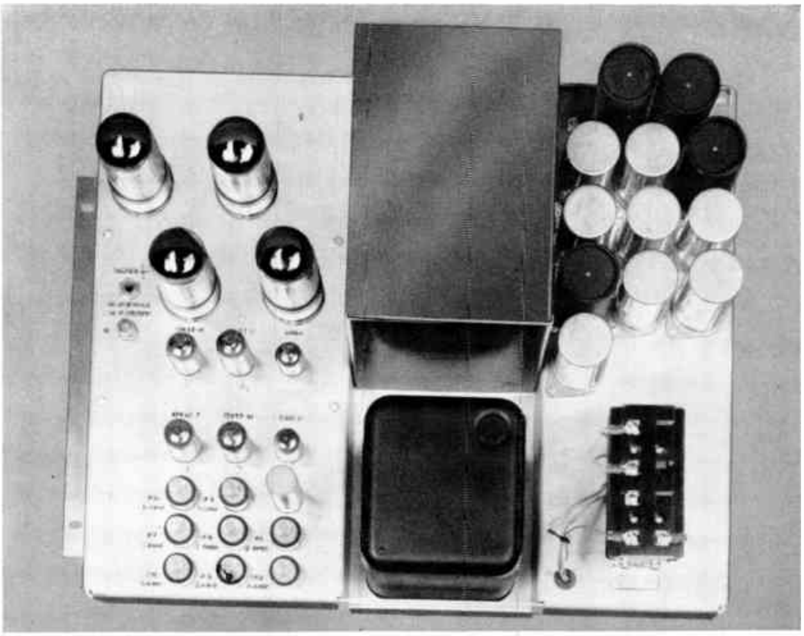


FIG. 17. Three-in-one power supply chassis.

may be taken for granted throughout most of the working day, leaving the operators free to concentrate on their major functions. Such stability has been achieved in the TM-21, so its "operating" controls are more properly called "set-up" controls. Even though the set-up procedure need not be carried out very often, no effort has been spared to make the procedure as rapid and straightforward as possible.

All of the controls needed for routine set-up of the TM-21 are mounted on the front panel, which is logically divided into three sections. The center section contains the convergence controls, which were discussed previously. The left-hand side of the panel (see Fig. 18) contains the deflection controls, whose functions are made obvious by clear labeling. Note that the FOCUS control is included in this section of the control panel, along with an A-C RESET button which restores the monitor to normal operation when the protection circuit trips it off. The SIZE switch is mounted directly under the FOCUS control.

The right-hand section of the control panel, shown in Fig. 18, contains the controls for adjusting the decoder and for setting up the kinescope for proper color balance. It is in this section of the panel that the TM-21 differs most radically from conventional color monitor or receiver designs. Not only are there fewer controls to

FIG. 18. Close-up view of control section. Located left to right are deflection, convergence and decoder control panels.

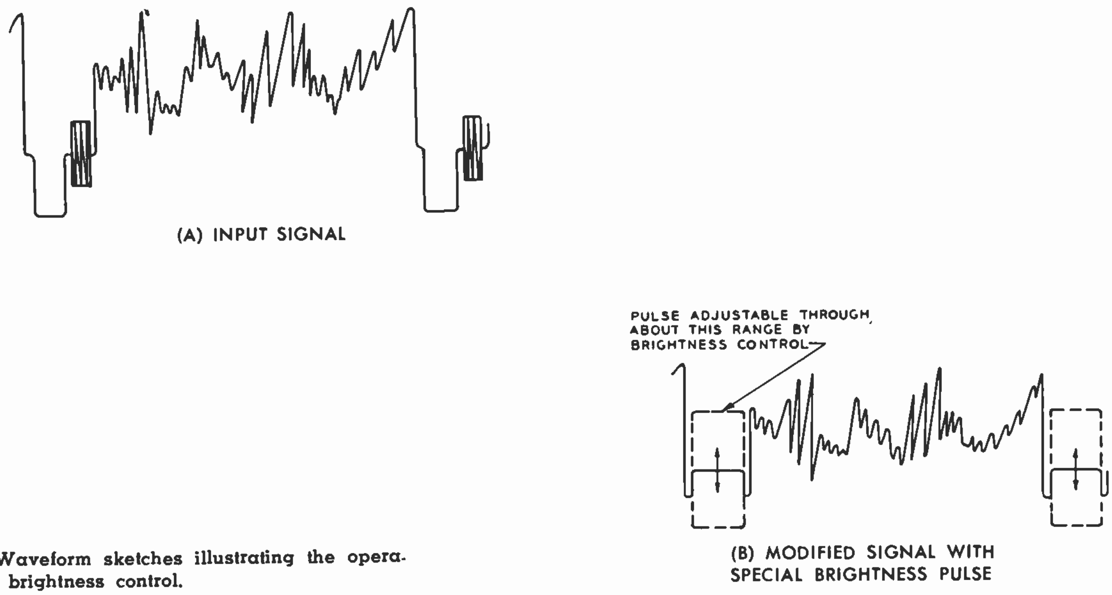


FIG. 19. Waveform sketches illustrating the operation of the brightness control.

contend with, but also the controls are designed to facilitate an unusually straightforward set-up procedure, requiring no external test apparatus other than a source of standard color-bar signals. While some of the controls shown in Fig. 18 are quite obvious, it may be helpful to describe briefly what they do in terms of the circuits they actually control.

The BRIGHTNESS control produces the same effect as conventional brightness controls, even though it operates in an unusual manner. Instead of varying the bias on the kinescope, it varies the level of a special pulse added to the signal in place of the normal sync and burst signals, see Fig. 19. This technique is made feasible by the use of keyed clamps in the output amplifiers, which operate during the time interval of the added pulses. The virtue of this brightness control technique is that it eliminates the need for individual red, green, and blue background controls. The single BRIGHTNESS knob automatically exercises the proper degree of control over the three color channels because the added pulse is passed through the standard decoder matrix.

The CONTRAST control varies the gain of the input stage in the decoder (see Fig. 7), and varies both the monochrome and chrominance components of the picture equally.

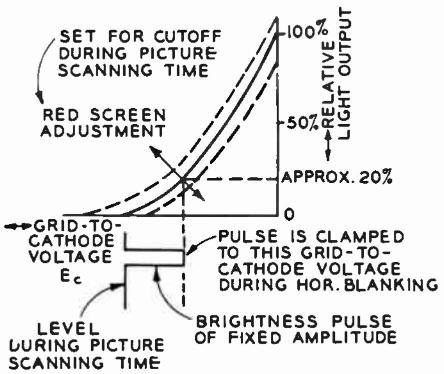
The SYNC SELECTOR enables the operator to switch conveniently between external sync and the internal sync pulses separated from the composite video signal. In the REMOTE position, this switch brings the sync interlock into operation, so that the use of internal or external sync is controlled from a remote point (such as a switcher) through a DC control lead.

The APERTURE COMPENSATOR adjusts the degree of high-peaking in the monochrome channel for optimum picture sharpness without objectionable overshoots.

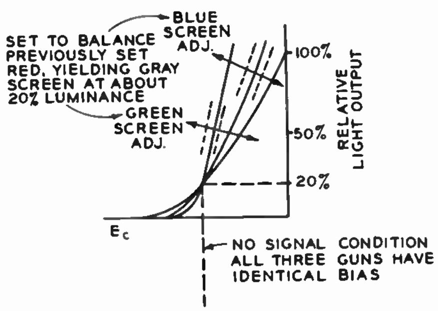
The TEST switch is the key to the simplified set-up procedure for the TM-21. By moving this switch through its several positions and making specific adjustments at each step, the monitor can be brought into proper operating condition with a minimum of effort. The following paragraphs go through each of these steps with reference to the diagrams in Fig. 19 and Fig. 20.

In the first position, the signal is automatically disconnected, but the brightness pulse remains. In this position, the RED SCREEN control is adjusted for cut-off. The SCREEN SELECTOR switch can be set at R to facilitate this adjustment by cutting off the green and blue beams to avoid confusion.

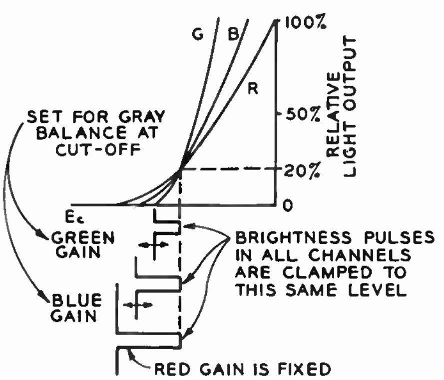
In the second position, SCREEN BALANCE, both the signal and the brightness pulse are disconnected, and the green and blue screen controls may be adjusted relative to the previously-set red screen to produce a gray screen of approximately 20 per cent brightness. The SCREEN SELECTOR switch must, of course, be in the RGB position for this adjustment. As shown by the sketches in Fig. 20, this step brings the kinescope transfer characteristics into coincidence at the point corresponding to about 20 per cent of the maximum signal level.



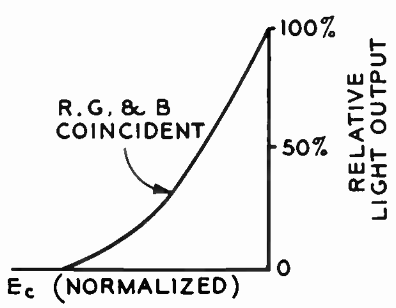
(A) ADJUSTMENT OF RED SCREEN



(B) ADJUSTMENT OF BLUE AND GREEN SCREENS



(C) ADJUSTMENT OF BLUE AND GREEN GAINS



(D) NORMALIZED CURVES AFTER CORRECT ADJUSTMENTS

In the next position, MONOCHROME, both the brightness pulse and the signal are applied, but the chrominance circuits are disabled. In this position, the green and blue GAIN controls may be set to provide proper color balance in all parts of the gray scale. This adjustment is facilitated by the use of a signal containing a gray-scale pattern.

As shown in Fig. 20(c), the absolute signal amplitudes required for the three guns are different because of different phosphor efficiencies. When the proper adjustments are made, however, and the signal scales are normalized, the effective transfer characteristics are essentially coincident, see Fig. 20(d).

The next position, UNITY CHROMA, is the normal operating position, in which the signal is applied to both the monochrome and the chrominance channels. The CHROMA control is inoperative in this position, and the saturation of the colors in the picture yields a good indication of the quality of the incoming signal. The PHASE control may be set conveniently while in the UNITY CHROMA position by examining the blue component of a standard color bar signal (using the B position of the SCREEN SELECTOR switch). When the phase adjustment is correct, the standard color bar signal produces four blue bars of equal brightness. If the phase adjustment is incorrect, the blue bars are of unequal brightness also shown on rapid set-up chart. This test is very sensitive, particularly if the brightness is temporarily reduced to place the blue bars near cut-off on the kinescope characteristic.

In the final position of the TEST switch, VARIABLE CHROMA, the conditions are the same as for the UNITY CHROMA except that the CHROMA control is made operative. This position is intended for operation in applications where the monitor is used to make the most pleasing pctures, even though the signals available are slightly substandard. The CHROMA CONTROL is simply set for the most pleasing over-all effect.

The TEST switch can be used to make a rapid test of the convergence adjustments in the monitor. If there is any uncertainty in the viewing of a color picture as to whether observed misregistration is a fault of the signal or of the monitor, it is only necessary to place the TEST switch in the MONOCHROME position. If the color fringes disappear, they are clearly a fault of the signal, while if they remain it is necessary to touch up the convergence adjustments of the monitor itself.

FIG. 20. Sketches illustrating the procedure for setting color balance in the TM-21. Note: all light ouput scales are normalized such that 100% R + 100% G + 100% B = 100% White.

PART 8

Switching and Distribution of Color Signals

Transmission of color imposes exacting tolerances on the frequency response and linearity of the system to insure proper color reproduction and conformance to FCC standards.

In a monochrome system, reasonable distortion in luminance, or brightness values, may not be noticeable to the average viewer. But in color systems, distortion can affect chromaticity, producing color differences which are readily apparent. Color reproduction at the receiver, therefore, is directly influenced by the transmission characteristics of the various elements of the color system.

Part Three of this manual describes the effects that certain distortions can have on the picture, and prescribes overall system tolerances required to maintain good picture quality. As pointed out, there are four parameters for which relatively small tolerance limits must be maintained. These are: (1) amplitude vs frequency, over the passband; (2) envelope delay vs frequency; (3) differential gain, or subcarrier amplitude vs monochrome amplitude; and (4) differential phase, or subcarrier phase vs monochrome amplitude.

Target Specifications (Fig. 1)

In considering the performance required to meet FCC standards, which are presently specified for transmitter operation, it is necessary to determine an appropriate division of tolerances between studio, STL and trans-

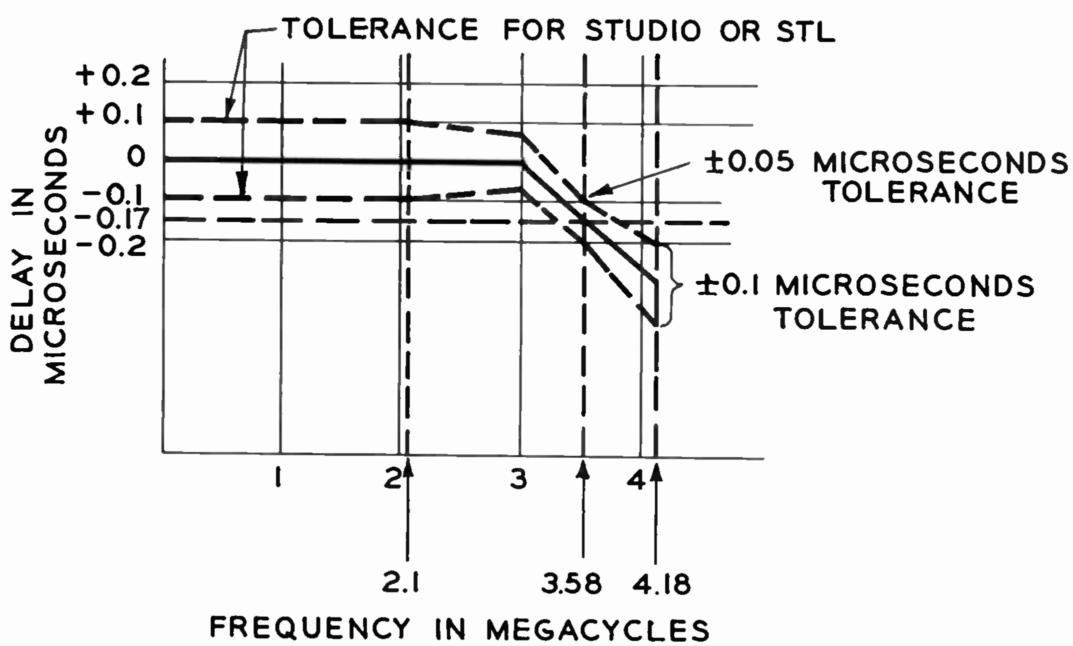


FIG. 1. Curve showing target specifications for envelope delay in studio and STL systems.

TARGET PERFORMANCE SPECIFICATIONS		
Parameter	*STUDIO*	*STL*
AMPLITUDE VS FREQUENCY RESPONSE	Peak-to-peak Variation less than 1.0 db, 30 cps to 4.5 mc.	+0.0, —0.3 db, 30 cps to 4.5 mc.
ENVELOPE DELAY (Tentative; very little data available due to difficulty of measurement)	See Fig. 1	See Fig. 1
DIFFERENTIAL GAIN 50% Average Picture Level (A-c axis at the same signal level as in a picture half-white and half-black).	0.5 db	0.5 db
DIFFERENTIAL PHASE 50% Average Picture Level	2 Degrees	1 Degree

mitter equipment. Although as yet no standards for such a division of tolerances has been specified, it has been proposed that the parameters mentioned be maintained within certain limits for the studio and STL systems.

The proposed tolerances are very tight, and extremely good system performance is required to meet them. However, through use of the figures, it is possible to set up target specifications for performance of the studio switching and distribution system, which are given in the table. *It must be emphasized that these tolerances are target specifications only, and should not be construed as a value of performance that can be expected from the equipment under all conditions.*

Timing and Clamping

An important factor that must be considered in planning a color system is that of timing the various synchronizing, driving, blanking and color subcarrier signals. In addition to precautions which are normally taken to insure proper relationship between these signals in the monochrome system, there are three additional requirements for color:

1. The timing interval between sync and blanking must be held within closer limits so that the proper relationship between sync, burst and blanking can be maintained. In systems employing non-composite switching with sync added after the switcher, the variation in delay time for the blanking signals associated with the various camera sources should be no more than the equivalent of 25 feet of RG/11U cable. This is much easier to maintain when a centralized system of camera control is used.
2. The phase of the bursts as they arrive at the switcher from various colorplexers should be maintained within one degree. If the delays in the system are sufficiently uniform, so that the blanking signals arriving at the switcher meet the tolerances described in paragraph 1, vernier adjustments of burst and subcarrier phase can be made by means of the phase shifter associated with each colorplexer. This should make it possible to match the colorplexer phases as accurately as they can be measured.
3. FCC standards require the use of low pass filters in the chrominance channels of the colorplexer. This has the effect of delaying the picture signal and blanking by approximately 1.2 microseconds. If color and monochrome are to be integrated, all sync generator signals delivered to monochrome cameras must be delayed artificially by a corresponding amount. Similarly, if non-composite switching is to be used, all sync pulses must be delayed.

A special problem arises in the case of equipment employing driven clamps which operate on the back porch of the video signal. Unless special precautions are taken, these clamps will distort or destroy the burst. This effect usually can be minimized by comparatively simple circuit modifications which should be incorporated in any new equipment designed for color. Also, older equipments frequently can be modified to avoid damage to the burst.

System Design Practices

Two widely different concepts have been advanced for the switching and distribution of color signals in the studio system. The first and by far the most commonly recognized approach utilizes a separate encoder for each camera chain and employs switching of encoded signals. The second less popular method is seldom used and employs switching of RGB signals from the various camera chains, ahead of a single encoder which processes camera signals "punched up" on the switcher.

The two concepts, which are identified respectively as "compatible" and "RGB" (or "simultaneous") switching systems, are illustrated in the block diagram of Fig. 2.

Advantages claimed for the RGB switching system are savings in cost and a more uniform output signal due to the use of a single color encoding device. Operational experience has shown, however, that any savings that might be effected in the cost of encoders is completely offset by increases in the cost and complexity of signal switching and distribution equipment. The claim of better uniformity in output was based on the performance of early encoders which were plagued with drift and general instability. However, as a result of design improvements brought about by the Colorplexer, it is now quite possible to achieve and maintain uniformity of performance without undue difficulty. Moreover, the experience of network operators as well as independent broadcasters with RGB switching has led to the conclusion that compatible switching has a number of important technical and operational advantages.

RGB vs Compatible Switching

One of the most important features of the compatible switching concept is that it permits complete integration of color, monochrome, remote and network operations. The limitations of the RGB switching method in this respect are obvious. Since two different types of signals must be handled, switching and monitoring problems are multiplied. Video transmission lines and distribution amplifiers must be installed in quadruplicate, three for

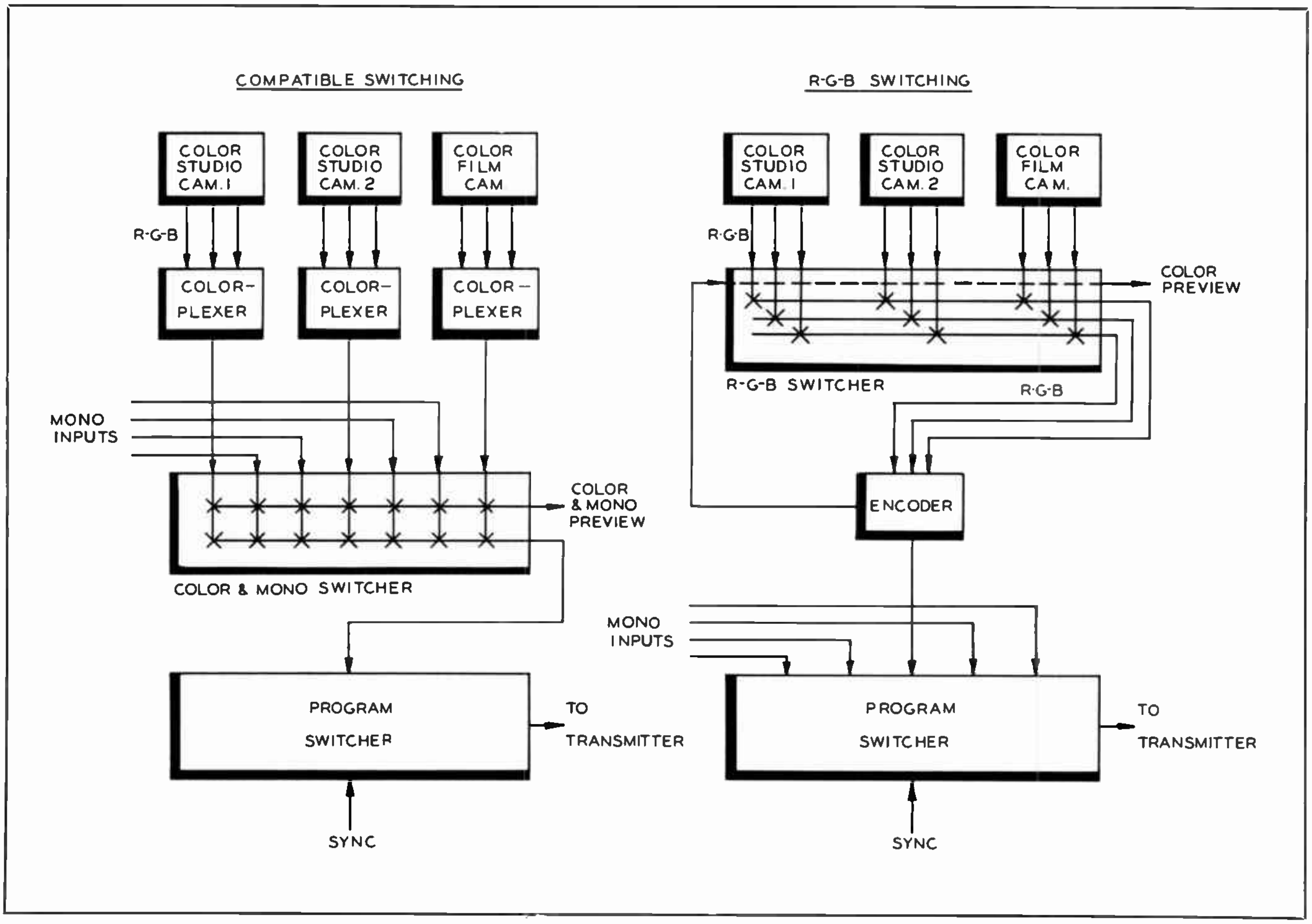


FIG. 2. Simplified block diagrams illustrating "compatible" and "R-G-B" concepts of color video switching.

color and one for monochrome. In switching from a monochrome or network signal to a local color origination, using the RGB system, it is necessary either to perform two switching operations, i.e.: selecting proper input to the switching system, and switching the output circuit from "colorplexer" to "monochrome," or to provide an interlock which will automatically switch to the colorplexer output when any local color inputs are punched up on the switcher. The temptation in such arrangements is to regard the local color originating equipment as a self-contained "island" with a single output which is handled like a remote signal. Other advantages of the compatible method of switching should be at least mentioned briefly: The simplicity of switching the encoded signal, particularly if remote switchers are used, compared with the difficulty of switching the three separate R-G-B signals *exactly simultaneously;* the ease of maintaining sufficient gain stability, and thus color balance, compared to the difficulty encountered in the RGB system, especially in a system of complexity utilizing several amplifiers in series; the simplicity of providing lap-dissolves and special effects; and the equally important feature of previewing a local color signal as it will be seen on the air, which is not technically possible using the RGB switching system.

Planning a System

There are a few special precautions which if observed in the planning and design of the video system will greatly aid the engineer in meeting the design requirements for color. If the objective is to add color facilities to an existing monochrome installation, steps should be taken to provide close integration of color and monochrome signal handling facilities. But whether modifying an installation or building a new one, the following suggestions will be found helpful.

1. The program path from camera to transmitter should be as simple as possible consistent with the operational requirements of the station. It must be remembered that each amplifier, switch, plug and every foot of cable contributes some to the distortion of the signal. All unnecessary elements, therefore, should be eliminated from the program path.

2. In achieving this simplicity, the use of centralized camera control and relay switching will be helpful. This confines video cables to the central control area, and reduces the number of amplifiers in the system.

3. In some cases cable equalization will be required. This should be avoided whenever possible since equalizers ordinarily have an insertion loss which necessitates an additional amplifier contributing other distortion.

4. All video cables of more than a few feet in length should be "sending-end terminated," i.e., the internal impedance of the amplifier driving them should be equal to 75 ohms, the characteristic impedance of the cable. This will minimize any variations in amplitude-frequency response due to an inevitable slight mismatch on the receiving-end termination.

5. A major improvement in linearity can be achieved simply by reducing the video signal level from 1.4 volts composite to 1.0 volt. This may require minor modification of some monitors, and will require more attention to hum and noise suppression. These problems, however, are usually minor compared with the advantages of the lower level.

6. Employ only the highest quality studio and microwave equipment in the installation.

Frequently the performance of older equipment designed originally for monochrome use can be made suitable for color by comparatively simple modifications. Modifications should be made in accordance with the manufacturer's recommendations.

In system practice, it frequently will be found that distortions of opposite signs will cancel. For example, a rising response in one part of the system will compensate for a falling response in another. Such fortuitous and accidental equalization, while satisfactory as an expedient, cannot be recommended as good practice. If the sum of the absolute values of the distortion is large compared with the required tolerance, an unstable condition usually exists and the overall distortion will soon drift outside limits. Furthermore, different program paths will result in different combinations of equipments and distortion cancellation may not occur for all of them.

Sync Delay

As mentioned earlier in this section in the discussion of timing and clamping, FCC color standards require the use of a low pass filter in the luminance channel of the colorplexer. This has the effect of delaying the picture signal and blanking by approximately 1.2 microseconds. If color and monochrome are to be integrated, this requires that all sync generator signals delivered to monochrome cameras must be delayed artificially by an equal amount. Simularly, if non-composite switching is used (switching before sync insertion), all sync pulses must be delayed.

For conveniently producing the sync delay, an artificial pulse delay line is available which will delay pulses up to 3.08 microseconds in increments of 0.077 microseconds (equivalent to 2000 feet of cable in increments of 50 feet). These are suitable for pulse delay use only, and are not intended for use with video signals.

Non-Synchronous Operation

Another step to be taken in the integration of color and monochrome is to abandon the use of the 60-cycle primary power as a source of frequency control for the sync generator. In the use of color, FCC requires that the sync generator be locked to a submultiple of the color subcarrier which, although very nearly 60-cycles per second, is not synchronous with the power source. If monochrome equipment is synchronized to the power source, non-composite switching between color and monochrome is impractical since there is the possibility of causing the receiver to "roll over" every time a switch is made. This can be avoided by operating both color and monochrome equipment from the same sync generator, locked to the color subcarrier frequency.

Difficulty may arise in operating certain types of film cameras non-synchronously with the power frequency. The projector normally is operated with a synchronous motor, and unless the film camera has adequate storage characteristics, a moving "application bar" will appear with non-synchronous scanning. The storage of the iconoscope pickup tube is inadequate to eliminate the bar, and it must be operated synchronously. The vidicon, on the other hand, has excellent storage, and the moving application bar can be reduced to a negligible amount if a long application projector is used (one in which light is applied to the film for 30% or more of the duration of each frame).

Fades and Superpositions

Special care must be taken in planning fade and superposition facilities for color or integrated color and monochrome signals. This arises from the fact that burst amplitude either must be maintained at its proper value at all times or completely eliminated. To operate with burst above or below the correct level is not only contrary to FCC regulations, but also causes undesirable effects in color receivers, particularly those employing automatic chroma control. In view of these requirements the following precautions should be taken:

1. To maintain the burst at full amplitude when fading from a color signal to black and back to another color signal requires a special input to the switcher consisting of burst only. The procedure then is to fade to this input, punch up the second picture input, and then fade back to the second input. The special input signal can be provided by circuits which will key-in the color subcarrier during the burst interval. Provision must be made of course for adjusting the phase of the burst.
2. Fades from color to monochrome should be avoided unless the burst is also added to the monochrome signal. Even this is undesirable, except possibly for occasional short monochrome scenes which might be inserted in an all-color program. In general, straight-forward switching rather than fading should be used in going from color to monochrome.
3. Split-level fades between color signals cannot be made using conventional switching equipment because of resultant improper burst level.
4. Superpositions in color and monochrome can be made using a switcher with a linear fader assembly providing the lever arms are kept together.
5. Monochrome and color signals can be superimposed by maintaining at full amplitude the lever which controls the color signal, and adjusting to the desired value the lever which controls the monochrome signal.

Color Genlock

In order to insert local commercials in a network color program it is desirable to genlock the sync generator to the incoming program. In color, an additional requirement is imposed on the genlock because not only must the local sync generator be locked to incoming sync, but also the color subcarrier must be derived from the burst on the incoming signal. This can be accomplished by looping the incoming signal through a burst-controlled oscillator which will then provide the subcarrier output. The picture signal is then fed to a stabilizing amplifier which will strip sync from it for use in genlocking the sync generator.

Color Switching Equipment*

As in monochrome operation, the complexity of the color switching system depends upon program requirements and the number of signal sources to be handled. Block diagrams showing typical equipment layouts which combine various monochrome and color programming facilities are presented in Part Nine of this manual.

Through use of the compatible switching technique previously described it is possible to utilize standard monochrome switching equipment to handle color as well as monochrome signals. This provides the station

* *See Appendix for Transistorized Switching Systems.*

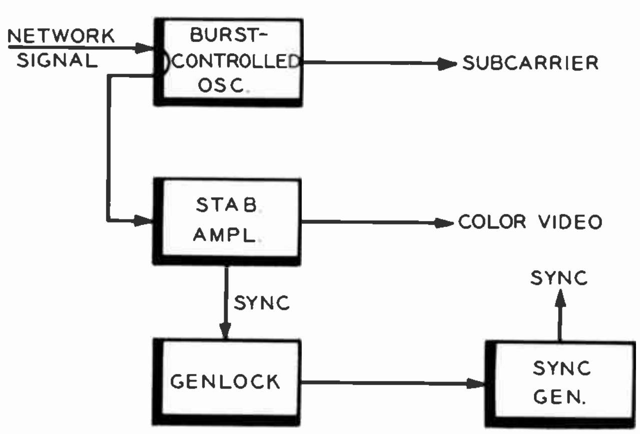


FIG. 3. Diagram showing method of deriving color subcarrier and sync from incoming signal for genlocking.

design engineer with a wide selection of commercially available equipment, which includes local, *direct-switching* systems and remote *relay switching* systems.

Direct-Switching Systems

Direct-switching systems employ mechanically-operated pushbutton switches designed for use in 75-ohm coaxial lines. The two systems which are described in the following paragraphs differ principally in the number of input and output circuits. Both systems incorporate fade and lap-dissolve facilities.

TS-5 Switcher

The TS-5 Video Switcher is a flexible two-unit equipment designed to fit in a standard console housing. The pushbutton and fader panel can be located either in the sloping desk area or in a standard remote control basic frame placed in the upper face of the console. In either case, the amplifier chassis is installed in the lower portion of the console within reach of interconnecting cables.

Provision is made for selection of any one of five input channels. The punched up signal is fed through the manual fader control to a mixing circuit and twin output line amplifiers. Pushbuttons are rear illuminated and interlocked.

The TS-5 is primarily designed for use in a small studio installation as an independent switcher as shown schematically in Fig. 4. Although, it can be used to advantage in conjunction with other switching systems to expand facilities with a minimum of expense as shown in Fig. 7.

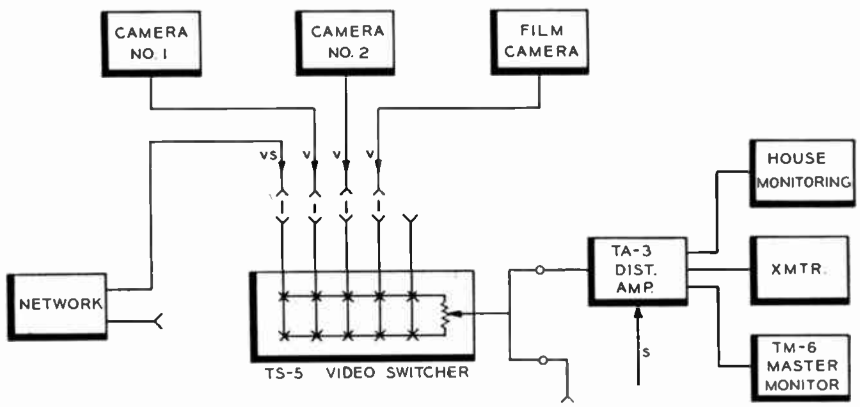
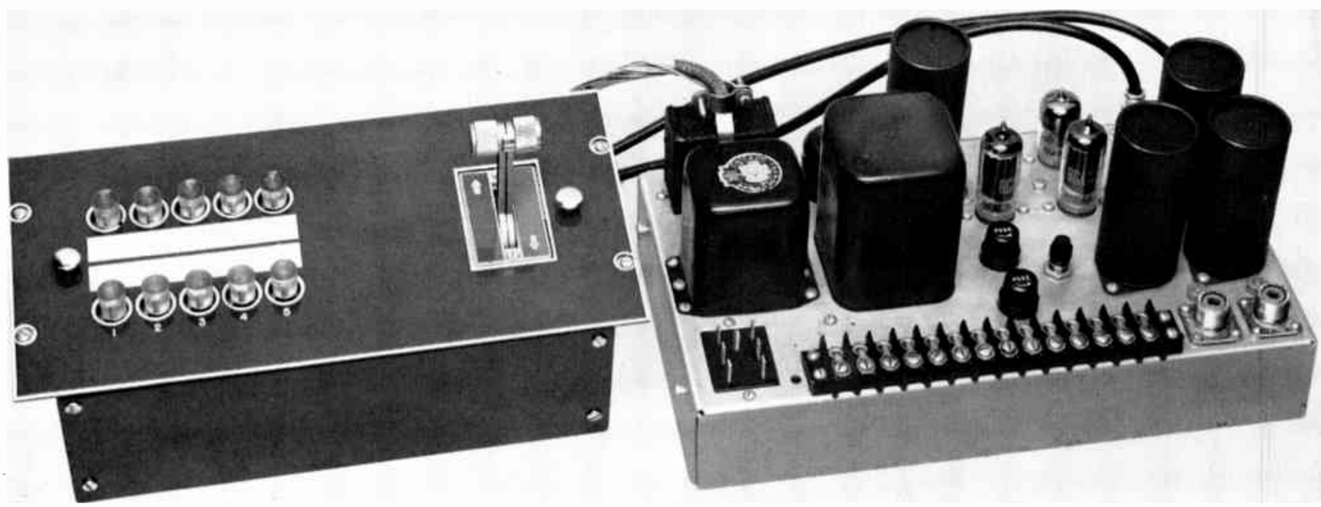


FIG. 4. Block diagram showing use of TS-5 as an independent switching system in small studio installation.

FIG. 5. TS-5 Switcher consists of two compact units which fit in a standard console housing.



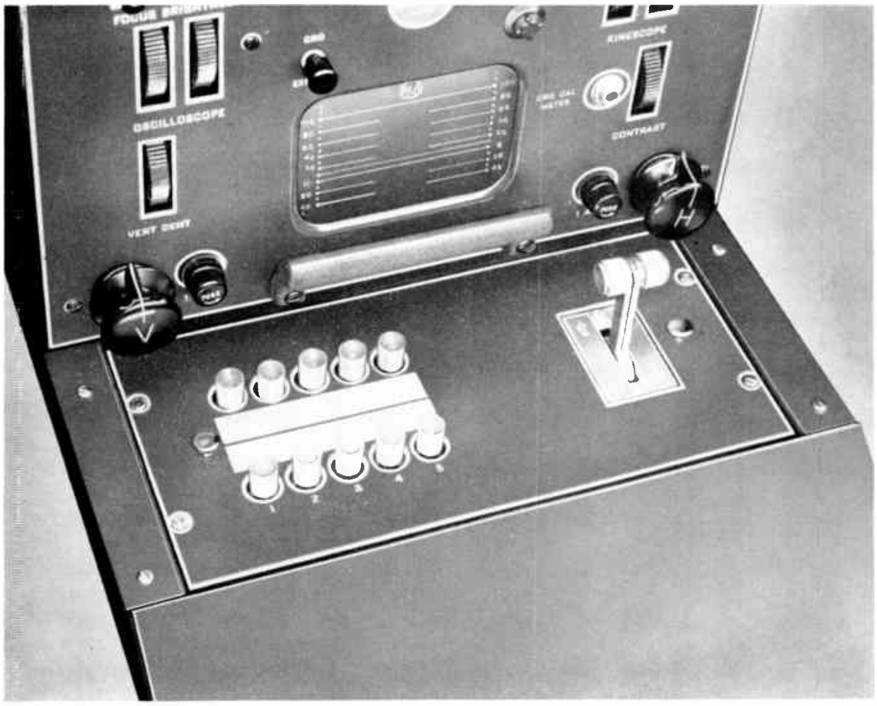
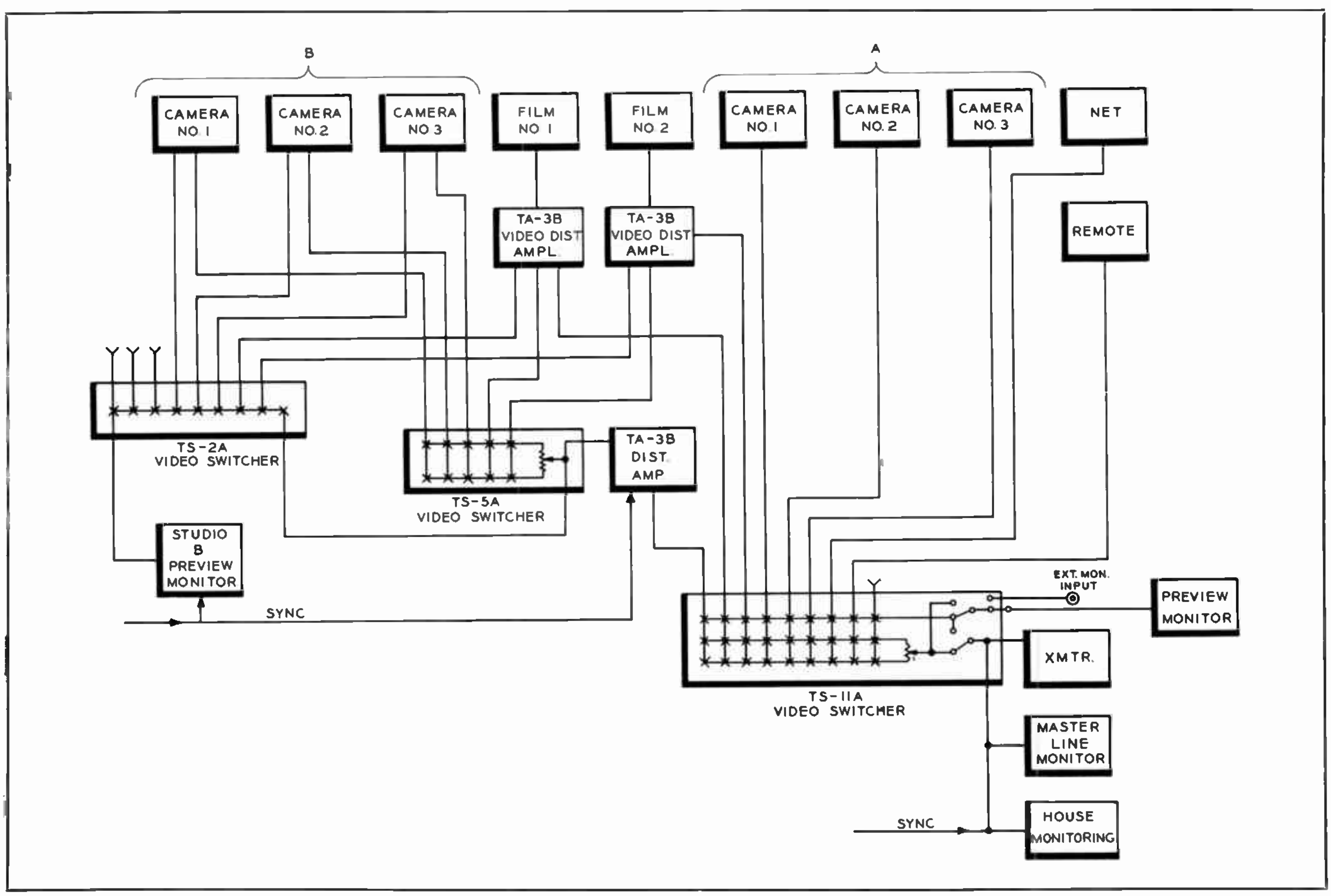


FIG. 6. TS-5 Switcher mounted in desk console section.

FIG. 7 Block diagram illustrating use of a TS-5 to add studio B to existing studio A facilities.



TS-11 Switcher

The TS-11 Video Switcher is a nine-input system designed for use in either studio or master control applications. Five of the nine inputs are for non-composite signals such as from studio and film cameras, and three inputs are for either non-composite or composite signals. These can be used for network or remote signal sources, or for additional studio or film cameras. The remaining input can be used for "black" or as a spare. The preview channels contains a tenth input which is used for monitoring the line or off-air signal.

Three rows of pushbuttons, a program transfer switch and a manual fader are provided to carry out the switching functions. Two rows of pushbuttons feed the manual fader which in turn feeds the program channel. The third row of pushbuttons serve for preview selection. Signals from the fader and preview channels are fed to the program transfer switch. This switch permits the preview channel to be used as the program channel while the fader channels are being used for previewing rehearsals or presetting lap-dissolves and fades.

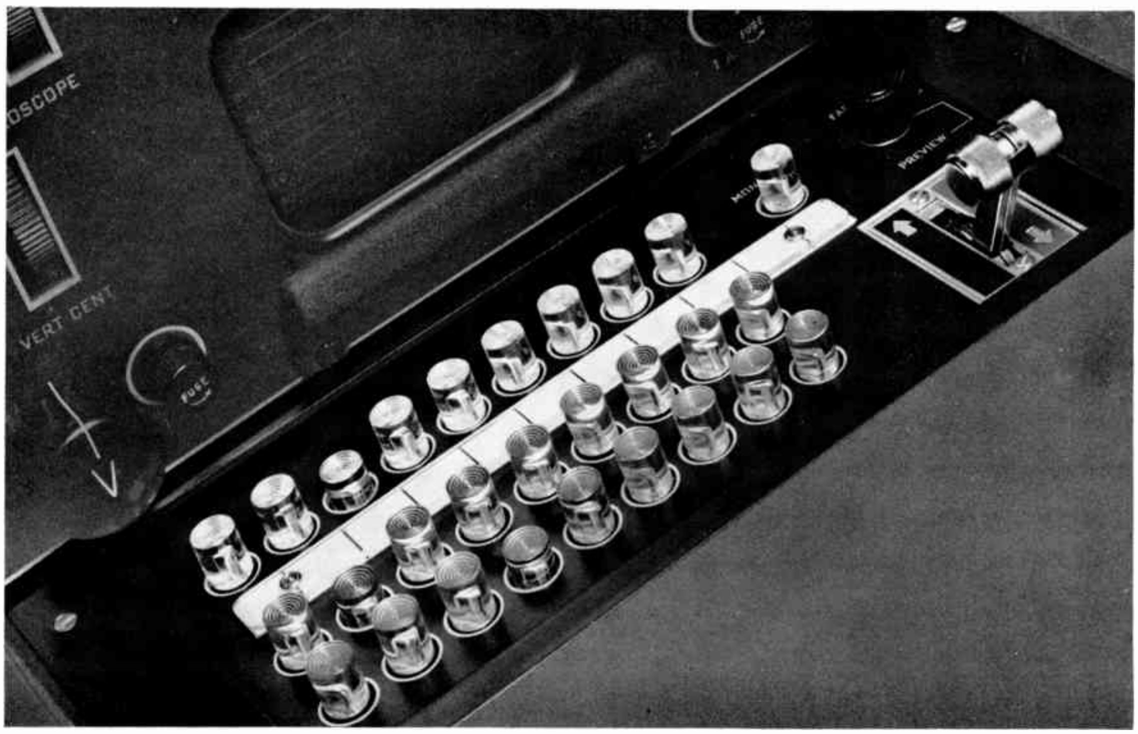
A single console housing contains the control panel, mixing circuits, output line amplifiers and terminal connections for power, tally and video circuits. A stage of isolation is provided between each pushbutton switch and following circuits to minimize the effects of wiring capacity, and to permit the use of a direct video fader circuit. This and other elements of the TS-11 switcher are illustrated in the block diagram of Fig. 9. Additional contacts are provided on the preview switching channel pushbuttons for use with audio tie relays. These contacts can be used for simultaneous audio-video switching of remote and network inputs.

Front Panel Features

As a part of the overall TV station plant, the video switcher pays its way in program versatility and operational smoothness which it offers. To the already familiar switching bus and fader arrangement, which has become a basic standard for television programming, two major facilities have been added: (1) full preview of all inputs and (2) means for providing a direct air channel by use of the preview switching bus.

Much greater freedom in control room layout may be gained without sacrificing the program director's view of camera pictures, since he may check every signal source on a single preview monitor. This preview monitor may be used to line up cameras for the next scene in a live program, to cue in or check film or slides, or to obtain a switching cue from the network or a remote. It may also be used as a standard monitor with which to set picture levels and double-check picture quality with the various camera control monitors.

FIG. 8. Control panel of the TS-11 Video Switcher shown mounted in sloping portion of desk console.



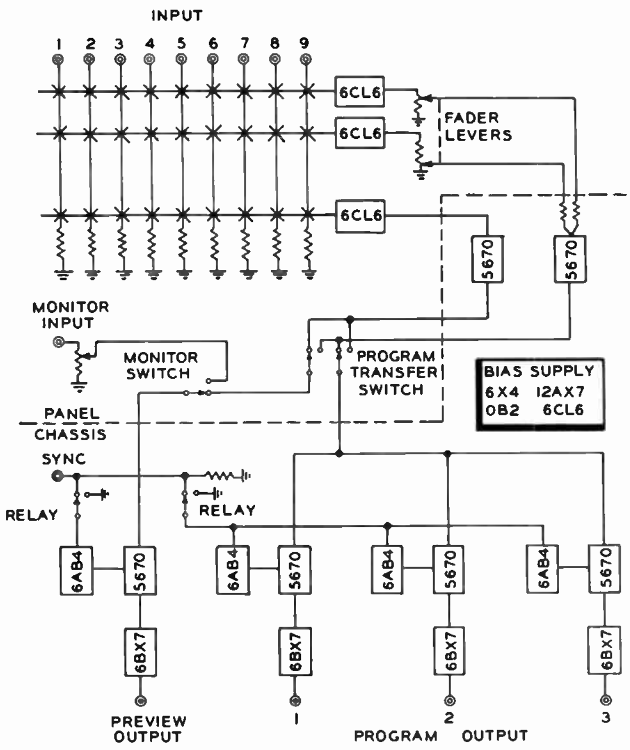


FIG. 9. Block diagram showing principal circuits of TS-11.

"Preview" via the Program Transfer Switch

With other fader arrangements in which the fader output is fed directly to the outgoing program line, it is difficult to line up cameras for a special superposition or dissolve effect without using the fader output. A means to free the fader for preview while carrying a direct camera signal on the output program line is needed. Most large network installations provide a completely separate row of pushbuttons (the program bus) for this purpose. Essentially the same operational advantage is provided in the TS-11, by using a program transfer switch. With this switch in its normal position (fader) the program output channel is fed from the fader while the preview output channel is fed from the preview pushbuttons. With the switch in its other position (preview), the program output channel is fed from the preview pushbuttons, while at the same time, the preview output channel is fed from the fader. Thus the special preview feature needed is provided in a single rotary switch.

"Rehearsal" via the Program Transfer Switch

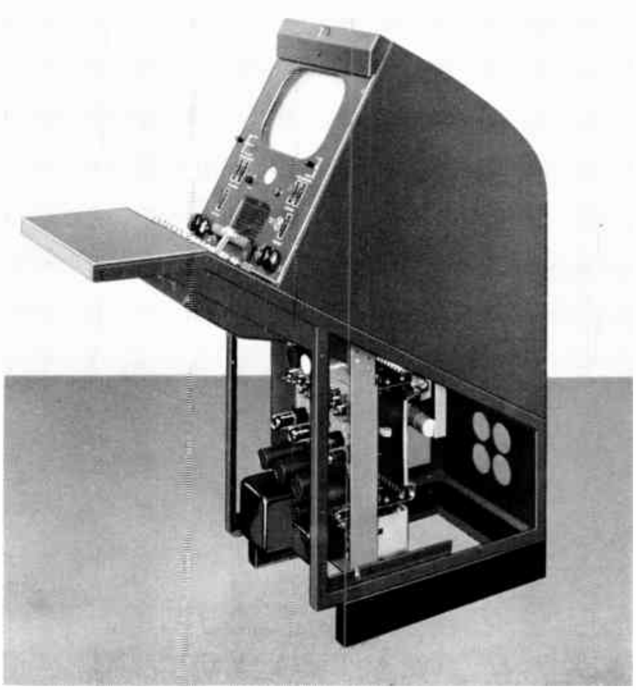
There are several other uses for the program transfer switch which may be valuable in certain installations. A station which obtains a large proportion of its daytime program material from the network or from film will find the rehearsal feature very useful. Instead of being forced to schedule rehearsal at odd hours when the switcher is available, the fader and its input switching pushbuttons may be fed to preview and floor monitors for rehearsal while the film or network show is carried directly through the preview pushbutton circuits. Instant return to normal operation is possible for station breaks or spot commercials. If "normal" operation is reversed, i.e., the program normally carried on preview pushbuttons, then a type of "preset" operation is possible. Two signals may be set up on the fader switching busses, checked on the preview monitor, then quickly inserted by a simple sequence of turning the transfer switch, showing the first picture, fading to the other, then switching back to the original program.

This is accomplished through d-c circuits on the various front panel controls which operate two relays on the main chassis (one for program, one for preview) and are used to switch the actual sync signal.

Input Selection

The control circuits on the panel are arranged to suit the normal choice of inputs used in studio installations. Five of the inputs (No. 1 to No. 5) provide for sync addition at the output at all times. These would normally be used for local camera sources. Two inputs (No. 6 and No. 7) may be either local or remote, the selection available at a toggle switch located on the main chassis. Normally the choice would remain for usual program

FIG. 10. Mixing circuits, output line amplifiers and terminal connections of TS-11 mounted in lower section of console.



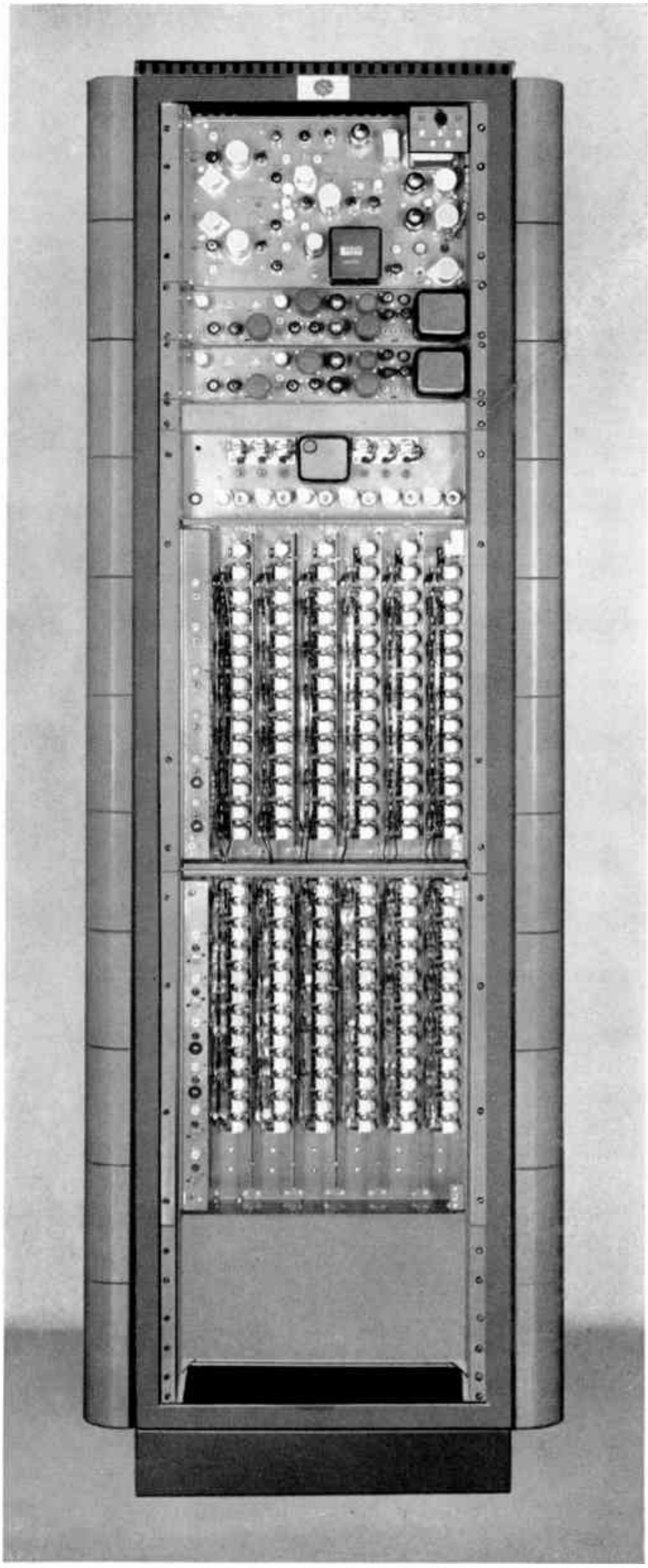


FIG. 11. Photograph showing rack mounted equipment of the TS-21 Relay Switching System, which includes the d-c relays, video distribution amplifiers, lap-dissolve amplifier and special effects equipment, if used.

plans, and the toggle switch would then only be used in case of a special or emergency patch.

One input (No. 8) is arranged to remove local sync addition so that it may be used for network. The ninth position, on the other hand, always provides for sync addition. In monochrome service this input will usually be used for release or black. In color service, the ninth position would also be used for black, but in this case must be fed with a black picture signal. For this reason No. 9 has the same video input circuits as all other inputs. Where, in a special case, nine picture inputs are needed, a local signal may be patched in.

Sync addition is automatically determined as the various pushbuttons are used. The interlocking function, of course, is also run through the fader limit switches and through the program transfer switch to insure transfer of sync control in relation to the signal actually being sent to the output amplifiers. Finally, the monitor switch has a contribution to the sync interlock. When switched from normal preview to a remote signal, it transfers control of the preview sync addition from the preview pushbuttons to a fixed remote condition.

Audio-Tie

Extra contacts are provided on the preview pushbuttons and brought out to a separate plug on the main chassis. In addition, a transfer set of contacts is also brought out from the program transfer switch to the same plug. The title "audio-tie" has been applied to these circuits.

In certain applications of the TS-11, particularly those in which the switcher will be required to handle all of a station's video traffic, there are definite advantages to combined audio and video switching, especially in those cases where the audio and video signals are both obtained from the same source. For instance, network video is always accompanied by network audio. Other typical combinations which may be treated as pairs are remotes, film and projector audio, slides and announce booth. It may be practical therefore in some stations for one man to operate both audio and video switching from the single TS-11 console position. The program bus arrangement in the TS-11 lends itself to such an operation. With appropriate relays in the audio system, it is possible to transfer control of these certain audio inputs to the TS-11 preview pushbuttons. When the transfer switch is turned to "Preview," audio signals are switched automatically. Instant return to normal operation from the TS-11 fader and the separate audio consolette results from turning the transfer switch back to the fader position. This also applies to break-ins for special combinations. For instance, the video can remain on film by using the same input selection in both the preview and fader channels, while the audio can be transferred from projector audio to another signal such as announce booth, as set up on the audio consolette.

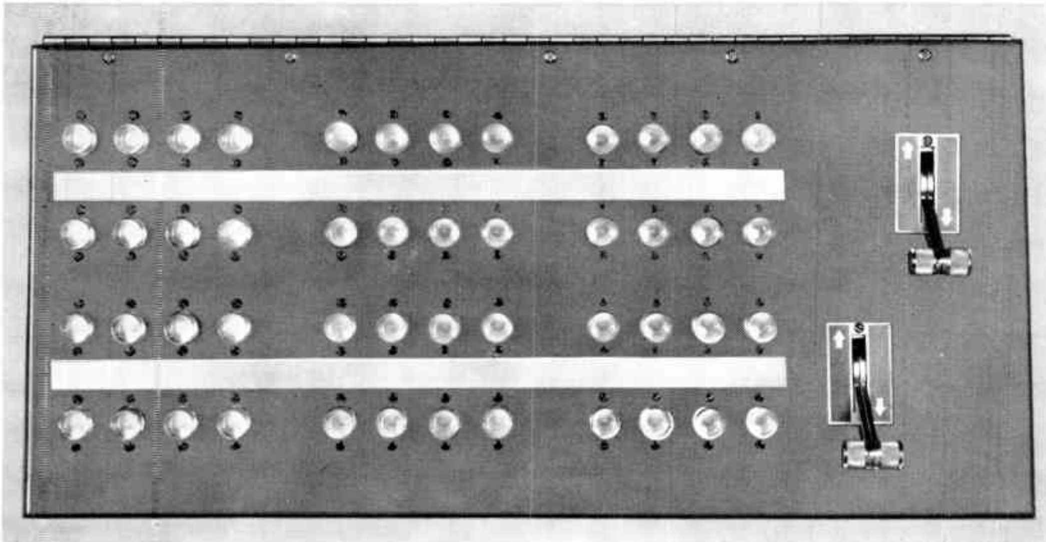


FIG. 12. Control panel for a 12-input and 4-output TS-21 switching system with two fader controls.

Relay Switching Systems

In installations where more flexibility is required than can be obtained with direct switching systems, or where more than nine inputs are required, the relay switching system is recommended. The relay switching system described in the following paragraphs provides a straightforward signal path avoiding unnecessary circuit complexity and keeping the signal distortions within controllable limits, which is especially important in handling color signals.

TS-21 Relay Switcher

The TS-21 video relay switching system is designed for use in studio and master control. It consists of different types and quantities of equipment depending upon the size and type of switching operation desired. The equipment may be used for switching a minimum of six inputs to two outputs, or a maximum of eighteen inputs to six outputs.

For the studio control room, the system can be set up to provide complete facilities for program monitoring, video switching between studio cameras, film cameras, remotes or network programs. Controls can be provided for fading and lap-dissolving between any of the above signals. The system can provide for program previewing and many other monitoring functions. For the master control room, the system can be set up to provide complete video switching and monitoring facilities.

Custom-built pushbutton control panels designed for the individual station can be housed in consoles or other convenient locations. Actual switching is accomplished remotely by d-c relays which are housed in racks at any desired location in the control room. Special high-speed transfer relays completely eliminate picture disturbance caused by switching. The use of d-c relays in the TS-21 system adds to the overall flexibility of television station layouts and simplifies the addition of studio facilities when expanded operating schedules require the use of more than one control room.

The system consists of several types of individual units which fall into the following categories:

A. The video relay switching chassis and panels used to extend functions of basic units.

B. Custom-built pushbutton panels (for operating the video relays) which are tailored to any switching scheme or mounting arrangement desired by the television station.

C. The utility or master monitors, for use in conjunction with pushbutton panels.

D. Associated amplifiers and signal distribution equipment.

E. Miscellaneous equipment such as power supplies, consoles, racks, panels, etc.

The basic TS-21 provides for six inputs and two outputs and consists of a chassis and two relay panels. Each relay panel has six pairs of video switching relays, each pair associated with a video signal input. The video transfer relay, which does the actual video switching, and the interlock relay are located at the top of each relay panel. The chassis contains space for four additional relay panels which when added expand the basic system to six inputs and six outputs.

An auxiliary relay chassis with two auxiliary relay panels is used when more than six and up to twelve video inputs are to be used. This chassis cannot be used without the basic chassis since the auxiliary relay panels contain only six video relay pairs and no transfer or interlock relays. Thus, a system of basic chassis and auxiliary chassis provides for twelve inputs and two outputs. By adding basic and auxiliary relay panels this can be expanded to a twelve input/six output system. Even larger systems are possible.

Equipment associated with the TS-21 are video distribution amplifiers, a lap-dissolve amplifier and special effects equipment, if used. Distribution amplifiers are used to achieve the following: Adjust the gain of the switching system to a 1.0 volt level (composite video and sync); to match the high impedance of the switcher output to the low impedance of the video transmission lines; to provide for sync mixing for non-composite signal switching and for disabling the sync mixing circuit when composite signals are switched. The distribution amplifier also provides the sending end termination for the long video output lines, and provides extra signal output for the master monitors, floor monitors, announcer monitor, house monitoring, and spare output lines.

The lap-dissolve amplifier is used for dissolves from one picture to another, for super-imposing one picture on another, and for fades to and from black. This amplifier has been designed for handling color signals with a minimum of degradation. Low-frequency bounce is non-existent so that stabilizing amplifiers need not be considered as part of the switching system. This fading action is remotely controlled by a d-c bias voltage supplied from the fader assembly on the control panel, and thus the entire TS-21 system is completely under the control of the director.

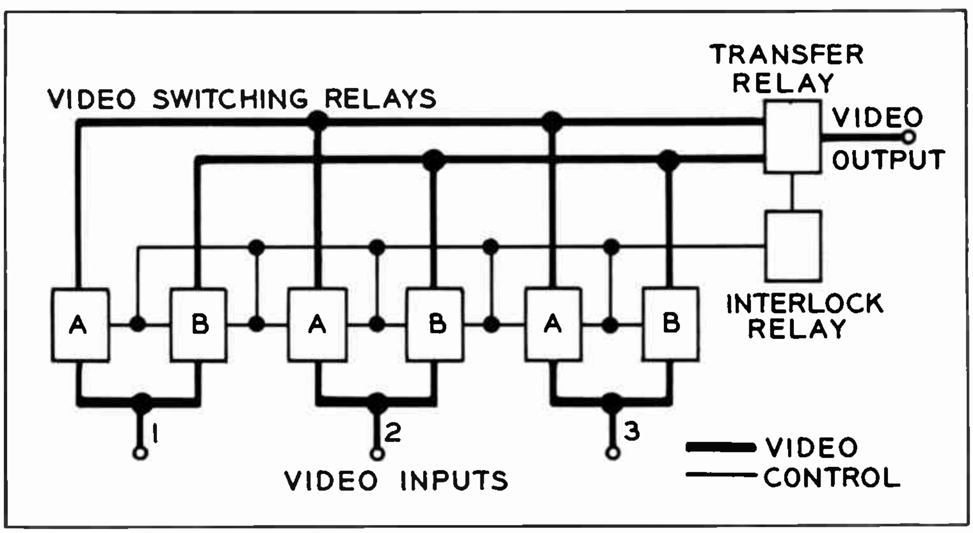
The fundamental switching scheme employed in the TS-21 is illustrated in the block diagram of Fig. 13. Each video relay operates alternately. If relay A in input 2 is in use and input 1 is selected, then relay B on input 1 will be activated. If input 3 is selected, relay A on input 3 will be activated, and so on for each input. There are two video busses for each output, one interconnecting all the A relays, and the other interconnecting all the B relays. These two busses are connected to the transfer relay. In this manner, the transfer relay makes the actual final switch, transferring the video input selected to the output bus. By using this pair of busses to feed the signals to the transfer relay, the bounce of the video relay contact dies out before the actual transfer is made.

Systems Considerations

The diagrams of Figs. 14, 15 and 16 show typical TS-21 relay switching installations. The first of these is a basic 6 input/4 output system. This consists of a basic relay chassis plus two additional basic relay panels. One output is connected to a TA-3 Video Distribution Amplifier which drives the program output line. The other outputs of the TA-3 can be used for monitoring. Another output also connected through a distribution amplifier feeds the preview line. Two other outputs are connected directly to the lap-dissolve amplifier. The output of the lap-dissolve amplifier is returned to and becomes another input to the basic relay chassis. In this way a lap-dissolve or superposition can be selected on the preview bus and the video level adjusted on the preview monitor before it is selected to go on the air. This is the standard method of handling this type of switching operation.

A more elaborate system is the 12 input 6 output switcher with separate switching busses for the special effects system, Fig. 14. The special effects as well as the lap-dissolve signals can be previewed in exactly the same way as described in the 6 by 4 system. The 12 by 6 system requires one basic relay chassis with four basic relay panels, and one auxiliary relay chassis with 4 aux-

FIG. 13. Fundamental switching principle of TS-21 relay switching system.



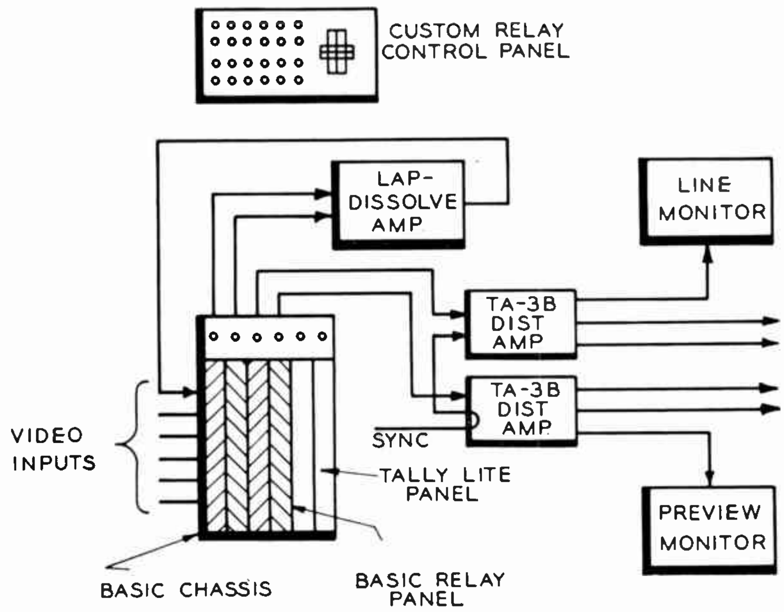


FIG. 14. Block diagram of a 6-input and 4-output relay switching system with lap-dissolve facilities.

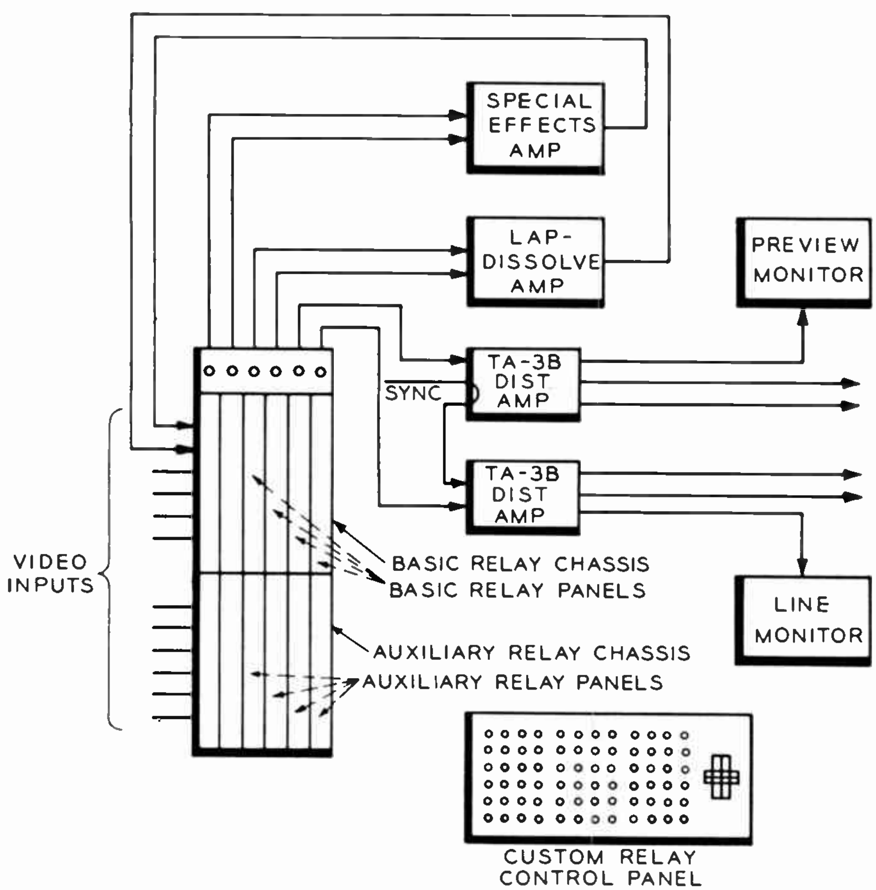


FIG. 15. Diagram of a 12-input and 6-output relay switching system with lap-dissolve and special effects.

iliary relay panels. Two additional TA-3 Distribution Amplifiers are also necessary for matching the high impedance of the switcher output to the low impedance input of the special effects system. The control panel will contain 6 rows of 12 pushbuttons and a fader assembly.

In some operations it is desirable to isolate the non-composite switching function from composite switching, or perhaps more functionally, to isolate studio from master control switching. Usually the special effects system is still retained, the only concession being that a lap-dissolve into or out of an effect is sacrificed. This can be regained if a lap-dissolve amplifier is installed between the composite switcher output and the output lines. Sync interlock provisions can be made so that it would not be necessary to fade composite signals. This system requires besides the basic 6 by 4 system. 2 basic relay panels, 1 auxiliary relay chassis, and 2 auxiliary relay panels, two TA-3 Distribution Amplifiers, and an appropriate control panel.

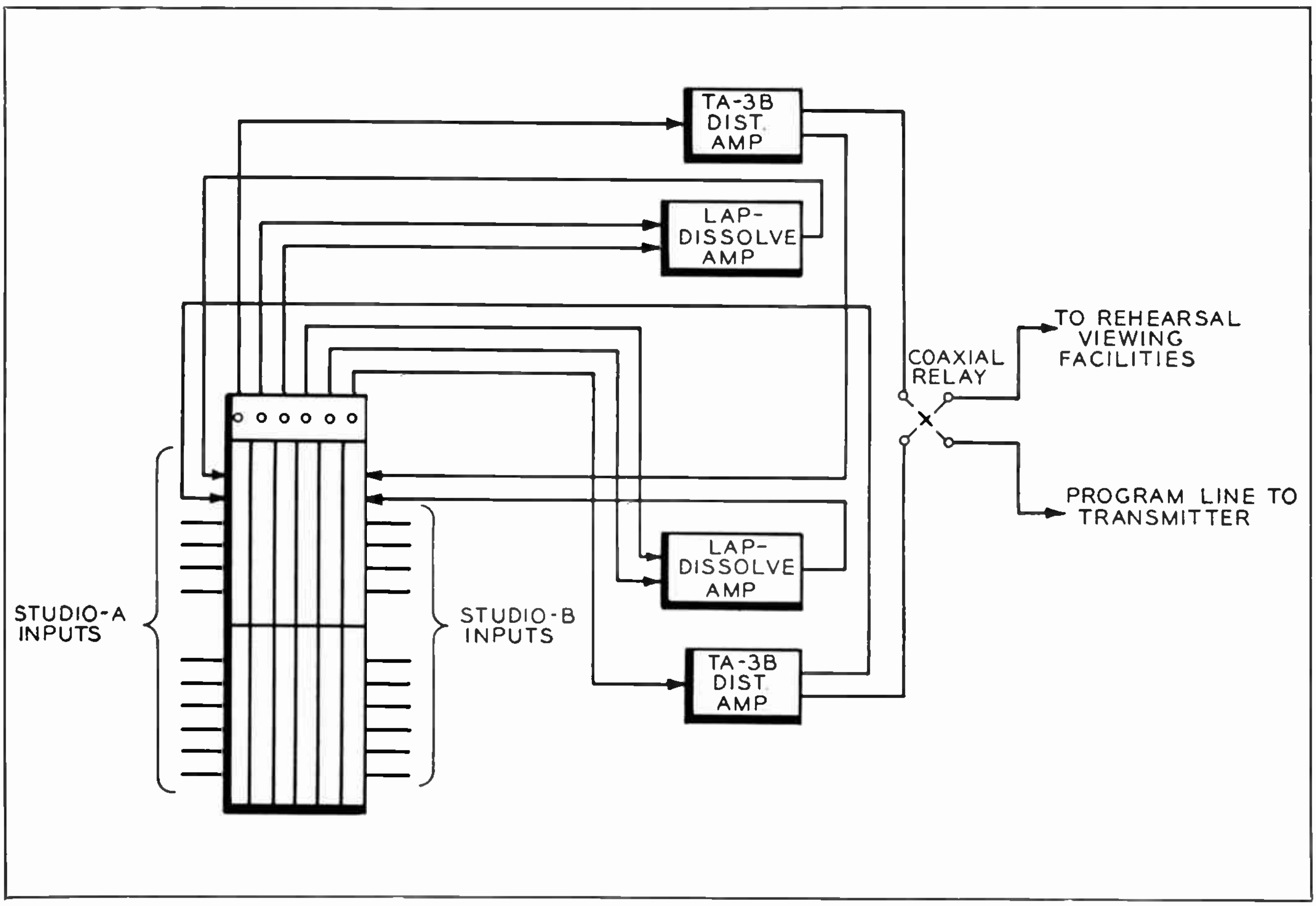
Other configurations of the TS-21 can be assembled to meet specific system requirements. For instance it is possible to have two studios share facilities in one switcher, as shown in Fig. 16, or to have one switcher controllable from two locations. Figure 17 shows a combination of composite and non-composite switching functions.

Most TS-21 installations are much the same as those shown in the functional diagrams, or are but minor variations of these systems in which the standard components are used with no modification. In some cases, however, system operation requires that the standard components must submit to some minor modifications. Applications such as preset switching, audio/video simultaneous switching, etc., are examples of the type of operation to which the TS-21 is easily adaptable.

Distribution Amplifiers

Experience in television broadcast operations over the years points to the desirability of employing signal distribution equipment designed specifically for either video distribution or pulse distribution. Video systems require linear amplifiers to insure exact reproduction of the signal, while on the other hand, pulse systems may actually

FIG. 16. Diagram of a 12-input and 6-output system for two studios. Two 12 by 3 control panels, one in each studio, can be used to control the 6 outputs.



utilize a high degree of non-linearity to advantage in improving the signal. Furthermore, while video systems are equalized for flat frequency response, improved performance for pulse operation is afforded by compensation for optimum transient response—a condition which is opposite in many respects to that required for video. These factors, in addition to the widely different line levels encountered, justify dividing the functions of distribution amplifiers.

Distribution systems requiring long coaxial transmission lines (i.e., in excess of fifty feet in length) provide best performance characteristics only if terminated at *both receiving and sending ends*. Therefore, amplifiers used to feed long transmission lines should have an output impedance equal to the surge impedance of the line. This is called sending-end termination, and will minimize standing waves on the line that would otherwise degrade the signal, particularly in color systems. Product designs employing a high order of stability, maximum power efficiency and compactness have a profound influence in reducing the initial cost and operating cost of the system.

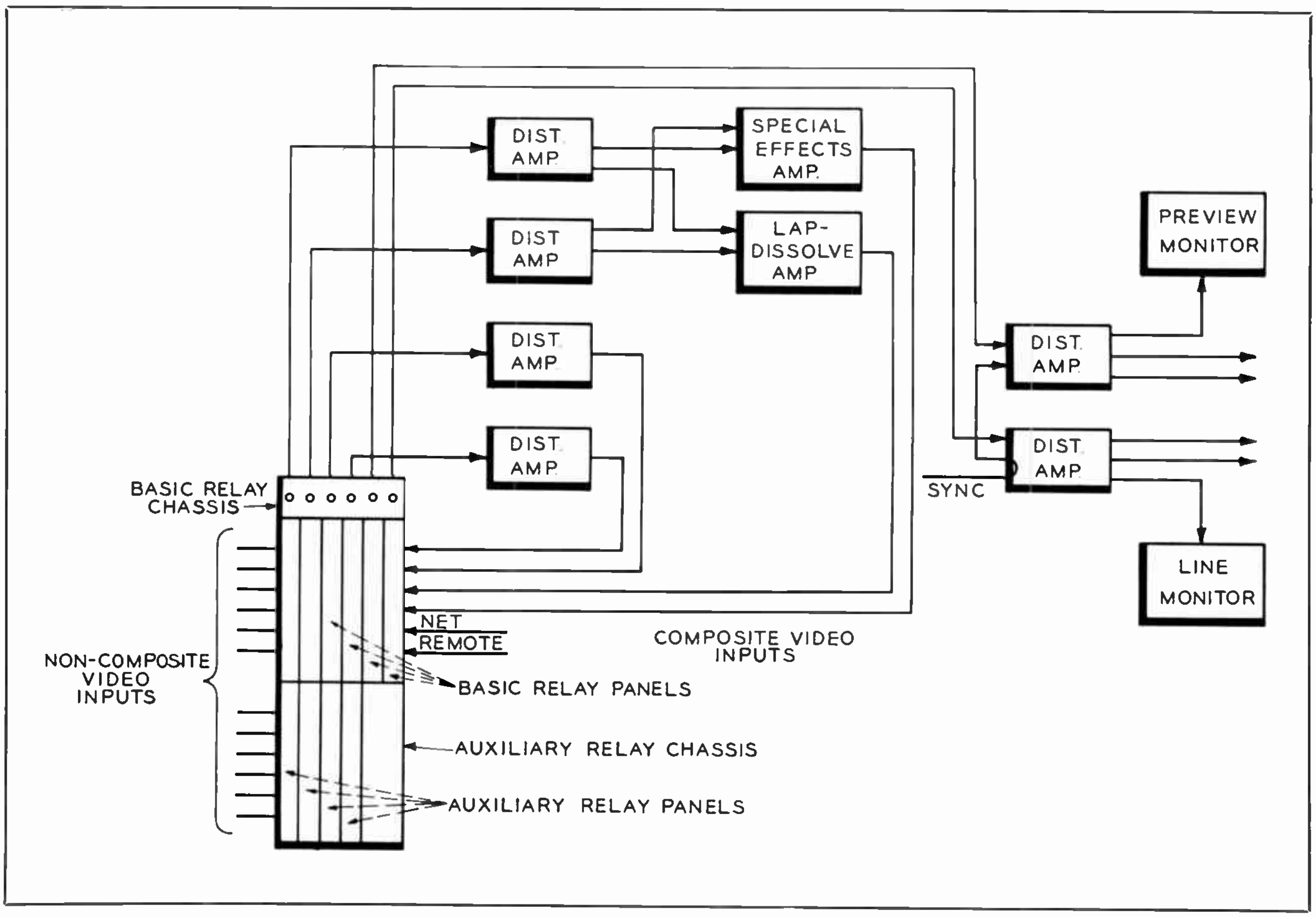
TA-4 Pulse Distribution Amplifier

Practical system operation usually dictates the use of only one synchronizing generator for the entire plant. In larger installations where there are many studios, often located at considerable distance from the sync generator, there is need for a system of pulse distribution wherein the individual timing and blanking signals from the sync generator can be fed over transmission lines to a multiplicity of remote points.

The TA-4 is designed to meet all requirements of both large and small distribution systems. Two coaxial input connectors in parallel allow bridging of the amplifier across a line. The input impedance of the TA-4 is high enough to bridge several of these units across a 75-ohm line without serious detrimental effects.

Figure 18 is a block diagram showing essential elements of the TA-4 amplifier. Signals fed into the TA-4 are amplified by an over-peaked amplifier stage to provide good sensitivity and minimize delay. The pulse signal is coupled from the amplifier to a regenerative

FIG. 17. Diagram of a 12 by 4 non-composite and a 6 by 2 composite switcher combined in a TS-21 system. Control panels can be separate or combined.



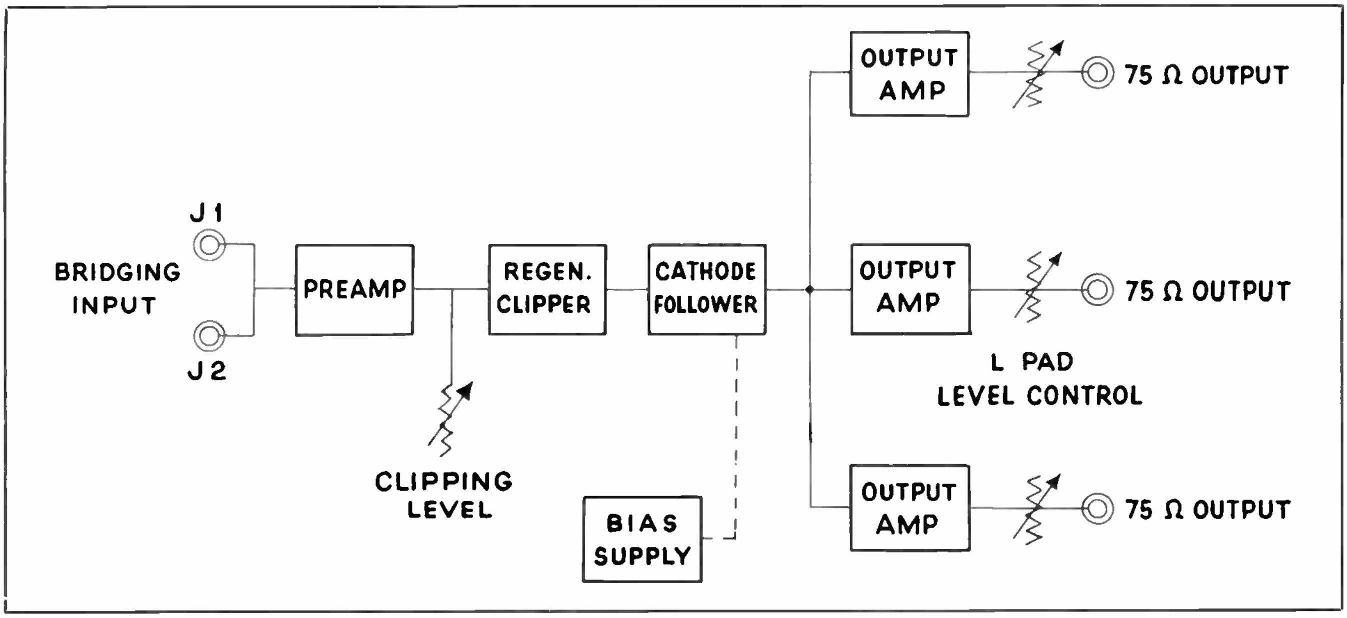


FIG. 18. Block diagram of the TA-4 Pulse Distribution Amplifier.

clipping circuit, which produces a new pulse that is dependent on the width and timing of the input pulse but is otherwise independent of it. The regenerative clipping operation forms an almost ideal pulse with fast rise time and no low frequency disturbances regardless of poor rise time, overshoot, hum, tilt, bounce or similar defects on the incoming signal.

A cathode follower drives paralleled inputs of three individual wideband output amplifiers with the signal from the regenerative clipper. Variable "L"-pad gain controls in the plate circuit of each output amplifier provide a 75 ohm terminating impedance for each line and enable independent adjustment of output signal levels. The gain controls are accessible at the front panel as are test jacks for input and output signals. The only additional variable element is a non-critical clipping level control that is set during manufacture and needs no further adjustment in normal applications.

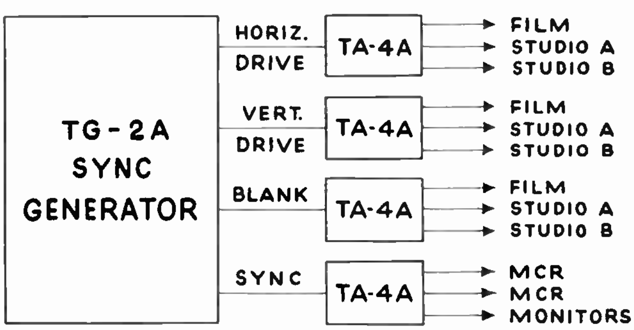


FIG. 19. Typical pulse distribution system employing TA-4 amplifiers.

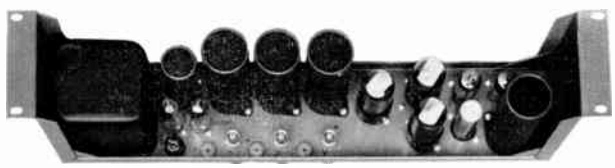


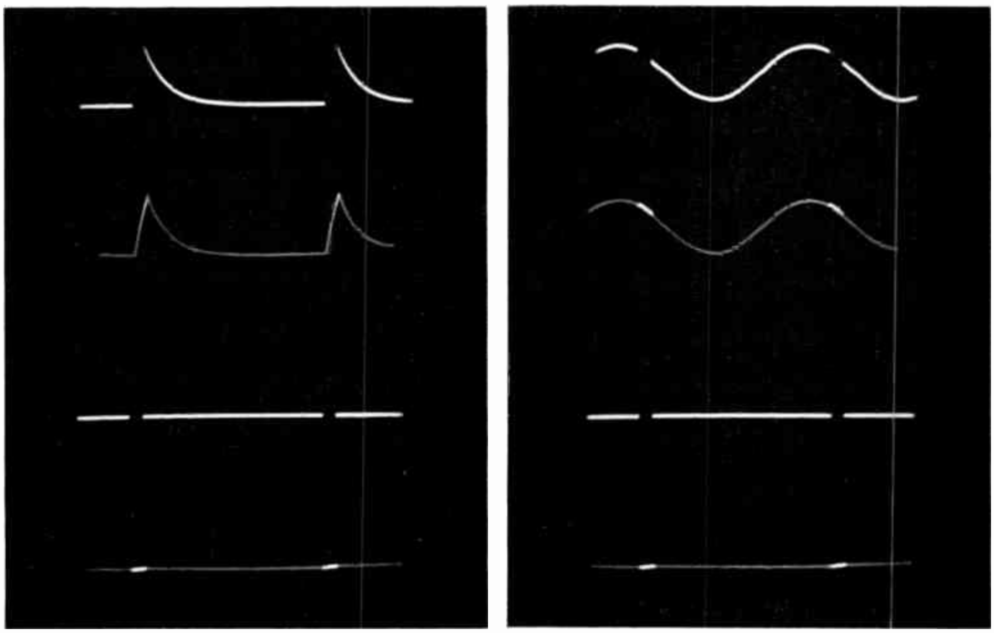
FIG. 20. TA-4 Pulse Distribution Amplifier.

The 75 ohm constant output impedance resulting from the use of "L" pads is an important factor in reducing pulse distortion in systems where long transmission lines with several impedance discontinuities such as patch boards, junction boxes, and capacitive terminations are used.

Figure 19 is a diagram of a typical television pulse distribution system utilizing TA-4 Distribution Amplifiers. The amplifier will operate with blanking, sync, horizontal drive and vertical drive pulses without any adjustment for the particular type signal to be used. Any input signal level between 2 and 8 volts peak-to-peak will insure proper operation even though tilt, hum, bounce, overshoots and long rise time may be present. Examples of the way in which the TA-4 treats these deficiencies are shown in the waveform photographs of Figs. 21 and 22.

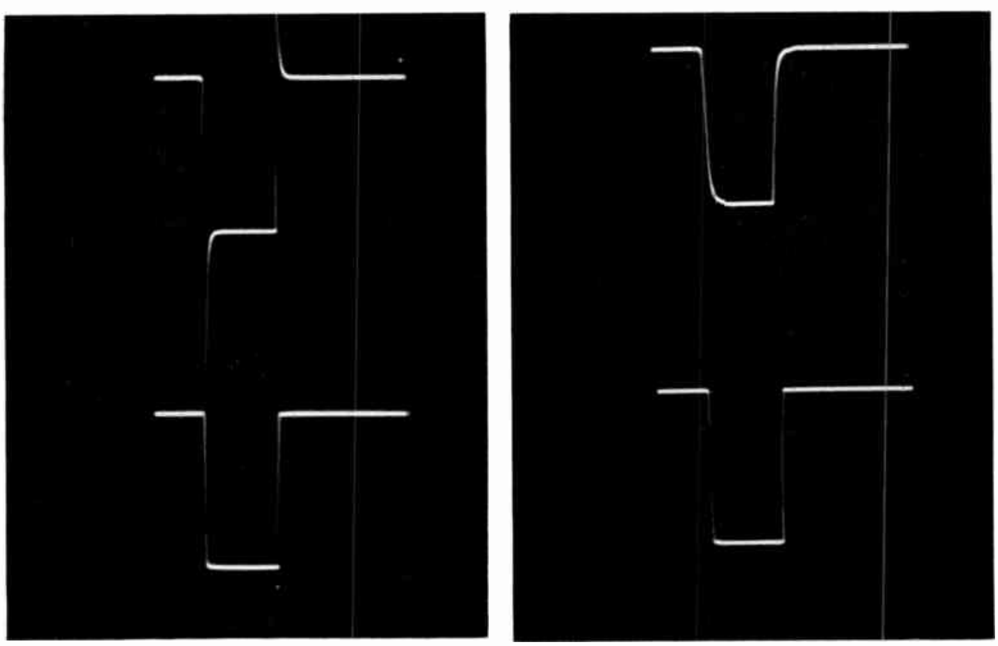
Video Distribution Practice

In broadcast video distribution systems, it is generally found necessary to feed a signal from a given location to several remotely located points. For example, master control output is fed to a line monitor located in the



(a) (b)

FIG. 21. Defects frequently encountered with pulse signals are tilt and 60 cycle hum. Waveforms at (a) show elimination of tilt, and in (b) removal of a hum component from blanking.



(a) (b)

FIG. 22. Waveform photographs showing the effectiveness of the TA-4 in removing overshoot (a), and restoring rise time (b). Regenerated horizontal drive at output is shown at bottom of photographs.

control room, to the station transmitter or STL, and in many cases to the telephone company for network distribution. It is not feasible to utilize the expedient of bridging at various points on a long transmission line; discontinuities in the characteristic impedance of the line cause reflections, resulting in serious deterioration of picture quality. To avoid this complication, several individual amplifiers can be located near the signal source. Bridging with as many amplifiers as needed can then be accomplished without affecting impedance matching.

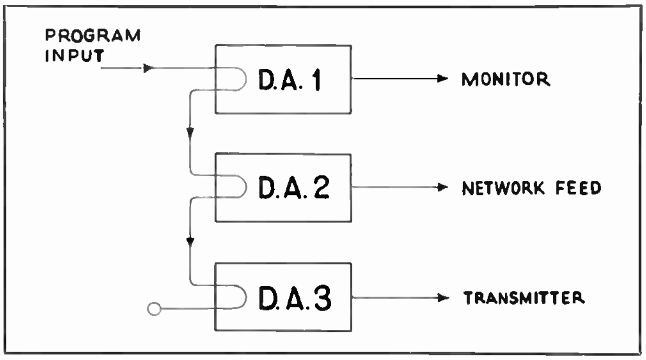


FIG. 23. Diagram showing use of separate channels to distribute video. This arrangement is desirable where high isolation between output lines is required, but it does not provide positive indication on the monitor of all possible amplifier failures.

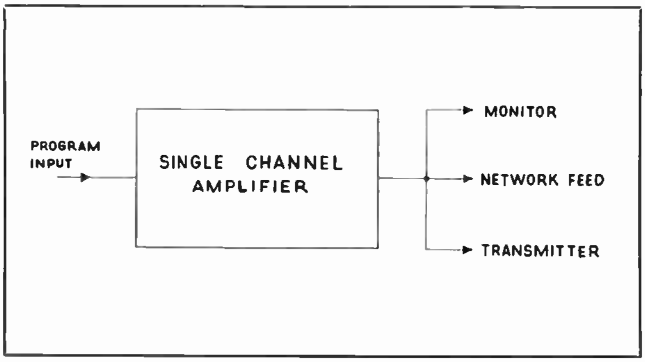


FIG. 24. This circuit is ineffectual in preventing monitor line disturbances from entering network feed.

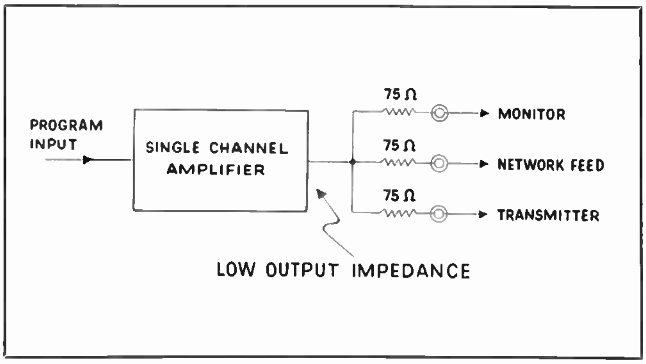


FIG. 25. This circuit provides necessary isolation between output lines, and terminates the "sending end" of the transmission line.

Individual channel distribution amplifiers, while simplifying bridging for multiple feeds, present an operational problem in that the program line signal does not pass through the same circuits as the monitoring signal. As a result, loss of signal to a network feed caused by failure of the network line amplifier is not indicated on the monitor, since the monitor is fed by another amplifier. Conversely, interruption of the signal at the monitor does not necessarily mean failure of the network feed.

To circumvent this problem by using a single channel amplifier to feed several lines with their sending ends paralleled as shown in Fig. 24, gives rise to another problem. Now, although the monitor displays a signal equivalent to the network signal, there exists the obvious disadvantage of disturbances occurring on the monitor line directly affecting the network signal. Frequent disturbances occurring in practice consists of 60-cycle hum due to ground loops, reflections caused by accidental removal of terminations or use of capacitive terminations, and transients resulting from proximity to heavy electrical equipment. Monitoring lines, particularly house monitoring lines, are often quite long and subject to any of these spurious signal sources.

The solution is an arrangement similar to that shown in Fig. 24 with the additional requirement that disturbances on one line not influence other lines. This isolation is best obtained using an amplifier with very low output impedance to feed several lines through series resistors. A method for this illustrated in Fig. 25. If the output impedance is made sufficiently low and the build-out resistors made large, a spurious signal developed on the monitor line will be greatly attenuated before reaching other lines, thereby resulting in an insignificant influence on the network channel. An additional benefit to performance is derived from the output circuit of Fig. 25 if the series resistances are equal to the surge impedance of the transmission line, providing sending-end termination of the line.

TA-3 Video Distribution Amplifier

The TA-3 Video Distribution Amplifier is shown in block diagram form in Fig. 26. The signal channel consists of two wideband feedback amplifiers connected in cascade. The series amplifier configuration offers considerable advantage over a conventional single tube amplifier. Curvature in the transfer characteristic is cancelled to a great extent due to the "single-ended pushpull" operation of this circuit, resulting in excellent linearity. Also, for a given static tube current, almost twice as much a-c load current swing is obtained with the series amplifier compared to the conventional tube and load resistor combination. A gain control, accessible from the front of the chassis, enables the overall gain of the TA-3 to be varied from 0.5 to 2.

A sync mixing channel is incorporated in the first feedback amplifier. The high impedance input to this amplifier makes it possible to loop sync through several

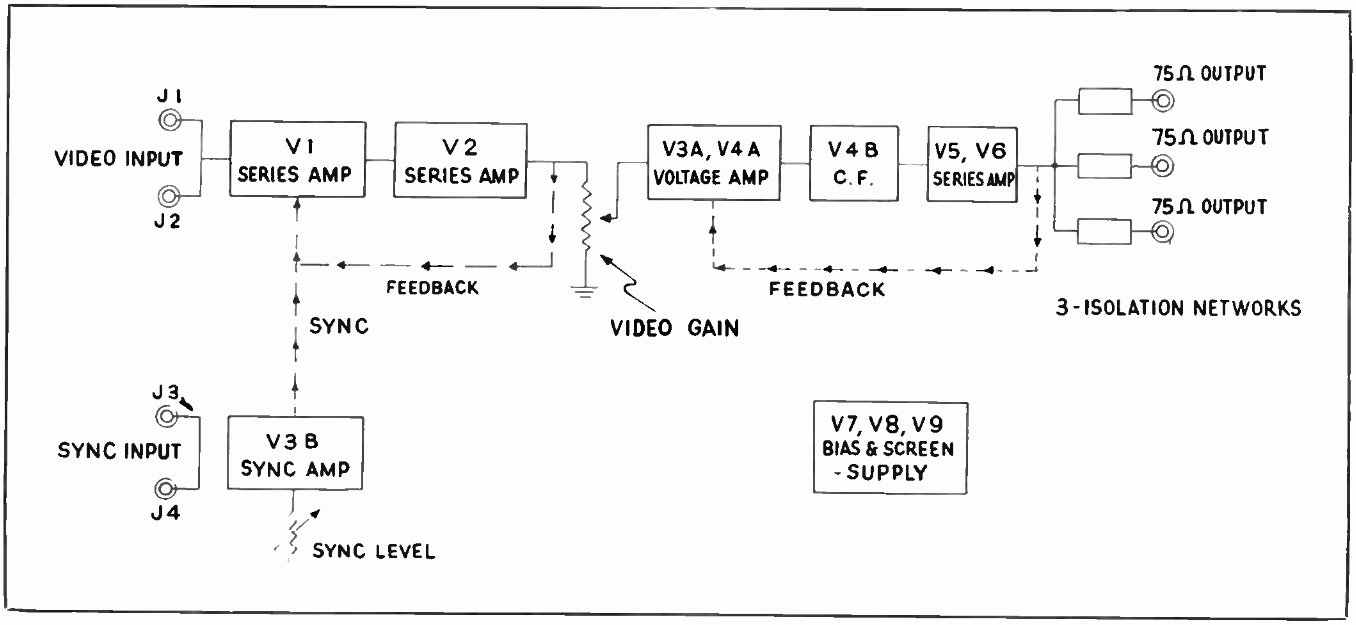


FIG. 26. Block diagram of the TA-3 Video Distribution Amplifier.

amplifier inputs. A gain control for sync level adjustment is accessible from the front of the chassis. Provision is made for an optional plug-in relay to control sync addition in applications requiring sync interlock.

The second feedback amplifier has unity gain and drives on RC coupling network to which the output lines are connected. It consists of two pentodes in parallel as a voltage amplifier feeding a cathode follower which in turn drives a cascode output amplifier. The cascode output stage has many desirable advantages that make it an excellent choice as an output amplifier. Many of the features of push-pull action are achieved while the output load can be single ended. The transfer linearity is inherently good, the power efficiency is considerably more than twice that of conventional single ended output stages, and the output impedance is inherently low. The output RC coupling network in conjunction with the very low impedance at the output terminal of the feedback amplifier provides a 75 ohm impedance when looking back into each output receptacle and at the same time provides a high degree of isolation between the output signals which prevents disturbances occurring on one line from affecting the signal on either of the other two.

Seven tests points, six of which are on the front panel, have been provided for convenience in rapid signal checking.

By the simple modification of incorporating a relay in the sync adding circuit, sync addition can be controlled at a remote point. When used in conjunction with a TS-5 Studio Switcher to feed other studio facilities as shown in Fig. 28, the modified TA-3 will replace a stabil-

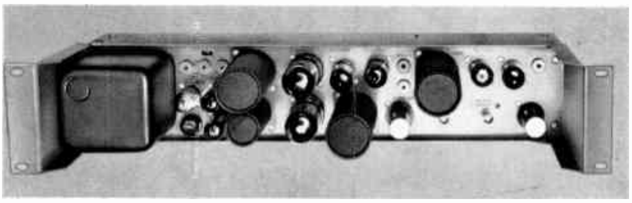


FIG. 27. TA-3 Video Distribution Amplifier.

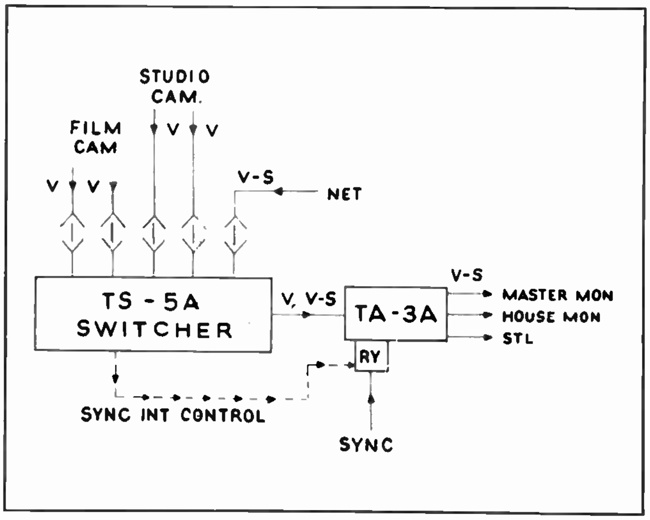


FIG. 28. A TA-3 modified to include sync interlock as shown can be used in place of a stabilizing amplifier when clamping and sync stretch are not required.

izing amplifier for the sync mixing function. It is unnecessary to clamp the output of a TS-5. The sync interlock relay added to the TA-3 will be actuated by control circuits in the switcher to remove local sync when a remote signal is switched through, or to add sync for local signals. Such a system is applicable in studio installations where the switcher does not feed a transmitter directly. When the switcher output goes direcly to the transmitter, a stabilizing amplifier must be used to furnish the sync stretch function.

Because of the high frequency attenuation introduced by coaxial cables, long lines require equalization that generally attenuates low frequencies to make the over-all response flat. Passive equalizers of this type insert a a constant loss of 3 to 6 db which can be recovered through the use of a TA-3.

TA-9 Stabilizing Amplifier

The stabilizing amplifier is truly the "workhorse" of the television plant. No other piece of equipment is more vital to proper operation at the studio or transmitter. In fact, so severe are the demands placed upon the performance of the stabilizing amplifier that broadcast equipment manufacturers are constantly in search of new techniques to improve its operation.

The TA-9 Stabilizing Amplifier design is the outgrowth of careful field studies of studio and transmitter problems plus the application of the latest circuit modifications for their solution. Considerable effort has been put forth to make the TA-9 a flexible and reliable amplifier featuring remotely controlled operation and a minimum of operating adjustments.

Basic Clamping and Clipping Functions

One of the primary applications of any stabilizing amplifier is to process a television signal that has been damaged (i.e., sync compressed or degenerated) and to remake it into a properly proportioned, stabilized television signal. To realize this, a stabilizing amplifier customarily contains clamping and clipping circuits. Quite often the amplifier must function under difficult conditions that also call for the removal of low-frequency disturbances such as hum, bounce, surge and tilt. To accomplish the clamping function, the TA-9 contains a highly stable feedback clamp that requires no subcarrier clamp blocks. Means are provided to make the clamp action immune to the effects of high-frequency noise impulses.

The sync clipping circuits in the TA-9 are also of a new, improved design, in that they are supplemented by an automatic gain control circuit which maintains proper clipping level even in the presence of widely varying input levels. Video signals received from networks and microwave links are often characterized by such random fluctuations in amplitude. Sync clippers when not stabilized by AGC action are sensitive to such variations and reflect this in the form of pulse width and delay variations in the separated sync pulse output. A "bonus" feature of the TA-9 is that even color signals may be base-line stripped of original sync with no effect on the color synchronizing burst or blacker-than-black subcarrier excursion. Thus, remote color signals may be converted to noncomposite signals.

How the TA-9 Solves the Color Problem

The color signal differs from a monochrome signal in two major respects, both of which pose problems. First, the addition of the color subcarrier components to the luminance signal causes the resultant color video signals to extend into the blacker-than-black and whiter-than-white regions. Second, a color-synchronizing burst is placed on the "back porch" following each horizontal sync pulse. These characteristics of the color signal give rise to two problems, as follows:

1. *Clipping of subcarrier blacker-than-black excursions.* In monochrome stabilizing amplifiers, the video signal is usually clipped at black level. This removes the sync signal and also any noise spikes or signal overshoots which extend into the sync region. The sync signal is regenerated by amplification and clipping in a separate channel and then added back to the video signal. The purpose, of course, is to restore the sync signal to its original wave shape and amplitude—i.e., to remove any distortion incurred during transmission. In stabilizing amplifiers intended for color, some means must be provided for bypassing the burst and subcarrier components around the clipper so that their infra-black excursions are not clipped off.
2. *Burst Distortion.* To insure that video clipping will automatically occur at black level despite changes in signal level or average brightness, the signal must be clamped during the back porch interval. Since it is during this time that the color sync burst is transmitted, steps must be taken to prevent the clamp action from distorting the burst.

These two problems, subcarrier clipping and burst distortion, are avoided in the TA-9 by passing the composite color signal through a spectrum separation network or crossover filter where the subcarrier components are separated from the luminance and sync signals. Essentially, this leaves a composite monochrome signal which can be processed in the normal manner.

Sync Channel Circuits

The simplified block shown in Fig. 29 illustrates the major circuit features of the TA-9. Note that the composite picture signal traverses three paths—chrominance, luminance and sync.

The input signal is first split into two channels—one for picture information and the other for sync. Provision is made for inserting a relay to select either internal or

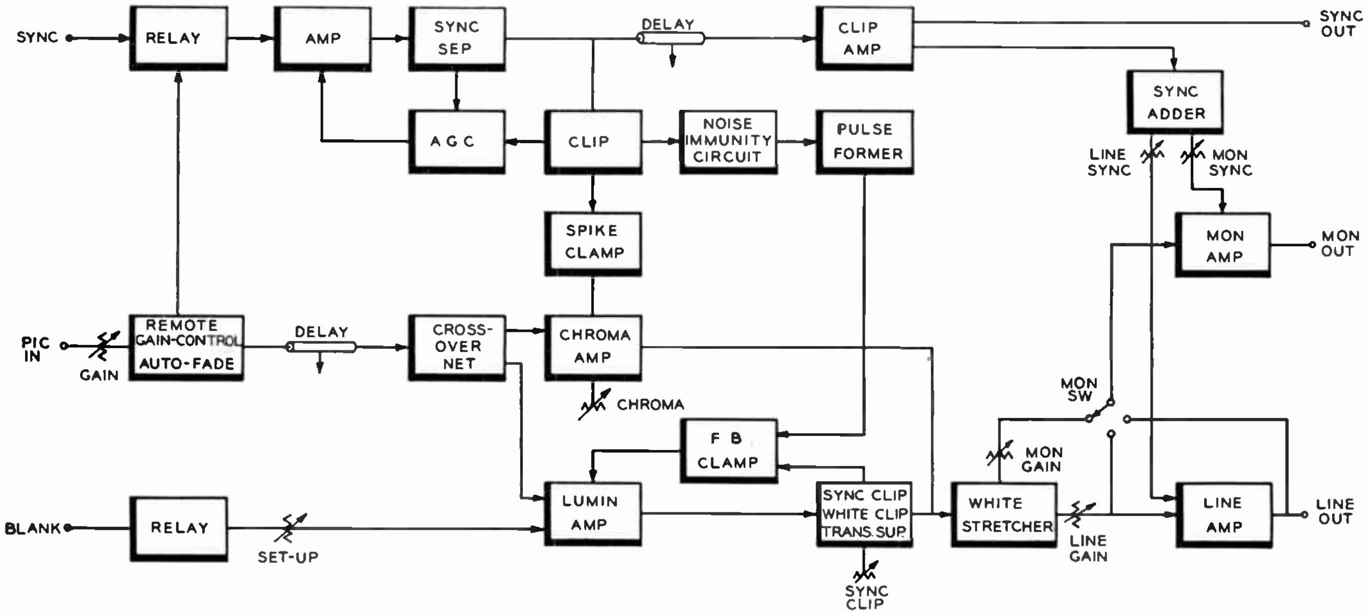


FIG. 29. Simplified block diagram of TA-9 Stabilizing Amplifier.

external sync. Use of this relay eliminates the need for the transient suppressor required in many stabilizing amplifiers of older design.

In the sync channel, separation of sync information is accomplished in a high level clipper. This stage is driven from an automatically gain-regulated amplifier to insure stable and accurate clipping over a wide range of signal level variations.

A noise immunity circuit is used between the clipper and pulse former to provide clamp pulses free from the spurious pulses which might otherwise be formed from noise spikes in the incoming signal. The circuit works by virtue of the fact that spurious noise impulses are normally much narrower than the desired sync pulses. The sync signal delivered to the noise immunity circuit has previously been doubly clipped, so that both the sync pulses and the spurious noise impulses have the same peak-to-peak amplitude. An RC integrating circuit is employed to greatly attenuate the narrow noise pulses, so that the sync pulses can trigger the pulse former.

Picture Channel Circuits

In the picture channel, the signal is again split into two paths, one carrying mid-band frequencies or chrominance information and the other the luminance information. The crossover occurs at the color subcarrier frequency, 3.58 mc, with a complete null at that frequency in the luminance channel.

The feedback clamp and clipper circuits are contained in the luminance channel. Here, the purpose of the feedback clamp is threefold: to maintain clipping at exact black level over long periods of time without readjustment; to automatically set the clipped signal at the proper position on the white stretcher characteristic; and to provide a high degree of immunity to tube ageing and supply voltage variations. Since color subcarrier is not present in the luminance channel, sync may be clipped off all the way to blanking level, and back porch clamping may be performed with full effectiveness without damaging the color burst in the color signal.

Following the clamp stage, where accurate reference level is maintained (for sync clipping, white stretching, etc.), a white clipper circuit is provided. The purpose of this clipper is to reduce intercarrier buzz in receivers caused when the carrier is overmodulated by peak whites. Chroma and high definition video components may still cause overmodulation, since these components pass through the chroma channel and thus bypass the white clipper. However, the frequency and energy of these components is such that the buzz is usually inaudible.

The chrominance information is passed around the clamp and clipper stages through a two-stage amplifier channel. This allows control over chroma gain and provides proper delay for later recombination of the chrominance signal with the luminance signal. Signals from the chrominance and luminance channels are mixed together and applied to the white stretch circuit. Here, an adjustable degree of amplitude nonlinearity may be introduced to predistort or compensate the signal for later passage through equipment which may cause compression. An example of this requirement is in transmitters which do not contain built-in compensation. A switch is provided

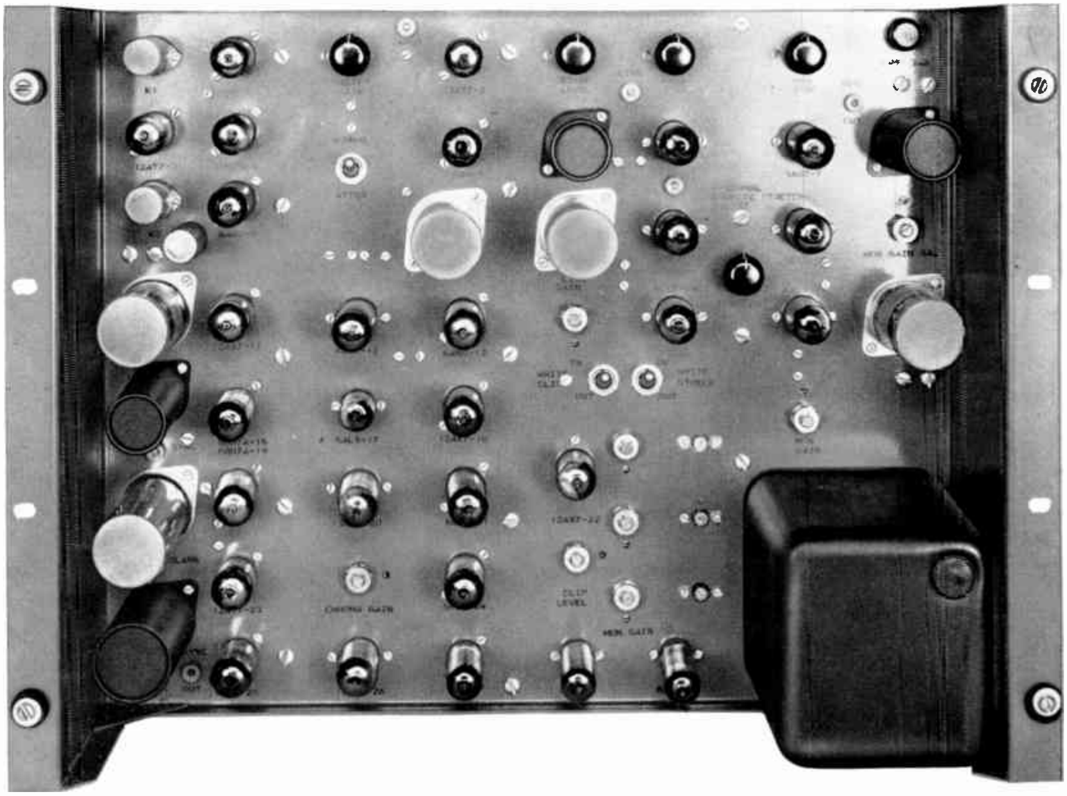


FIG. 30. TA-9 Stabilizing Amplifier.

to bypass this function when it is not needed. The output composite picture signal is finally formed by addition of the reshaped sync signal to the clamped picture signal.

Special Features

For studio operation the TA-9 provides semiautomatic fading action to permit smooth transitions between network and local programs. This is controlled by a remotely located fade switch with no additional level adjustments necessary. The picture input stage shown on the block diagram is actually a variable-gain amplifier connected to the remotely located fade switch. Operation of this control will cause the picture portion of a composite signal to fade down to black at a smooth rate without affecting sync. After fading to black, the output signal may be switched at the regular switching console to provide the "sync only" or "black" switch often used in transitions from network to local signals. The fading process can then be reversed to return to normal operation.

Also, a pedestal control feature has been included for local or genlocked operation so that proper setup level can be maintained should incoming signals lack the necessary amount of setup. This control operates by adding an adjustable amount of blanking to the original signal in the luminance channel.

Output and Monitoring Circuits

For greatest flexibility in studio and transmitter application, the TA-9 utilizes two indentical feedback video output stages. One of these is permanently arranged to feed the program line. By means of a monitor output switch, the other amplifier may be used as follows: to feed an unstretched signal to a monitor when the line amplifier is feeding a stretched signal to a transmitter; to monitor the signal directly as it appears on the program line; and to provide a signal identical (with the exception of different sync levels, if desired) to that of the line amplifier with high isolation between the two outputs. Both amplifiers are adjustable for unity gain, and each has a sync level control.

If a noncomposite output is desired, sync may be cut off completely in either or both channels (see the SYNC ADD controls at the far right of the block diagram in Fig. 29). If stretched sync is required to compensate for compression in the subsequent equipment, the sync level may be increased to twice the normal level.

Note: See APPENDIX for Transistorized Switching Systems.

PART 9

Color System Planning

Planning of a color system must be done very carefully to avoid unnecessary and expensive duplication of equipment. This caution should be exercised by broadcasters contemplating additional color facilities, as well as by those getting into color for the first time.

A background experience in television broadcasting, though only in black and white, will be helpful in the planning of a color system. The general arrangement of operating positions and controls is much the same for both. Color telecasting utilizes most of the techniques to which program people and technicians working in monochrome stations have become accustomed.

Functions of cameramen, technical directors, program directors and master control operators can be performed in the color system by people of the same occupational skill as for black and white. This applies to video control and transmitter operators as well, except that additional knowledge must be acquired. Test and maintenance of color equipment requires more experience and broader knowledge. In most cases, this has been accomplished by further training of people already on the station staff.

The language and symbols of colorimetry, and the technique of multiplexing video signals will be new to many. But these principles are not fundamentally difficult and can be understood readily by the average technician who is skilled in his job.

The question foremost in the minds of most broadcasters planning to get into color is the extent of equipment facilities required to handle the anticipated programming. A full scale color operation, with provision for film and live studio originations requires additional studio and equipment space; while the amount of equipment required for telecasting network color programs is relatively small, and in most cases can be installed in space already available. Most additional space requirements are in connection with the control room equipment; the existing monochrome transmitter can be made to handle color with only very slight modification. These and other factors have been taken into consideration in suggesting the color installation steps described.

Some of those getting into TV broadcasting for the first time may prefer to install all color equipment at the start, and thereby provide immediate facilities for all types of color programming. A typical layout for an all-color station of this type, i.e., for telecasting color film shows, live studio programs, and color television material recorded on video tape, is presented on Diagram 2 in Appendix D of this manual.

Color Equipment Groupings

The single most important factor in color planning is the selection of equipment units that will perform together as a system. RCA color equipment units are designed to provide for considerable flexibility in arrangement. Nevertheless, it is preferable to use them in "equipment groups" which have been carefully worked out in accordance with broadcast requirements, and "proved-in" by actual performance tests. This has been confirmed by the experience of "color stations" on the air, most of which are using these color equipment groupings.

Another very important part of this philosophy is that the groupings are designed to permit the station to start in color on a modest basis, derive the most efficient use of both color and monochrome equipment, and add color facilities from time to time without unnecessary cost or duplication of equipment.

RCA engineers in studying the course of color development, designed five basic equipment groups to correspond to three successive steps which most television stations follow in building up to a full scale color television operation. The equipment groups required for each of these three steps, and the programming facilities provided are listed in the table. Three of these groups represent the particular equipment needed for each type of programming. The other two groups comprising the color test equipment and the local origination equipment are listed separately because in some cases this equipment may be on hand, or may be obtained at other times than during expansion of programming facilities.

The three steps upon which these equipment groupings are based, consist of:

Step 1—Installation of Equipment for Telecasting Network Color Programs

Step 2—Addition of Equipment for Telecasting Color Slides and Color Film

Step 3—Addition of Equipment for Telecasting Live Color Studio Programs

Integration with Monochrome

The 3-step plan for color described in the next few pages has been related to the equipment found in a typical monochrome station. While stations differ to some extent, the facilities and their general arrangement will be sufficiently close to illustrate the basic considerations.

Most station engineers desire to keep their color programming facilities separate from their monochrome facilities, at least during the period of transition. However, efficient station operation usually requires some provision for switching between the two facilities. This means that the switching system and some of the items associated with it such as stabilizing amplifiers and distribution amplifiers must function for both monochrome and color. In fact, all equipment associated with program distribution must be capable of handling both monochrome and color.

Specially prepared equipment block diagrams are included in the Appendix D of this manual. Diagram 1 represents an integrated color and monochrome television station. Elements shown in black on this diagram (including the equipment lists and suggested rack mounting layout) are those of a typical monochrome station; the various color equipment groupings, corresponding to the 3-step plan to be described, are identified by the different colors appearing on the diagram. Diagram 3 illustrates the transmitter equipment of a typical television station; and Diagram 2 represents an all-color station with facilities for telecasting color film shows, live studio programs and tape-recorded color video programs.

Typical Monochrome Station

The functional block diagram, equipment list and rack equipment layout shown *in black* on Diagram 1 (see Appendix D) represents the studio equipment of a typical monochrome station. Major facilities include a live studio, two cameras, projection room, film and slide units, studio and master control equipment, microwave STL equipment and provision for programming network and remote pickups. As shown on the left side of the diagram, a 6 x 2 video switcher (Control "A" Video Switcher No. 2) located in master control can be operated remotely from studio control "A" for selection of five program sources (plus a spare), and for performing lap-dissolves and other programming functions. Input signals to Master Control Switcher No. 1, also a 6 x 2 switcher, are fed through distribution amplifiers and consist of projection room output, network, remote, and the output signal punched up on the control "A" switcher No. 2. A 9 x 1 switcher in master control provides for preview selection of network, remote and program line signals.

Studio equipment of the typical monochrome layout as illustrated in Diagram 1 is capable of transmitting network color shows. However, additional equipment will be required at the transmitter as shown in Diagram 3 and described in Step. 1.

3-STEP PLAN FOR COLOR

	Equipment	Program Source
Step 1	Network Color Equipment	Transmission of color programs received from network source.
	Color Test Equipment	Required by all stations for maintaining a high quality picture.
Step 2(A)	Local Color Bar Origination Equipment	Local generation of color sync signals plus color bar signal for system checking and advance training of personnel.
(B)	Color 3-Vidicon Film and Slide Camera Equipment	Origination of color pictures from motion picture film and color slides.
Step 3	Color Studio Camera Equipment	Origination of live studio pictures in color.

STEP 1 Installation of Equipment for Telecasting Network Color Programs (No Local Origination)

Many television stations have made a start in color programming by installing just the equipment needed for telecasting color programs received from the network. The amount of equipment required is relatively small and consists of units all stations will eventually require, regardless of whether they start with just this step, or simultaneously install more elaborate color programming facilities.

Video Equipment at Transmitter

Items of color equipment required in Step 1 are shown in dotted lines on the block diagram of the typical transmitter installation, Diagram 3 (Appendix D). These consist of two equipment groups. The first includes all video equipment (amplifiers, phase-correcting networks and monitors) needed to transmit color. The second group includes the test equipment items necessary to be certain of high-quality operation.

The composite color signal from the studio (or directly from the net) is fed first to a Type TA-3 Distribution Amplifier. This distribution amplifier, which was particularly designed for color systems, provides sending end termination, variable gain from 0 to 2, and a sync addition circuit.

From the distribution amplifier the color signal is fed to a Type TA-9 (Universal) Color Stabilizing Amplifier. This amplifier differs from the monochrome models (5B, C, D) in that it is designed to pass the color subcarrier "burst" and in addition incorporates a non-linear amplifier. Its use at this point in the system is necessary in order to provide setup and white stretch adjustments for proper operation of the transmitter.

Phase Correction Equalizers

In order to comply with the FCC standards, two phase correction equalizers must be installed in the input line to the transmitter as shown in Diagram 3. These provide a calculated amount of phase predistortion to make up for phase distortion in the rest of the system. The low-frequency network compensates for the phase shift in the vestigial side-band filter. The high-frequency network compensates for the deficiency in high-frequency response of the receiver. This equipment is rack mounted external to the transmitter with other items such as the stabilizing amplifier and distribution amplifiers.

Monitoring Equipment

In order to be able to visually monitor the picture transmitter, a Type TM-21 Color Monitor is required. The color monitor must be fed from a high-quality demodulator. Most stations presently have either a BW-4 or BWU-4 Demodulator. With minor modifications either of these may be used. A demodulator conversion kit is supplied as part of *Step 1* equipment for making the necessary changes. A standard monochrome monitor is used (in addition to the color monitor); however, this unit is not listed in the "required equipment" since the monitor which is part of the standard transmitter control console can be used for this purpose.

Color Stripe Generator

In areas where color programs are telecast only occasionally it is difficult for servicemen to check color receiver installation. Most servicemen have a portable bar and dot generator with which they can check the operation of the color receiver itself. However, if there is no color signal on the air they are unable to check the antenna and transmission line. In color transmission it has been found that in some cases multi-path effects have a tendency to cancel the color burst. Faulty transmission lines also sometimes result in loss of color. For this reason the serviceman should make an "on-air" check of every color installation.

Stations can help the serviceman by using a WA-8 Color Stripe Generator. This unit, when inserted in the video line feeding the transmitter, generates two color bursts, one at the beginning and one at the end of each horizontal scanning line. This produces a vertical yellow-green stripe at the right-hand edge of the monochrome picture. The stripe is imperceptible on a monochrome receiver but is easily observed on color sets by adjusting the horizontal frequency control until the color circuits of the receiver are actuated by the burst at the beginning of each line.

By using the WA-8, stations can transmit color information all day long without interfering with regular commercial monochrome operations. This enables the serviceman to determine that the transmission path is passing the color burst and that the overall installation is satisfactory.

Color Test Equipment

High-quality color telecasting requires close adherence to carefully specified transmission standards. This can be accomplished only with an adequate amount of test equipment of the proper type. Because the color system is much more complex than monochrome additional test equipment is needed. Much of it is of new and unique design.

Test equipment is used in a color station for three important purposes. These are: (a) adjusting color origination equipment, such as studio and film cameras, colorplexers, etc.; (b) checking "system" elements such as distribution amplifiers, stabilizing amplifiers, switching equipment, S-T-L's and the main transmitter; (c) adjusting color monitoring equipment. In installations where the studio and transmitter are separated by some distance, it is advisable to provide duplicate color test equipment for use at the studio.

The first operation does not occur in a Step 1 color station since no "origination" equipment is involved. (Thus the WA-1 Color Bar Generator, which is the key unit for this purpose, is not included in required equipment until Step 2.)

A Step 1 station will have to check all system units and adjust color monitors for proper operation. To do this, it will require nearly as many different test equipment units as a larger installation. For this reason it is strongly recommended that every station purchase a fairly complete set of test equipment as a part of the first step in color.

How It Is Used

Figure 1 shows in chart form the test equipment setups necessary to make all basic color equipment measurements. The list of equipment included in Step 1 includes only the items necessary to make the tests shown in the first two groups. The remaining groups are included to show how the same units are used later (with the addition of a color bar generator) to make adjustments on local originating equipment.

Before attempting to put color pictures on the air, equipment in the station system should be checked to be sure the transmission characteristics are satisfactory. Each piece of equipment through which the signal must pass introduces some distortion. Even though the distortion may be very small, cumulative effects of many units in series may well prevent the proper transmission of color video. Four parameters must be contained well within reasonable limits. These parameters are amplitude vs. frequency, phase vs. frequency, differential gain, and differential phase. Differential gain is defined as the change in gain measured against signal amplitude. Differential phase is defined as the change in phase shift measured against signal amplitude.

Four instruments are provided for the precise measurement of these parameters. They are the linearity checker, the color signal analyzer, the burst controlled oscillator and the television oscilloscope.

WA-7 Linearity Checker

The differential gain characteristics of any unit of the system, or the system itself, can be measured with the WA-7 Linearity Checker and the TO-524 Oscilloscope. The linearity checker has an output signal consisting of a low-frequency step wave with an RF signal superimposed on it. This signal is fed into the system under test and the output is observed on the oscilloscope after being passed through a high-low filter which is a part of the WA-7. When the filter switch is in the high position the step wave is removed from the output signal and only the RF components remain. Any change in amplitude of the RF envelope from beginning to end of sweep indicates differential gain distortion, and the percent change in amplitude of the RF pattern is the measure of differential gain distortion in the system.

WA-6 Color Signal Analyzer

The WA-6 Color Signal Analyzer is used with the linearity checker and scope (as shown in Fig. 1) to measure the subcarrier phase shift and the differential phase of the system. Two input signals are required for operation of the Color Signal Analyzer: (1) the composite color signal to be measured and (2) a continuous reference subcarrier signal. For making phase measurements, both these signals are provided by the Linearity Checker. In Steps 2 and 3 the Color Signal Analyzer is used (in conjunction with the WA-1 Color Bar Generator) for precise alignment of the colorplexers.

WA-4 Burst Controlled Oscillator

In many instances a source of subcarrier for use with the signal analyzer may not be available such as at a transmitter location remote from the studio facilities. To measure the four parameters involved in color transmission of a studio transmitter link, it would be necessary to have available a source of subcarrier. The WA-4 Burst Controlled Oscillator fulfills this requirement. The color burst is picked off the incoming signal and used to precisely control a crystal oscillator, the output of which is a continuous subcarrier signal. This item is not needed if the studio and transmitter are at the same location and if test measurements are not required at a point remote from the location of the Linearity Checker.

Grating and Dot Patterns

Grating and dot patterns are included as output signals of the TG-2 Sync Generator. The grating signal is used to adjust the deflection linearity of any monitor. This signal produces a grid pattern on the monitor consisting of horizontal and vertical lines. Any difference in the spacing of the lines over the face of the monitor represents non-linear deflection. The dot output is used for checking the beam convergence adjustment of color monitors. The dots are really rectangles which are adjustable

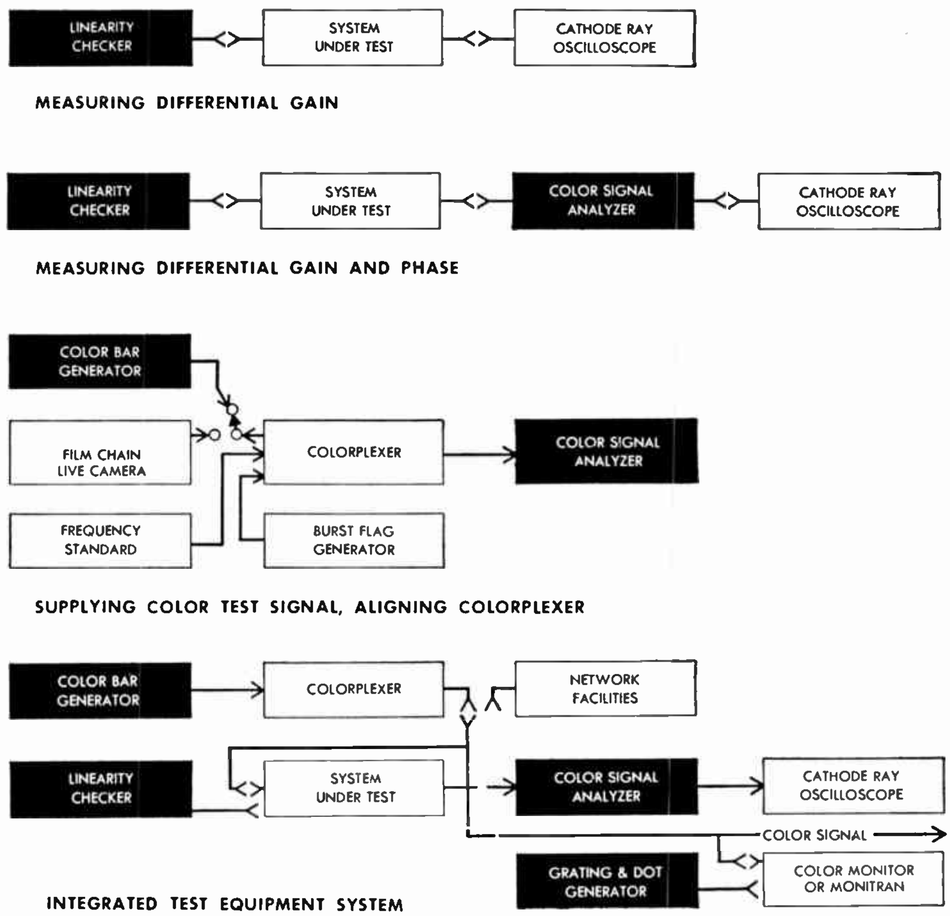


FIG. 1. Chart showing how various units of color test equipment are used in testing the parameters of the color system.

in size to suit the individual using the instrument. If the convergence is not set properly, dots of three different colors appear displaced from one another by the divergence of the respective beams. If properly adjusted, only white dots appear on the monitor with a minimum of color fringing.

The color monitor at the transmitter location can be adjusted by having the studio feed grating and dot patterns to the transmitter (over the STL) during periods of no programming.

WA-9 Calibration Pulse Generator

This unit, although not used in the tests shown in Fig. 1, is strongly recommended as a part of every studio's test equipment. Designed for the accurate calibration of studio signal voltages it can be installed in a television system as one input to a switcher or it may be made available at a jack panel so that it can be patched to any part of the system as desired.

For permanent installation, it is convenient to have the WA-9 installed in master control so that operating personnel can have it available at any time. It can also be used to calibrate all master monitors and oscilloscopes by merely substituting it for the normal input signal. When it is used as a video input to a switcher, it can be rapidly switched in and out for precise matching of video signals from various sources.

The WA-9 is also very useful in setting up the processing amplifier in the 3-V color film chain. Here the WA-9 makes possible an accurate match between all three color channels. Switches are provided on the processing amplifiers for rapidly switching between the signal voltages and the calibration pulse signal.

TO-524 Oscilloscope

The TO-524 oscilloscope is an instrument designed especially for television applications. The wide bandwidth coupled with the precisely controlled sweep circuits provide for observing almost every conceivable point of interest in a composite signal. The trigger circuits make it possible to examine very minutely the vertical synchronizing interval as well as each horizontal line. This is useful when determining the position of the burst with respect to horizontal sync and blanking signals.

STEP 2 Addition of Equipment for Telecasting Color Film and Slides

For most stations the second step in color will be the addition of equipment for telecasting color slides and color film. Color films provide the simplest means of originating color programs at the local level. It is expected that before long many of the syndicated film programs will be made available in color. Color films are also of great interest to the advertiser. Of course, one of the big features of color is the added impact it lends to product advertising. At the present time many commercials are supplied on short film strips. With the growth of color this trend will undoubtedly increase. In addition, there are many short subjects that are available in 16mm color film which program departments will be anxious to use.

Availability of equipment for telecasting their own color slides will enable stations to make station breaks in color (definitely desirable when telecasting network programs in color) and to sell color "spots" to local and national advertisers. Color slide programs are relatively easy to make up because 35mm color transparencies can be used as color slides.

Equipment Required

The equipment for televising color slides and films does not require a large amount of additional space, and operating cost is reasonable. Thus it represents a much smaller and less expensive step than installation of live studio color. A list of the equipment items that must be added (in order to make a *Step 1* station into a *Step 2* station) is shown on Diagram 1 (see Appendix D).

Step 2 Equipment Groupings

It will be noted that this equipment is divided into two groupings. The first group, referred to as "Color Bar and Local Origination Equipment," includes the units necessary to generate color sync signals locally plus a studio-type color bar generator and a colorplexer. The second group includes the film/slide camera chain plus associated projectors, multiplexer, etc.

A station which telecasts only network color (*Step 1*) does not require a local sync generator because the color signal received over the network line is a complete composite signal (i.e., it includes all necessary sync pulses as well as picture signals). However, when a station decides to start local color programming, (no matter how simple) the color sync signals, as well as the color picture signals, must be generated locally. Thus before a station can start color slide programming it must install its own color sync generating equipment.

The color bar generator is required in order to correctly adjust the colorplexer used with film and studio cameras. Thus it is a necessary prerequisite to *Step 2* operation. It also provides a convenient means of generating a color test signal which is very useful in testing and measuring of studio and transmitter systems. In addition the color bar signal can be used as an on-the-air signal during periods when regular commercial transmission is not in progress so that servicemen may utilize this signal for the adjustment of color receivers.

In order to familiarize and train station personnel in advance with color TV equipment and principles, some stations may wish to install the color bar generator and local origination equipment well ahead of the film and slide camera facilities. In order to show how this may be done the following description of the *Step 2* equipment has been divided into (A) and (B) parts. Part A covers installation of the Color Bar and Local Origination Equipment only. Part B describes installation of the film and slide camera chain, projectors and associated equipment.

STEP 2(A)

Color Bar and Local Origination Equipment

The list of equipment units included in this grouping is shown in red on Diagram 1. The functional arrangement of these units (when added to the station described in Step 1) is also shown in red on Diagram 1. Most of these equipments are described in detail elsewhere in this manual. However, a brief description is included here for convenience to the reader.

Color Sync Signal Requirements

Color sync signals differ from monochrome sync signals in two major respects. One is that they employ a "burst" of subcarrier frequency (3.58 mc) superimposed on the "back porch" of the horizontal sync pulse. This "burst" is supplied by a Burst Flag Generator.

The second difference in color sync signal is that they are controlled by the subcarrier oscillator (rather than the 60-cycle supply). This thermostatically controlled 3.58 mc oscillator is contained in the Color Frequency Standard.

Color Frequency Standard

This unit provides the color synchronizing information necessary for proper color operation. The subcarrier output of the frequency standard is fed to each colorplexer where it is modulated with the chroma information. Another output from the frequency standard is used to lock the sync generator to the frequency standard. The frequency of this output is the subcarrier frequency divided by 445/2. This frequency has been selected to eliminate cross-talk between horizontal scanning frequency and the color subcarrier.

Burst Flag Generator

The burst flag generator is an adjunct to the TG-2 sync generator. This unit is used for keying-in the color subcarrier burst. Its output consists of a series of horizontal pulses which key the burst of subcarrier onto the back porch of the blanking signal in the colorplexer. These pulses are suppressed during the vertical synchronizing interval so that no burst is keyed at this time.

TG-2 Sync Generator

The TG-2 Synchronizing Generator is designed especially for color operation. Miniature tubes and other miniaturization techniques have been used to reduce the size of this new unit to approximately one-third that of previous models. Providing extra stability, small size and combining all sync functions in a single chassis, it is ideal for color TV applications. It includes a built-in dot generator, grating generator and regulated power supply.

Sync Generator Changeover

Some stations operating today may be equipped with one or more TG-1A Generators. It is possible to modify the TG-1A Sync Generator for color operation by means of modification kit, MI-40405. This kit contains all of the necessary parts and a complete set of instructions for making this modification. By modifying the station's original generator for color it is possible to use either it or the newly installed sync generator for either monochrome or color. This provides for emergency operation in case of failure in either while on the air. To facilitate changeover a special Sync Generator Changeover Switch is included in the list of equipment as well as a Remote Panel for controlling the switch form the console.

WA-1 Studio Color Bar Generator

The WA-1, when fed into a standard color system which includes a TX-1 Colorplexer, produces a standard color signal pattern containing bars of various identified colors (white, yellow, blue, green, cyan magenta, purple). This signal pattern, which corresponds somewhat to that of the Monoscope Camera in monochrome, is of great usefulness in checking the whole color system. In conjunction with the signal analyzer it is used for precise alignment of the colorplexer modulator circuits. As a source of color signal for routine measurements throughout the system it is unsurpassed.

The WA-1 has red, green and blue output channels. These outputs are fed to corresponding inputs on the TX-1 Colorplexer. The matrixing section of the colorplexer combines these signals and feeds them to the I and Q modulators at the proper polarity and amplitude to produce a colorplexed bar signal at the output of the colorplexer.

The test pattern from the color bar generator can be used effectively by viewers in their homes as well as by station engineers and servicemen. In order to adjust the set for best color balance, the viewer merely has to adjust the color or chroma control until the color bars are vivid and pleasing to the eye. Then, the phase or hue control is adjusted to achieve the best yellow hue in the second bar from the left. If the hue control is out of adjustment on one side or the other, the yellow bar will appear either greenish or too orange. If the yellow bar is set properly in this way, all the other colors normally fall into correct adjustment.

TX-1 Colorplexer

The TX-1 Colorplexer performs all the matrixing and multiplexing operations necessary to process the red, green, and blue signals provided by a color camera to produce a signal conforming to the FCC signal specifications.

The colorplexer has inputs for color signal sources such as a color bar generator and a camera (live or film). A switch on the colorplexer enables the operator to switch between the color bar generator and the camera. An automatic "carrier balance" unit which eliminates color "drift" problems is furnished with each colorplexer.

STEP 2(B)

Color Film and Slide Equipment

The major equipment units needed for originating color slide and film pictures include the 3-V Camera Chain, a multiplexer, two film projectors, a slide projector and video distribution equipment. This equipment is shown in green on Diagram 1. The 3-V Camera could, of course, be used with just one film projector or a single slide projector, in which case the multiplexer is not required. Or it might, if desired, be installed originally with one film projector and one slide projector. However, the provision of two film projectors provides for continuity on multi-reel shows as well as adding flexibility in programming.

The ease with which the 3-V Camera can be multiplexed is one of the outstanding features. Color cameras of the flying spot scanner type are usually difficult to multiplex. Also they require a special type of projector using a complicated arrangement of rotating mirrors or prisms. The 3-V Camera can be multiplexed with the same ease as a monochrome film camera. And it can be used for monochrome. Stations having RCA TP-6 Projectors can use these for color by slightly modifying them for long light application. (The RCA TP-6CC Projector is designed for long light application, and can be used for either color or monochrome.)

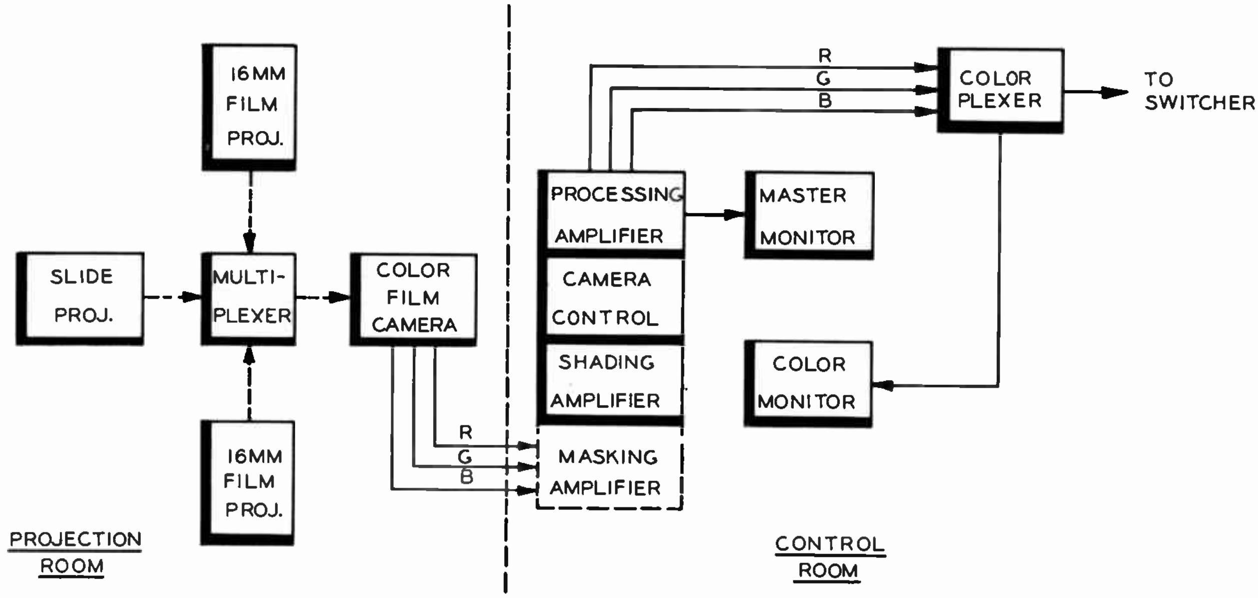


FIG. 2. Block diagram of TK-26 Color Film System.

TK-26 Color Film Camera

The RCA TK-26 color film camera employs three vidicons, one for each of the primary colors of the color film being transmitted. These vidicons "look" at a real image produced by the projector and reflected by the multiplexer to a field lens in the camera. By use of a separate lens at each camera and appropriate choice of dichroics and color shaping filters, one camera sees only the red component, the second camera sees only the green component, and the third the blue component of the color image.

The three identical vidicon camera subchassis are located, together with the light-splitting optics, in the top part of the camera cabinet. Mechanical alignment of the three sub-chassis is easily achieved by thumbscrew adjustment. The "in line" arrangement of the camera sub-chassis also simplifies this initial set-up. Final precise registration is easily achieved electronically, and once registered, there is excellent stability of registration. In day-to-day operation, only minor touch-up of controls will be necessary.

High resolution and maximum stability is obtained in this 3-vidicon system. Gamma is ideal—needs virtually no correcton; color fidelity approaches the high quality standards set by RCA's color studio camera. Use of the vidicon tube also provides a very high signal-to-noise ratio in both the color and the compatible monochrome picture. This feature is particularly important, especially in the first few years of color operation when color programs will be viewed on a great number of monochrome receivers.

Camera Control Console

The 3-V Camera Control Equipment is normally mounted in a control console. The control position includes (1) a TM-6 Master Monitor mounted in a 13-inch console housing, and (2) a 19-inch console housing, in which the camera control panel and the processing amplifier may be mounted. This 19-inch console housing is designed to mount the camera control panel in the indented desk section, and the processing amplifier and masking amplifier in the top sloping portion of the console. The processing amplifier performs a number of functions previously requiring several other units. Integration of these electrical functions in a single unit results in a simple, space-conserving, low cost system. Use of this design allows set-up time to be substantially reduced. A large reduction in power required as well as increased tube life due to extremely conservative operation of tubes resduces costs, at the same time improving performance and overall system quality.

The basic circuit elements in the processing amplifier are three plug-in video amplifiers which perform the following functions: cable compensation, video amplification, blanking insertion, shading insertion, feedback clamping, linear clipping, gamma correction and output amplification.

A fourth plug-in unit serves as the video section of an electronic switcher which is an integral part of the main chassis. The switcher, used with the TM-6 Master Monitor, provides an individual or combined presentation of red, blue and green video. To complete the control function a TM-21 Color Monitor is needed.

Several alternative arrangements are available to stations that wish to integrate their color and monochrome equipment. For example, all of the 3-V color film equipment can be rack mounted. In this case a rack mounted control desk and accessory kit is available to provide desk space at the rack location.

Masking Amplifier

The color masking amplifier can be either console or rack-mounted, depending upon requirements. It is designed to correct deficiencies in color film by enhancing and enriching colors that have faded, and by compensating for differences, between various brands of film. The amplifier can be used to vary saturation, or shift the hue without shift of gray scale, thus maintaining white balance automatically.

Rack Equipment

Rack-mounted units which complete the 3-V Camera chain include a TX-1 Colorplexer, an associated aperture compensator and a set of power supplies (three WP-15). The colorplexer combines the outputs from the processing amplifier through the masking amplifier with the subcarrier to form a composite video signal. It does this in two operations as follows: (1) it cross-mixes the R, G and B signals to form the luminance (or monochrome) signal and the two chrominance signals and (2) it multiplexes these signals with the subcarrier to produce a composite color signal suitable for feeding the transmitter.

The rack-mounted units of the 3-V Camera Chain, including power supplies can be mounted in one standard cabinet rack. A typical rack arrangement for a Step 2 station is shown in green on Diagram 1.

TP-6 Film Projectors

The two TP-6 Film Projectors used in the monochrome layout (together with the existing TP-15 Multiplexer and TP-7 Slide Projector) are used in conjunction with the added TK-26 Film Camera Chain. One of the important features of the TK-26 3-vidicon film camera system is that it utilizes the excellent storage characteristic of the vidicon tube. This allows operation with intermittent type film projectors of the type with which most television operators are already familiar. Use of the intermittent type projector means that, while the sync generator is phased from the color subcarrier crystal as

FIG. 3. Projection room equipment consists of film camera, two film projectors, multiplexer (center) and slide projector located on opposite side of multiplexer.

required in a color system, the projectors can operate directly from the power line. If available projectors are used it is necessary to modify these projectors for long application. The TP-6CC professional projectors, however, can be used in the 3-vidicon system without modification since the long application feature has been incorporated in its design.

The TP-6 projectors provide an ample reserve of light to produce the best possible pictures from films of the highest density.

TP-7 Slide Projector

The TP-7 Slide Projector allows the station to make station breaks in color and to present color commercials on standard 2 x 2 color slides. These are easily made up by mounting Kodachrome color transparencies in standard mountings. The TP-7 Projector accommodates 32 slides in two drums arranged for optical fade between slides.

TP-15 Multiplexer

The TP-15 Multiplexer provides the optical system required to project a number of film sources into a 3-V camera and a 1-V camera. Using mirrors, the multiplexer provides for two film projectors (16mm or 35mm) and a single 2 x 2-inch dual-drum slide projector. Selection of film or slide sources can be remotely controlled. Each of the four mirrors in the multiplexer is hinged so that they will fold out of the way as required. The movement is electrically activated so that the proper combination is obtained by operation of projector controls. The image from any of the projectors can thus be relayed to the field lens in the 3-V camera, or the 1-V camera.

STEP 3 Addition of Equipment for Originating Live Color Programs

The third and final step in color is the installation of equipment for telecasting live studio color programs. Eventually, nearly every station will need such equipment, not only for studio color originations but also for pickup of local events. Many stations will want a live color camera immediately in order to be able to do local commercials in color. Experience of stations now operating with local color indicates that many color commercials are best when done "live."

The equipment recommended in Step 3 provides live studio facilities viz., two cameras and necessary associated equipment. With this equipment studio shows and live commercials can be telecast in color.

Step 3 shown in blue on Diagram 1 (Appendix D), provides the ideal setup for live studio color. When this equipment is added to Step 1 and 2 facilities, the station can program from four different sources, (1) network, (2) films, (3) slides, and, (4) studio.

The camera equipment supplied in Step 3 is identical in every respect with that used in the largest camera setups.

TK-41 Color Camera

Principal components of the TK-41 Color Studio Camera Chain are shown in the block diagram of Fig. 4. The TK-41 features considerable space and cost saving advantages over previous color chains.

As in the standard monochrome camera, the optical system, the deflection circuits, the pickup tubes and the preamplifiers are located in the three-tube color camera. A complete description of the TK-41 Color Camera chain is given in Part Five.

Studio Camera Control

The studio camera control equipment is similar to the film camera control supplied in Step 2 and includes the same type processing amplifier and master monitor. Mechanically, this equipment is housed in two console housing units and may be mounted next to the film camera control to form a single console, if desired. The advantages of standardization such as common tubes, panels and circuits are realized.

Electrically, the three video signals from the camera are fed directly to the camera control panel on which both operating and selected set-up controls are located. These signals are fed in turn to the processing amplifier which performs the functions of cable compensation, video amplification, blanking and shading insertion, feedback clamping, linear clipping, gamma correction, and output amplification as well as providing auxiliary switching for the master monitor. The processing amplifier takes the place of numerous rack equipment items formerly required to perform the functions mentioned above.

The processing amplifier feeds a master monitor, which provides both kinescope and CRO displays of the processed camera signals, and a colorplexer, which combines the processed video signals into a single FCC standard color signal. The colorplexer feeds a TM-21 Color Monitor so that the color picture may be viewed by the video operator.

Colorplexer and Rack Equipment

The colorplexer, distribution amplifier, aperture compensator and miscellaneous power supplies are the Step 3 rack mounted items.

The colorplexer operation is similar to that previously described in Step 2. The R, G and B signal outputs of the studio color camera are fed through a processing amplifier into a colorplexer, just as are the outputs of the film camera. A colorplexer is supplied as part of each camera chain. The video signal from each chain is an independent compatible color signal. The color bar generator is used to align the colorplexer which can be adjusted for perfect matrixing. Using this adjustment as a reference, and color monitor for observing, the elements of the camera chain can be lined up for the best possible picture. An aperture compensator is mounted above the colorplexer and connected to function as part of the colorplexer's luminance channel.

Monitoring

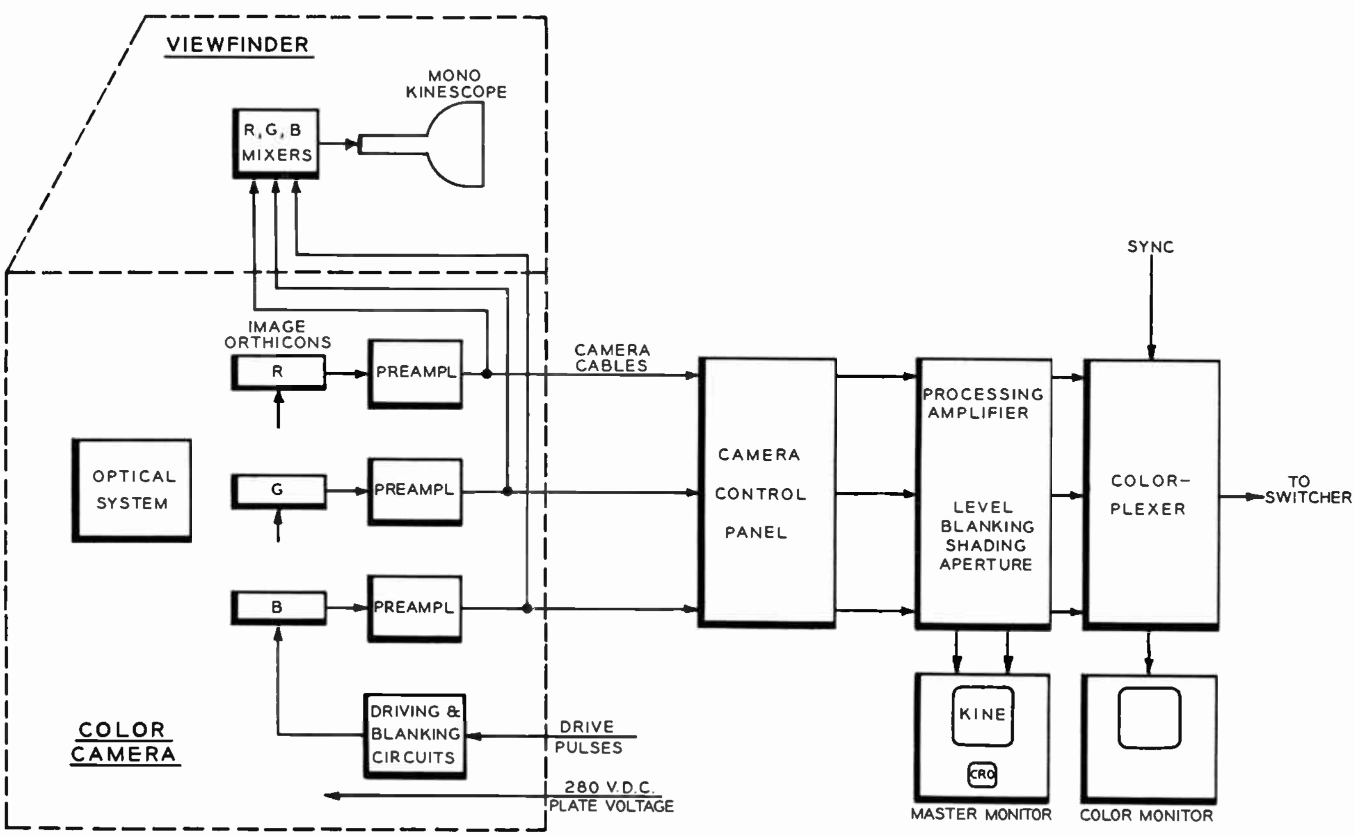
In Step 3 (as in Step 2) a monochrome master monitor (TM-6) and a color monitor (TM-21) are furnished. The master monitor which is mounted in the console housing permits the checking of levels of individual color signals and camera registration. The video operator sees the picture in black-and-white on the camera control monitor and he may select a black-and-white presentation of a separate red, green or blue signal or any combination (red plus green, green plus blue, or red plus green plus blue). A color picture presentation can be seen on the color monitors. The color monitor is a separate unit and can be mounted on a table, suspended, or mounted on top of the control console.

Color Switching Facilities

The description on preceding pages has indicated how unit equipment groupings may be added step-by-step to increase the color video facilities of a TV station. Further increases can be made by installing additional film and/or studio cameras.

In most cases it will be desirable to add a complete equipment grouping for each camera (film or slide) which is added. This arrangement (i.e., of making each camera chain a complete system in itself) is advantageous in providing flexibility, facilitating maintenance and avoidding loss of air time because of failure in a single color coding equipment. It also makes for much simpler switch-

FIG. 4. Block diagram showing major components of complete live color camera chain.



ing between cameras and between cameras and other program sources. (See Part Eight for a complete description of various switching methods.)

Console and Camera Space Required

Each camera chain—whether slide, film or studio—includes two units designed for console mounting. One of these is a master monitor and the other unit is the color camera control. The two units are mounted in standard console housings similar to those used in the RCA monochrome installations. There is an alternative method of mounting these units, however, in a standard cabinet rack with a special desk accessory. This is illustrated in Fig. 5.

The color studio camera is larger than a standard monochrome camera. However, it is moved by similar type dollies and, therefore, does not in itself require more floor space. The film and slide camera space is indicated in a floor plan presented in Part Six. Here also space must be left for access and convenient working room on both sides. Studio space required will depend, of course, on the scope of programming, number of cameras and other factors.

FIG. 5. Alternative method of mounting processing amplifier and master monitor in a standard cabinet rack. Camera control is shown in desk below amplifier.

Intercom for Color

In any TV setup, a good *intercom system* is a necessity. The first significant step is when film facilities are added. In most existing stations some form of intercom system is in use, and the addition of color film into the same area may not require any additional talk circuits. However, the addition of a color studio camera which has an intercom circuit built in, will require terminal equipment for communication in accordance with the number of cameras and control points involved. Inasmuch as the intercom circuit constants are the same as those used in the RCA monochrome cameras they may be easily integrated with an existing monochrome system.

Microwave Equipment for Color

A microwave system, type TVM-1, has been designed to transmit both color and monochrome. In the TVM-1 microwave transmitter, power has been increased over that of previous models to give more reliable transmission over longer distances. This increased power makes economical multi-hop operation feasible for both color and monochrome transmission.

Planning of All-Color Installations

Diagram 2, which will be found in the Appendix of this manual is a functional block diagram showing a typical studio equipment layout for an all-color television system. Facilities include two independent studio control rooms for two separate studios, which are each equipped with two color cameras and monitoring equipment, a film projection room with two separate film and slide systems plus two film cameras, a master control room, and microwave STL and remote pickup facilities.

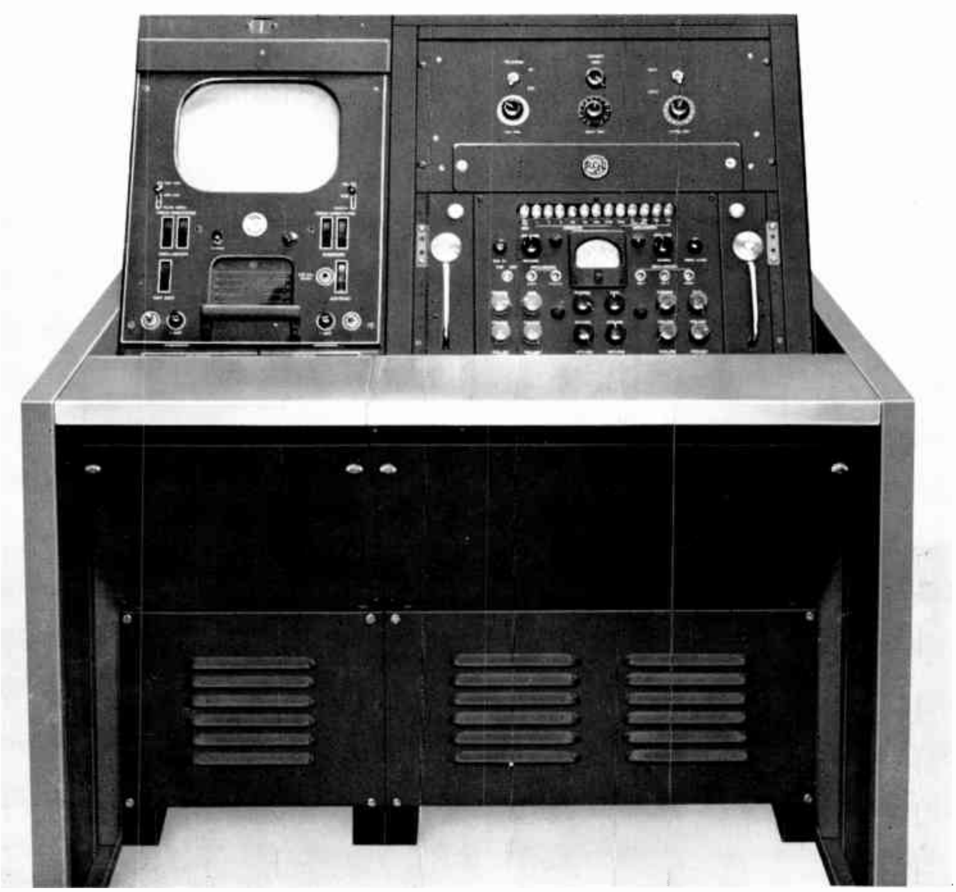
Also indicated on the block diagram are complete studio facilities for two color video tape recorder/reproducer equipments. The additional switching busses for the tape recorder are indicated on the block diagram. A complete description of the color video tape recorder is presented in Part Eleven of this manual.

The Video Tape Recorder provides a means of recording and immediately playing back either color or monochrome video signals simultaneously with program sound. It will reproduce both video and audio signals with quality and fidelity that rival closely that of the original program material.

The complete color video tape recorder is contained in six standard cabinet racks. These three racks associated with the tape transport must remain together; however, the other three racks containing the color processing equipment, servo amplifiers and power supplies can be remotely located. Also, operating control can be delegated at the master control panel to a remote control panel if desired.

One or two video tape recorder systems can be added to the integrated monochrome and color station Diagram 1 (Apendix D) as easily as to the all-color station.

FIG. 6. Processing amplifier mounted in console desk section adjacent to camera control.



The Color Transmitter

Broadcasting of color signals usually requires no major change in the circuits of a television transmitter which is capable of high quality monochrome transmission.

The color signal requires complete utilization of the available television channel, as does a high quality monochrome signal, and therefore exacts a higher standard of performance than necessary for what is often considered a satisfactory monochrome signal. Color and high-fidelity monochrome broadcasting, therefore, call for the same high standards of transmitter performance; a transmitter that is satisfactorily adjusted for color can be expected to transmit a superior monochrome signal.

As explained in Part Two, which presents the principles of multiplexing, color information is transmitted by the addition to the monochrome signal of sidebands produced by phase and amplitude modulation of a 3.58 mc subcarrier. In the modulation process, this information is converted into I and Q sidebands produced by amplitude modulation of two carriers of the same frequency, but displaced in phase by 90 degrees. Although the subcarrier information is not transmitted as such, it is reconstituted at the receiver by special circuitry deriving the necessary information from a burst of subcarrier on the back porch following each horizontal sync pulse. Also as pointed out earlier, the characteristic hue (red, green, yellow, blue) of the color at any particular instant is dependent on the phase of the color information with respect to the subcarrier burst; while the saturation (amount of white mixed with the color) is dependent on the relative amplitude of the color signal superimposed on the monochrome signal.

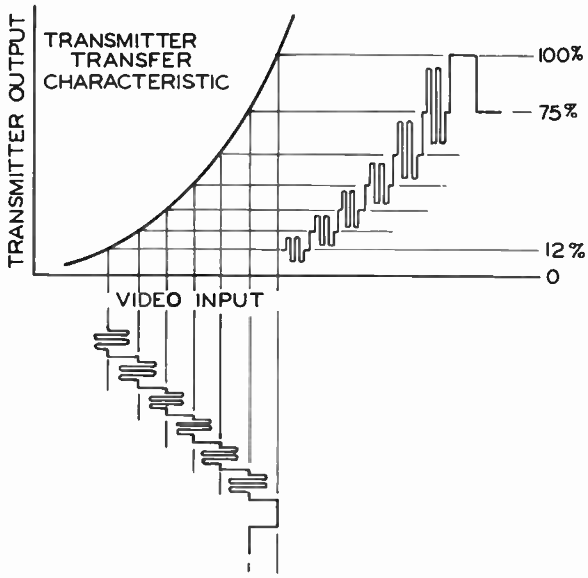


FIG. 1. Diagram showing how non-linear characteristics produce change in gray scale and color saturation.

Transmitter Evaluation

Evaluation of transmitter performance in producing the color signal is measured in terms of its transmission characteristics with respect to several parameters which can affect the color signal. These are identified in the following paragraphs.

1. Proper operation of clamp circuits is required to preserve the waveform of the color burst on the back porch of the horizontal sync pulse.
2. Good frequency response must be maintained to assure proper hue and saturation values. Poor frequency response can result in complete loss of color. As described later, an effect which might be called *"differential frequency response,"* a change of frequency response with picture level, may be encountered. This effect can occur with the use of linear r-f amplifiers.
3. Differential gain, or variation of transmitter gain with change of picture signal level, must be controlled within very close limits. Differential gain resembles intermodulation distortion as in an audio signal. It is usually evidenced as a loss of gain at

low output power levels, and can be measured by observing the change in amplitude of a small high frequency signal superimposed on a relatively large signal of low frequency. Differential gain is characteristic of grid modulation, which is extensively used in television transmitters, and of diode detection used for demodulation. It has the effect of producing poor gray scale rendition with loss of detail in bright areas of the picture, as well as errors in brightness and color saturation.

4. Differential phase, a change in subcarrier phase with power level or picture brightness, must be kept at a minimum. Differential phase produces changes in hue with changes in the intensity of scene lighting. This effect is also similar to that for intermodulation distortion, although the concern in this case is phase modulation of high frequency components by the presence of low frequency amplitude variation. This kind of distortion is produced by an impedance fluctuation with changes in signal level. A most common source for this effect is the change of amplifier plate impedance with changes in operating points on the tube characteristic curve. Another source is the change of load on a circuit that can result from variations in power level, as in the case of an amplifier or modulator which is driven to grid current over part of the operating level. Also, unwanted feedback in a video amplifier, modulator or power amplifier may cause distortion of both the amplitude and phase of the output signal.

5. Envelope delay, which describes the relative time relationship between the frequencies of the spectrum, as compared between input and output signals, must be kept constant. If the delay of all parts of the spectrum is not constant, the picture output signal will have distortion such as loss of detail, smear and ringing. A difference of delay between high and low frequencies causes lack of registration between color and luminance parts of the signal. If the delay is not constant in the range about the color carrier, crosstalk will occur between the color sidebands, giving rise to transient distortion and resultant distortion of hue and saturation particularly in color edges and small color areas of the picture.

Delay distortion is usually the result of factors involving restriction of frequency response, such as attenuation of the signal at 4.2 mc and above, to prevent the sound signal from interfering with the picture information, and to provide removal of most of the lower sideband. Transient distortion also can be caused by poor terminations of video lines and equipment, and by impedance variations and or poor termination of the feed lines to the antenna. Distortion-correction equipment normally used with transmitters is not intended for the correction of this type of delay distortion.

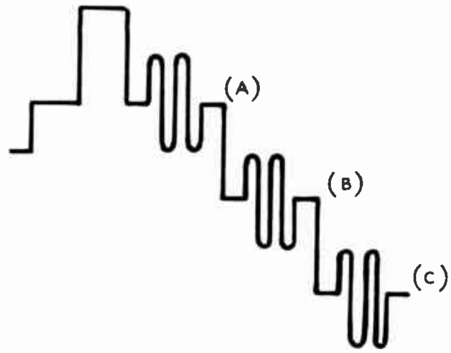


FIG. 2. Waveform illustrating desired independence of brightness and subcarrier phase.

Clamp Circuit Modifications

The back porch of the horizontal synchronizing pulse is the portion of the signal which is used as a reference point for operation of the clamp circuits to set d-c operating level. D-c clamping is essential in the modulation of the transmitter to make full use of transmitter carrier power. Operation of the clamp circuit can be compared to the closing of a switch to set the modulator grid potential at a point which corresponds to black level in the video signal. A similar d-c restoration also takes place in the stabilizing amplifier normally used in the video circuit preceding the transmitter input.

Since the modulator grid is driven by a relatively small blocking capacitor, there can be no variation of signal in the interval during which the clamp operates, other than the brief and small transient of voltage level adjustment. Thus, unless the clamping switches are made high-impedances at color subcarrier frequency, there will be no reference color burst in the transmitted signal. This modification is usually made by putting a choke of low Q, which is self-resonant at the color subcarrier frequency, in the switch lead of the clamp; if the Q of the choke is not low, the clamp current pulses will cause it to ring near color carrier frequency and thus change the character of the burst signal. Another effect which can be troublesome stems from the fact that the clamp switch has a small capacity in the open position, which gives rise to a series-resonant circuit to ground through the clamp circuit. This often results in loss of response in some area of the video frequency spectrum. The clamp problem has been considered in some detail, although the information will be of value mainly for parts replacement or emergency use of old equipment.

Frequency Response

Frequency response problems may be divided into two general areas of the transmitter system. One of these is in the transmitter itself, and the other is in video equipment used at the input circuits of the transmitter. Essential input equipment consists of a stabilizing amplifier, distribution amplifiers, networks for correcting envelope delay and a low-pass video filter. The stabilizing amplifier is used to remove hum from the input signal and reshape and stretch horizontal sync pulses, and may have provision for control of color burst amplitude relative to monochrome amplitude; it usually has provision for compensating white compression of the signal by the transmitter. The stabilizing amplifier also has a separate output containing no white stretch, that can be used to monitor the input signal to the transmitter. It should be mentioned that this point is the only one in the system where a good signal can be obtained for monitoring the video signal input to the transmitter. Beyond this point, the signal is distorted by white stretch if this is accomplished in the stabilizing amplifier, and by distortion introduced by the delay correction networks. These networks introduce delay distortion in the signal to the transmitter. It is intended that they should be so adjusted that after passing through the transmitter and antenna coupling circuits, the video components in the modulated carrier have the same time relationship to one another as existed in the signal from the program source. In addition to delay correction, there is distortion introduced by an equalizer which compensates for high frequency video delay distortion in the receiver. Thus, at points in the system after the stabilizing amplifier there is no undistorted monitoring signal available, except as obtained through use of a delay-corrected demodulator such as the type BW-4B operated with its sound notch in and with the r-f drive taken from the feed line of the antenna.

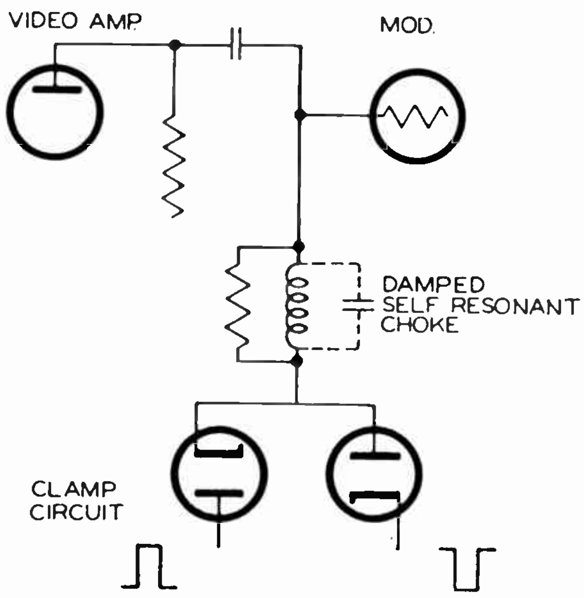


FIG. 3. Diagram showing modification to "soften" clamp circuit. A damped, self-resonant choke is inserted between clamp diodes and modulator grid.

Measuring the frequency response of an amplifier or other usual video equipment is generally a simple procedure. However, the results of such measurements made on equipment containing delay-compensation circuitry present some surprises to the inexperienced. There are several reasons for this: (a) The oscillator producing the test signal usually generates a number of harmonics in addition to the desired sine wave signal; (b) the delay correction circuits produce a delay which varies with frequency; (c) the relative phase of the signal components changes with each shift of the test frequency. Even though the input voltage is held constant and the response of the measured circuits is flat, the output voltage can change with test frequency in a discouraging manner. These problems have existed for some time in the measurement of transmitter response, and these circuits produce the same effects as those produced by the transmitter except in a complementary manner.

Equalizers delay the signal by a considerable amount, behaving very much like long cables. Impedance irregularities caused by incorrect types of cable, poor assembly of cable connections, inaccurate terminations or use of a signal source which provides poor sending end termination, will result in reflections of the signal, altering transient and frequency response. The transient response of a delay equalizer itself will not be good, for it is intended to correct the poor delay characteristic of other circuits to produce an overall uniform delay. The solution to the response measurement problem lies in the use of the best possible test equipment available, and an understanding of the difficulties involved in making measurements of this kind.

Test Equipment Requirements

The first requirement is a test oscillator with very low harmonic distortion in its output. A sweep oscillator is much more desirable than a fixed-frequency oscillator for speed in making measurements. The sweep generator in recent versions of the BW-5 Sideband Response Analyzer is quite satisfactory for this use.[1]

Regardless of type or make, the sweep oscillator can be checked for harmonic content by passing its signal through the receiver delay equalizer which is part of the High Frequency Delay Equalizer. The output of the equalizer should be terminated with 75 ohms ±1% at the vertical input of a Type TO-524 Oscilloscope. The response should be quite smooth and show a gradual drop of about 1 db at 4 mc when the distortion of the sweep source is low. The frequency response of the sweep source can be evaluated by employing a video envelope detector and a 75-ohm termination at the vertical input terminals of an oscilloscope to view the output

[1] RCA Technical Bulletins TB-60-4 and TB-60-6 available from the RCA Commercial Electronics Products Department, Camden, N. J., describe circuit changes which can be made in the BW-5A Sideband Response Analyzer so that it can be used for making these measurements.

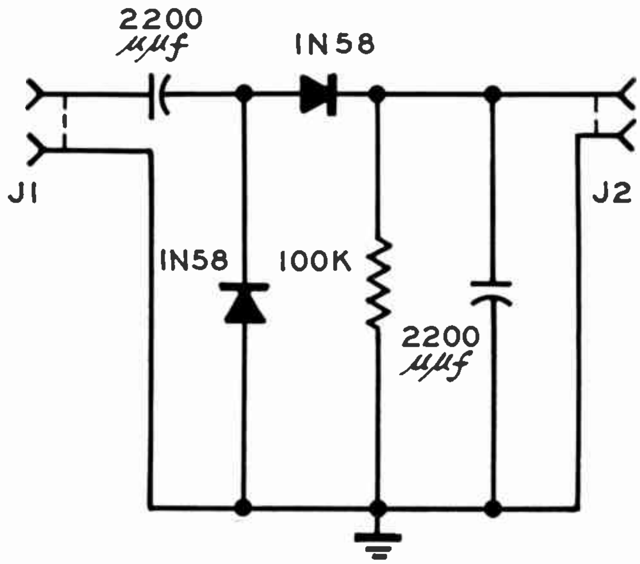


FIG. 4. Circuit diagram of video envelope detector for use in checking frequency response of the sweep source.

of the sweep oscillator, which can then be adjusted for flat response. A temporary detector using a 1N58 crystal will provide for checking flat response, 1N58 crystals provide better detector linearity at low signal levels than the 1N34 crystals. When the output response of the sweep oscillator has been satisfactorily adjusted, the video response of the oscilloscope can be evaluated and the oscilloscope may be serviced to improve its performance if necessary. Since the oscilloscope will be needed for square wave tests in adjustment of delay equalizers, it is important that it have flat response to at least 4 mc with a gradual loss at higher frequencies.

Frequency Response Measurements

Figure 5 is a block diagram of the transmitter video input equipment showing the approximate peak-to-peak signal voltages that should be realized when all adjustments are properly completed.

The video low pass filter is designed to produce a sharp cutoff of video response at frequencies above 4.2 mc. This filter, which incorporates delay compensation for its sharp high frequency cutoff, is placed at the end of the video chain for best effectiveness in removing unwanted high frequency components ahead of the transmitter input. This functional location is also advantageous because it permits observation of frequency response without the presence of confusing harmonic frequencies above 4.2 mc. As previously mentioned, the stabilizing amplifier location permits viewing the quality of the video input signal without white stretch and minus the delay distortion contributed by the delay correction circuits.

Delay correction circuits are sensitive to driving source impedance and load termination. Each individual unit is designed to present a 75-ohm load to its driving source when terminated in a 75-ohm load. Theoretically, it might seem that these circuits could be used in series, that is, one feeding the next. In practice there are always imperfections in the adjustment of the units and in the means used to interconnect them. In order to hold these effects to a minimum, two distribution amplifiers are inserted between units of the delay correction circuits.

Delay equalizers exhibit a droop in response which may be of the order of 1 db per unit at 4.2 mc. This is the reason for use of the two amplitude response equalizers. Distribution amplifiers should be capable of more than unity gain to make up for circuit losses incurred by equalizers and compensators. Amplitude response equalizers introduce no delay distortion.

The peaking circuits of the distribution amplifiers provide for final adjustment of video input circuit frequency response. Neither of the two amplifiers should require more than a slight adjustment. These peaking circuits do not generally provide response characteristics of a shape which will eliminate the need for amplitude response equalizers. With these equalizers and the amplifier peaking controls it is generally possible to obtain a response characteristic which is flat $\pm\frac{1}{2}$ db for the input chain exclusive of the stabilizing amplifier. Final adjustment of frequency response is of course dependent to some extent on the required setting of the delay equalizers for a particular transmitter.

Frequency response of the stabilizing amplifier cannot be checked with a simple video sweep signal because of its clamp circuits. However, through use of a modified WA-7 Linearity Checker it is possible to obtain a sweep signal with synchronizing pulse and blanking.[2] To use the linearity checker in this way, the sync pulse is set to ¼-volt amplitude, the step wave turned off, blanking adjusted to fall half-way between black level and white level, and external r-f input from the sweep generator is adjusted so that the sweep portion of the signal does not extend beyond black or white level. The resulting test signal should be inspected for uniformity of video response and the video peaking circuits in the linearity checker adjusted if necessary. This test signal will be useful also in checking overall response of the transmitter, from stabilizing amplifier input to BW-4 or BW-5 output with all circuits in use as in normal program operation.

[2] RCA linearity checkers beginning with the type number designation WA-7C provide sweep with synchronizing and blanking pulses. Earlier models can be modified to produce such a signal by following instructions contained in Field Letter EK185 Bulletin No. 3.

Measuring the transmitter frequency response is relatively simple using the BW-5 Sideband Response Analyzer. The transmitter is placed in AC operation position with the carrier power adjusted to ¼ of sync peak power level. If the transmitter termination is a dummy load of good quality, the pickup for the BW-5 receiver can be a simple capacity probe in the feed line to the dummy load. If the antenna is used as the load, however, a properly adjusted directional coupler should be employed to sample the signal. The response of transmitters particularly those with one or more linear power amplifiers in addition to the modulated stage should be checked near black level, at mid-level, and near white level. The signal from the linearity checker is very useful for these tests because the brightness level of the test signal can moved about as desired by changing the blanking control setting on the linearity checker. The sweep amplitude must be low for these tests to avoid over-modulation into blacker-than-black or whiter-than-white signal areas. The frequency response will not necessarily be the same for these three test conditions. The change in frequency response with change in power level is a function of the coupling circuits between stages and the loading of these circuits. If the load were constant there would be no problem. Where practical, a swamping resistor is used to help reduce load fluctuation. At high power levels this is not economical. A factor which has a pronounced effect on performance is the length of the transmission line from the driver to the power amplifier stage. A line which is one half wave or a multiple of one half wave long at carrier frequency will act as a direct connection, while a line length of one quarter wave or odd multiple of a quarter wave will have poor regulation. Because the matching circuits at the driver and at the amplifier influence the effective length, it is not ordinarily practical to measure the line length except for approximate results. In stubborn cases, it is necessary to change the line length in small increments to arrive at the optimum length. The need for this procedure increases with higher-frequency channel operation to the extent that at UHF some line connections incorporate built-in "line stretchers" to facilitate adjustment of line lengths. Line connections between r-f driver and the grid of a modulated stage may also be found critical to length.

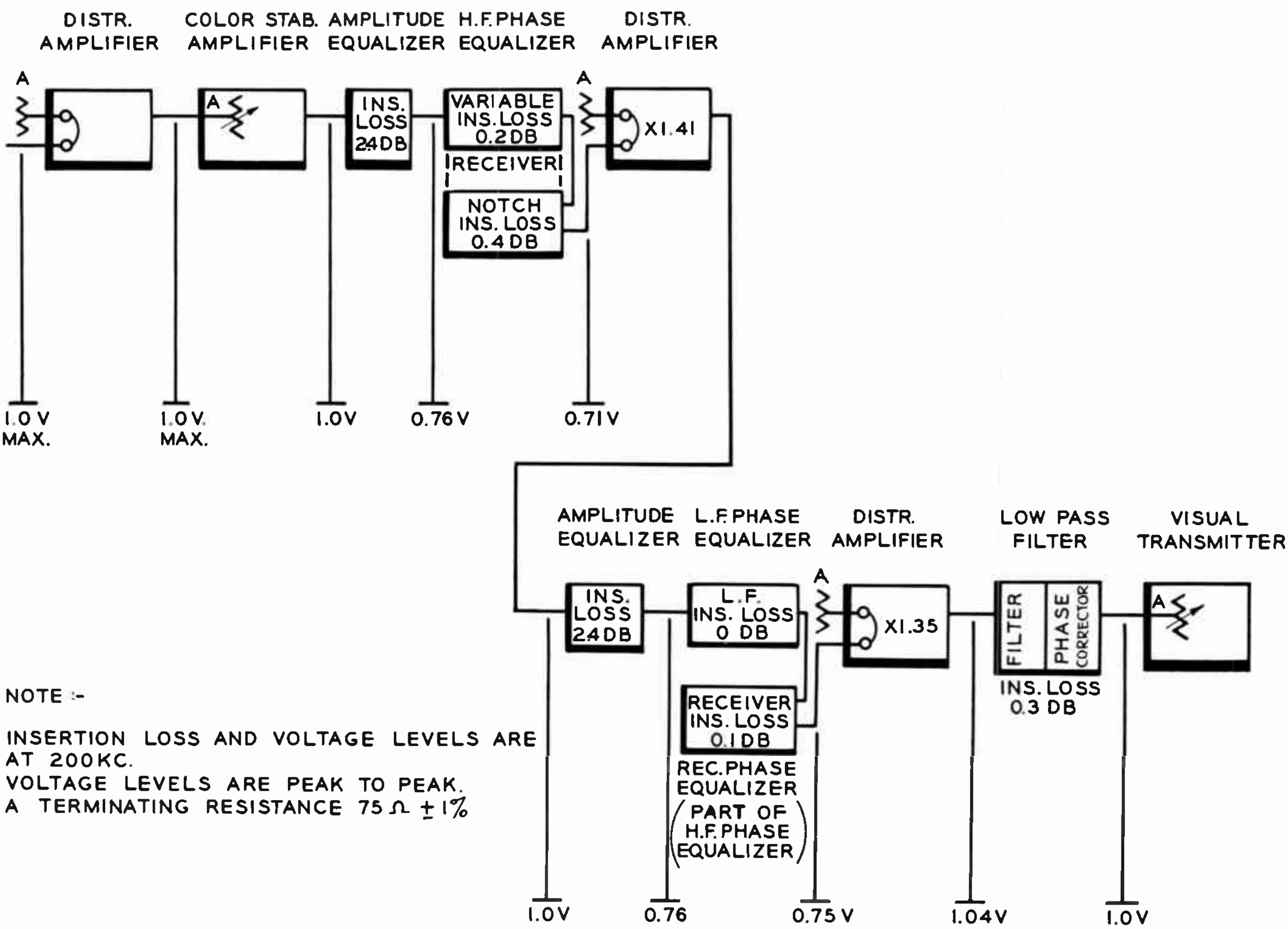


FIG. 5. Block diagram of transmitter video input equipment.

In every case, adjustment of line length will also have an influence on differential gain and phase as well, and all of these factors should be taken into consideration at one time.

Differential Gain Measurements

Differential gain, as previously described, is a change in gain with signal level. This is a more precise way of specifying linearity than to define the parameter in terms of input/output curvature. Differential gain measurement requires use of a linearity checker which provides a high-frequency signal of low amplitude superimposed on a low-frequency signal of large amplitude. The low frequency signal serves to shift the operation point for the high frequency between black level and white level. Provision is made at the output of the equipment under test for removal of the low frequency component so as to make variations in level of the high frequency component more easily discernible.

The linearity checker is completely described in Part Twelve of this manual. It generates horizontal sync pulses, and in the interval between pulses produces a stair step wave with an adjustable number of steps to move the operating point from black level to white level. The unit also contains a crystal controlled oscillator which provides a high frequency, color carrier that can be keyed on the output signal during the step interval. A simple filter removes the step wave at the output of the equipment under test.

It should be mentioned that in the event a transmitter is subject to change in frequency response with signal level, the differential gain measurement technique to be described will not be entirely reliable because it is predicated on a fixed frequency response. If differential frequency response is present, blind use of the test signal will result in linearity of color information at the expense of poor linearity for luminance information. If the test signal is set up with care so that each step of the step-wave is uniform in size, the relative amplitude of color carrier to each step will be constant on the input signal. Inspection of the output step wave after linearity correction will show agreement in relative amplitude of color carrier to step amplitude provided there is no serious difficulty with differential frequency response.

In the measurement procedure, the test signal is introduced at the stabilizing amplifier input, unless the transmitter itself has provision for white stretch. The output signal should be taken from a monitoring rectifier, taking care to see that the rectifier has sufficient r-f drive to provide maximum rated video output. This assures the most linear operation of the rectifier. Modulation of the color carrier on the step wave probably will appear only half that on the input wave as the lower sideband is normally filtered off at the transmitter output. The white stretch controls of the stabilizing amplifier should be adjusted in accordance with the instruction book for the type of equipment in use. There are usually three controls for this purpose, each of which takes effect at a different rate. It is customary to begin with the control giving the most gradual curvature. Then, the middle control can be set, and finally, the last of the curvature at white level can be removed with the third adjustment. It is quite probable that before the third adjustment is reached it will be obvious that the first estimate of input signal level was over ambitious, and white level will have gone off the scale on the oscilloscope. This of course requires a fresh start. With a little practice, this becomes a rather simple adjustment.

White stretch is normally accomplished by using adjustable biased diodes to shunt resistance across an unbypassed cathode resistor, thus increasing the gain of an amplifier tube in the video circuit. The point in the signal at which each diode begins to conduct is set by individual bias controls. A different value of resistance is used in series with each diode to graduate the change in gain produced by each unit. When the diodes are not conducting, there is a small amount of distributed capacity across the cathode resistor. As the control diodes begin to conduct, there is a reduction in the value of effective cathode resistance with very little increase in capacity. This change in phase angle with change in signal level produces a change in phase shift with signal level in the white stretch stage. This effect, which has been called differential phase shift is brought under control in this case by placing an adjustable capacity across each diode load resistor. These capacities must be adjusted for best performance of the circuit.

If the stabilizing amplifier is used to provide white stretch, it may be convenient to measure its performance in this respect before setting the white stretch circuits. This can be done by passing a test signal through the amplifier and setting its gain control so that the output signal is of the order of 1.5 volts peak-to-peak with maximum white stretch for all three circuits. Turn each white stretch control to the zero stretch position. Connect a WA-6 Color Analyzer to the amplifier output and observe the differential phase pattern as each control is advanced for maximum stretch. Set the compensating capacity of each stretch control so that as it is advanced the best compensation is obtained. If maximum compensating capacity appears too little, add fixed capacity across the variable capacity until best results are obtained for each individual white stretch control. The white stretch for the transmitter can then be set. Recheck the differential phase shift of the stabilizing amplifier alone, and "trim" settings of the differential phase compensating capacitors for best operation without disturbing the position of the white stretch controls.

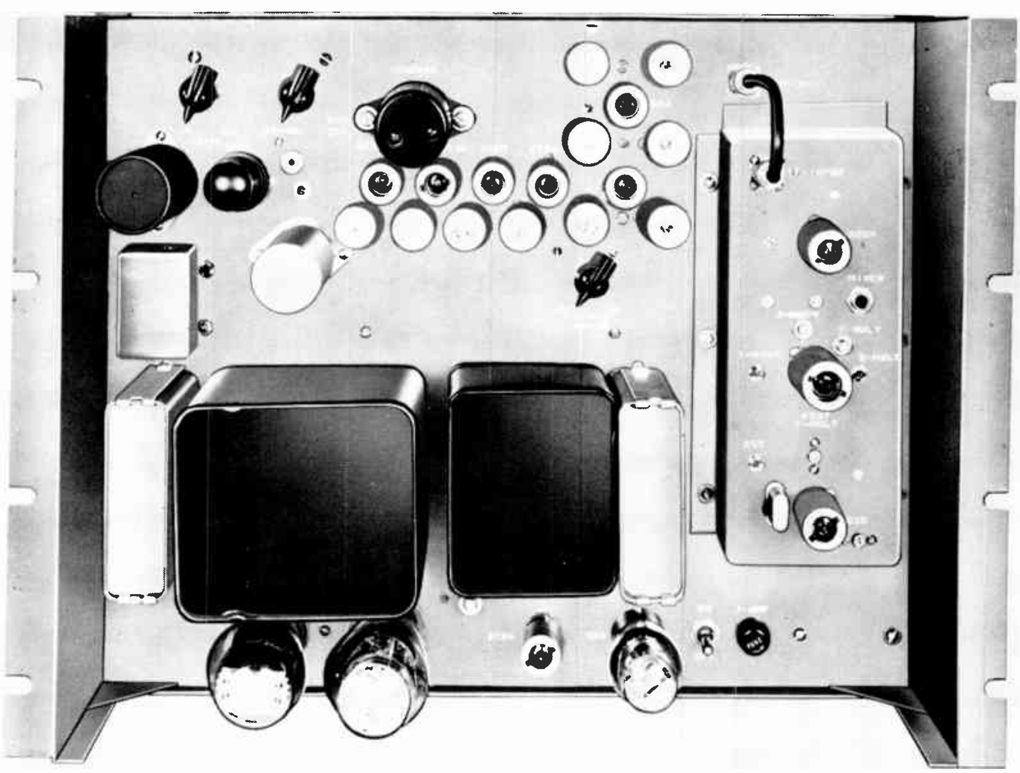
A point that should be kept in mind regarding white stretch compensation is that once a compensating curve is set up it will be correct only as long as the gain of the following circuits remain the same. In other words, if stabilizing amplifier white stretch is used, the gain control at the transmitter input and on the distribution amplifiers must not be changed. Transmitter depth of modulation, must be adjusted using a gain control which precedes the white stretch circuit.

Differential Phase Measurements

Differential phase measurements are made using the same test signal as for differential gain measurements previously described. In the test signal there is no phase shift of the color carrier between black level and each step of the test signal. This can be confirmed by use of the color analyzer which is a companion equipment to the linearity checker. The color analyzer contains circuitry which removes the step wave and passes the signal through a phase detector, which in effect compares the phase of color carrier on each step with an adjustable reference phase. Observation of the test signal should reveal a d-c output from the phase detector which is the same on each step. During the sync interval there is no output from the phase detector. By use of the coarse and fine phase controls to adjust the phase of the reference color carrier, the voltage on the steps can be brought to the same value as exists during the sync interval. When measuring the differential phase of a piece of equipment the phase on the steps will not be constant unless the performance of the equipment under test is perfect. Since this is seldom the case, the output of the phase detector changes from one step to another. By use of the reference phase controls the sync interval can be made to line up with the lowest step in the differential phase presentation. The reading of the calibrated phase control setting should be noted, and the reference phase then shifted using the calibrated controls so that the sync interval will now line up with the highest step in the phase presentation. Again, the phase control setting should be noted. The difference in the two settings is the differential phase shift.

When making differential gain and differential phase measurements the step wave should be set up to give correct modulation of the transmitter. Normally the last step of the step wave will be at white level and the level of the color carrier on the test signal will be set to fill the step, peak-to-peak amplitude equal to two steps. In measuring differential phase the output signal of the transmitter should be taken from the monitoring diode. As was mentioned previously the transmission line lengths between driver and power amplifier and between RF driver and the grid of the modulated stage may have considerable influence on differential phase readings. There also have been occasions where tuning the coupling circuit to the monitoring diode so as to make it accept carrier and sidebands but discriminate against harmonics has cut differential phase readings to one half the value without tuning. If this is attempted care must be taken

FIG. 6. Type BW-4B Television Demodulator.



to make sure that the pass band of the tuned circuit used is broad enough to accept the whole signal without attenuation of sidebands.

In making differential phase measurements a measurement should be made which will be representative of FCC requirements which are stated in terms of fully saturated color of 75% amplitude. This may be approximated with the step signal in the following manner.

A test signal with 10 steps between black level and white level has been in use. The step wave should be decreased in amplitude so the last step now falls where step 8 used to be. The amplitude of the color carrier is then increased so that the color carrier reaches white level at the top step. In terms of IRE scale units (100 divisions from black to white level) the last step will now be at 80 IRE units and the peak-to-peak color carrier will be 40 IRE units. In making tests of differential phase shift on a transmitter it is usually most convenient to set the linearity checker so it will repeat the test signal after each horizontal synchronizing pulse. This gives a bright picture which can be synchronized on the oscilloscope with maximum ease. However, in order to have complete data, measurements should also be taken with the step signal set to appear only one in ten lines. The level of blanking in the lines with no step signal is then adjusted and readings may be taken with blanking set near white level and another set taken with blanking set near black level. This procedure will indicate whether AC coupled stages in the modulator, distribution amplifiers or stabilizing amplifier change in their contribution to differential phase depending on shift of operating point as the picture changes from predominantly black to white.

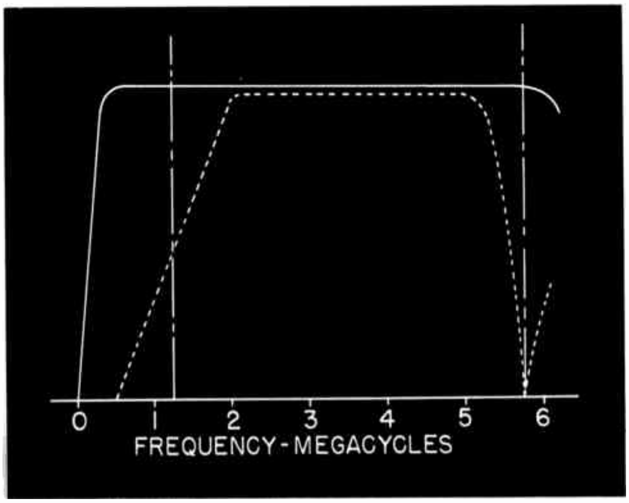


FIG. 7. Output response, with notch (after sideband filter) shown in dotted lines.

Envelope Delay Adjustment

After the foregoing transmitter adjustments have been completed it is possible to make tests to arrive at the proper setting of the controls on the envelope delay equalizers. For this purpose a demodulator must be used to obtain a video signal from the feed line to the antenna. The demodulator must be compensated for its own delay characteristic and the radio frequency pick up from the antenna feed line should be by means of a properly adjusted directional coupler so as to respond only to power going to the antenna. The RCA BW-4B TV Demodulator is available for this use. When making these measurements the sound transmitter should be turned off, the receiver delay equalizer, which is part of the high frequency delay equalizer, should be switched out of circuit and the sound notch of the BW-4B Demodulator should be switched out of circuit. These conditions call for a uniform delay in the transmitter and provide the best available accuracy of delay compensation of the BW-4B. After all adjustments have been made the receiver delay equalizer may be switched back into the circuit with good assurance that the overall transmitter than will meet FCC specifications with regard to envelope delay, within the accuracy of the transmitter adjustment. When the BW-4B is used as a program monitor with its sound trap in circuit the delay introduced by the sound trap is well compensated by the receiver delay equalizer in the transmitter, though the accuracy is not as good or as reliable over a period of time as the setup suggested for delay measurement.

The delay equalizers should be set up with a preliminary trial adjustment. As noted above the receiver equalizer should be switched out. The variable equalizer may be switched in and the delay knob set at 3. The fixed delay of the variable equalizer is optional. The notch equalizer is used only if the transmitter antenna feed circuit uses a filterplexer or notch diplexer. If either of these coupling systems is used, switch the equalizer in. Whether curve A or curve B is used must be determined from measurement. The low frequency delay equalizer should be placed in circuit and set at position 1 for a first estimate.

The most convenient method of adjusting delay equalizers makes use of a 100 KC square wave as a test signal. The general procedure is to adjust the delay equalizers while observing the shape of the output pulse from the demodulator until it best resembles the input test signal. In theory the pulse may be considered as composed of a fundamental frequency dependent on its repetition rate plus a great number of harmonic frequencies. If the same pulse shape is to appear at the output of the equipment under test, several requirements must be complied with. The frequency response must be flat so that all components will have the correct amplitude. All frequency components of the pulse must be delayed by an equal time so that the phase relationship of the com-

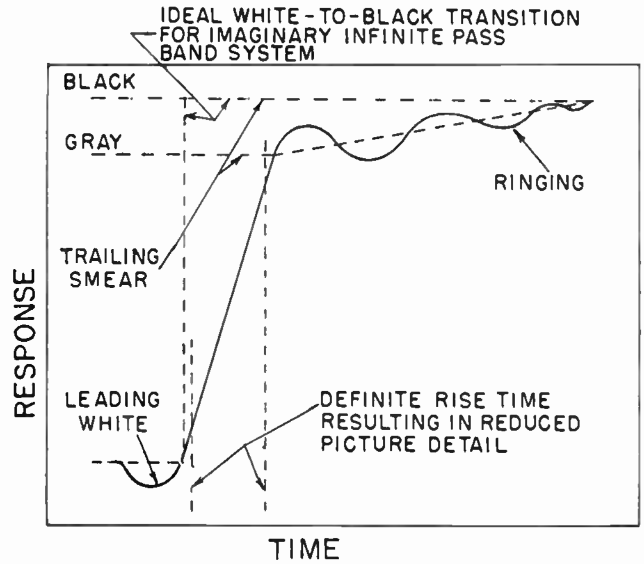


FIG. 8. Typical square wave response.

ponents will be as in the input signal. No new components may be added. All, or nearly all the components must be transmitted.

Obviously some care must be exercised to be certain, when delay adjustments are made, that the output signal distortion is the result of delay distortion and is not caused by failure to comply with other requirements. The frequency response can be made flat over the video band to 4.2 megacycles. The cut-off at 4.2 megacycles can be evaluated for its effect on the test signal by observing the test signal after passing it through the compensated low-pass filter which is part of the transmitter video input equipment. The output pulse obtained at the demodulator after best compensation has been effected should look like this pulse. Fig. 9 is a photograph of a 100 kc square wave after transmission through such a filter. The adjustment of the delay equalizers will effect the rise time of the square wave and the ringing preceding and following the transition. When best equalization is obtained the ringing will be symmetrical about the transition and of minimum amplitude.

White Compression

The remaining source of distortion that would affect the shape of the pulse from the demodulator is that resulting from non-linearity, or the generation of added frequencies. There are two major sources of this form of distortion. One is white compression which is compensated, for program operation, by the white-stretch circuits of the color stabilizing amplifier. The other is quadrature distortion which results from demodulation of a single sideband signal at the second detector of the demodulator. Both of these sources of distortion may be minimized for delay testing by operating the transmitter near black level with the modulation depth restricted to something in the order of 15 percent of the carrier. The delay equalizers are intended to compensate for normal effects that are present in properly functioning circuits. They cannot correct for poor frequency response, defective cable or connections, improper choice of cable, poor terminations of video or radio frequency circuits, defective tubes or circuit components, nor maladjustment of equipment. All of these factors must be carefully eliminated before attempting to adjust the delay equalizers.

It should be kept in mind that work on the transmitter, though carefully done, will still not produce a perfect picture on a monitor or home receiver *under all picture conditions*. The quadrature distortion occuring at the video detector of the receiver is a factor in all receivers presently available. This effect is small for small changes in picture luminance near black level but can become quite noticeable if the picture content results in near complete modulation of the signal as for sharp white characters on a black background or black characters on a white background. This type of distortion may be eliminated by the use of exalted carrier to reduce the effective depth of modulation or through the use of special detector circuits. It is a factor which can be brought under control in the laboratory now. Circuits may soon be available for general application.

The circuits of each BW-4B Demodulator are carefully adjusted at the factory to complement its delay equalizer. Field alignment should not be attempted, because wing trap and sound trap adjustments are particularly critical.

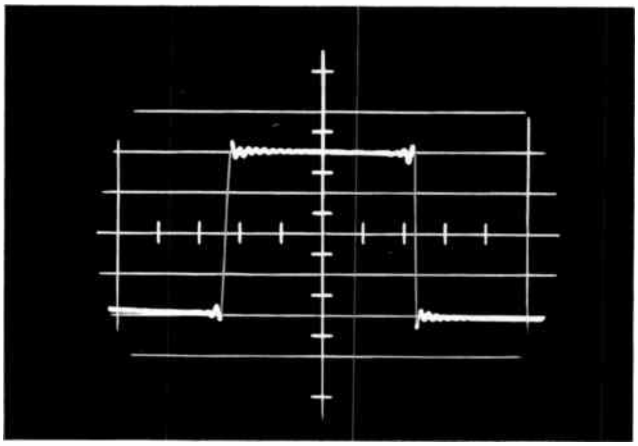


FIG. 9. 100-KC square wave after transmission through compensated low pass filter.

PART 11

Associated Equipment

Video Tape Recorder · Microwave Relay
Mobile Units · Microwave System Planning

Color television equipment such as the video tape recorder and the mobile studio unit are valuable adjuncts to the color station's programming facilities. The tape recorder provides a convenient means for quickly recording color or monochrome program material for use at selected times; while the mobile unit is virtually an outdoor studio and control room which can be maneuvered quickly for "on-the-spot" local programming; portable microwave units, in this case, providing the link for relaying remote pickups back to the studio or transmitter.

STL microwave equipment, on the other hand, performs a basic function in certain broadcast installations. In those plants where studio and transmitter are separated geographically, microwave STL equipment can be installed to provide a permanent, high quality program link between the studio and transmitter. In other applications, the STL is used as a permanent link to relay network programs from a distant trunk line.

Color Video Tape Recorder

The RCA Video Tape Recorder provides a means of recording and immediately playing back either color or monochrome video signals simultaneously with program sound. It will reproduce both video and audio signals with quality and fidelity that rival closely that of the original program material.

Tape speed is 15 inches per second which is the same as that used in professional audio recorders. A standard 12½-inch reel containing 4800 feet of tape provides 64 minutes of recording time; a one-hour recorded program will play back in one hour plus or minus a small fraction of a second. Special provisions have been included for editing and splicing tape as well as for playing back spliced tape. A tape footage counter facilitates logging of the exact position of any recording on the reel. This and the continuously variable rewind/fast forward speed control are very useful in cuing. Voice or special signals that might be required for control of the recorder in an automatic programming system can be recorded on a separate cue channel provided.

Basic Recording Principles

The storage medium of the video tape recorder consists of a two-inch wide tape made of 0.001-inch-thick mylar base with an 0.003-inch magnetic oxide coating. At the time of tape manufacture, the magnetic particles are oriented in the transverse direction, i.e. across the width of the tape, instead of in the logitudinal direction as in audio tape. Video tape is oriented transversely because the recorded video tracks are at approximately a 90-degree angle with respect to tape motion. This transverse orientation gives a playback signal level which is about 6 db higher than that obtained with logitudinal orientation.

Figure 1 is a photograph of the actual tracks recorded by the video tape machine. This photograph was made by immersing the recorded tape in a volatile suspension of very fine carbonyl iron particles, whereupon the iron particles adhered to the magnetized areas. The tape was pulled out and after it had dried, the iron particles were lifted off with transparent adhesive tape. This results in a permanent display of the recorded tracks which can be readily photographed. The transverse video tracks can be seen very clearly with the white thin transverse areas being the separation between successive tracks. The program audio track is on the left with the control track and cue track on the right. The control track is discussed in a later paragraph.

The signal in the video tracks is a frequency modulated one. FM deviation is roughly 5 to 6 mc and the

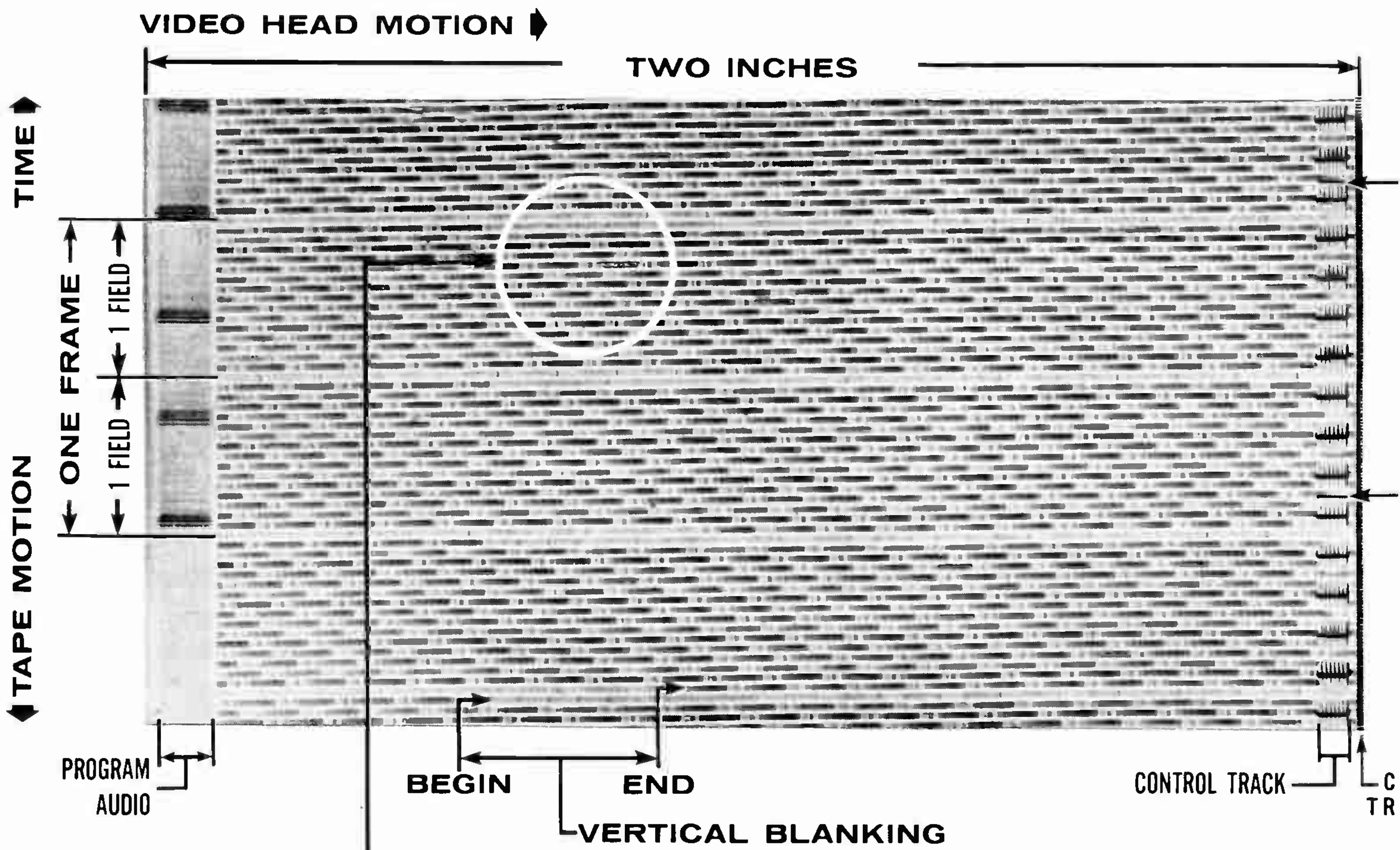


FIG. 1. Display of actual tracks as recorded by the RCA Color Video Tape Recorder.

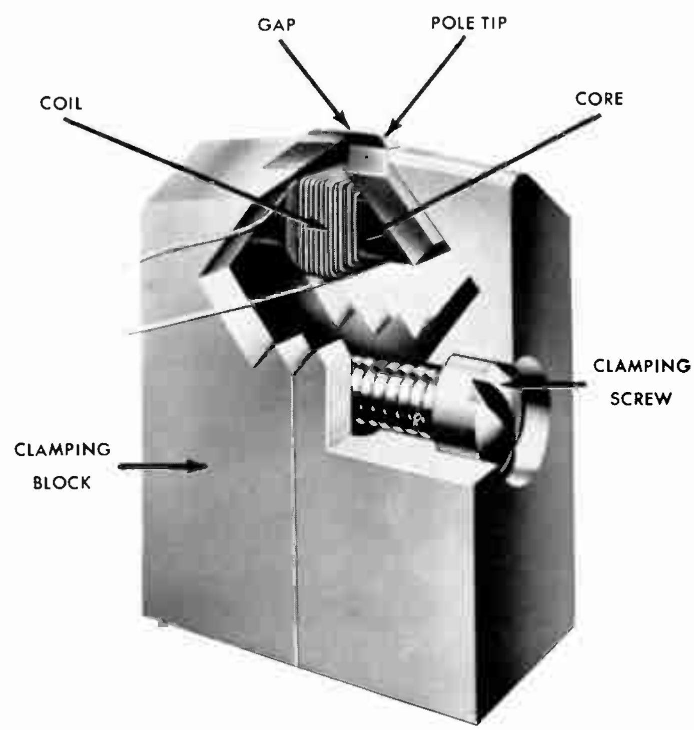


FIG. 2. Enlarged sketch of the magnetic video head assembly. Four of these heads spaced 90 degrees apart are mounted in a two-inch diameter wheel as shown in Fig. 3.

signal is essentially single sideband. Because of this, there is a small amount of amplitude modulation present. This accounts for the fact that the horizontal sync pulses and vertical blanking interval can be seen in Fig. 1. It is necessary to use FM in the recording and playback process so that tape signal amplitude variations which could result from slight errors in playback head tracking along the recorded track, or from any differences in output between the four magnetic heads, can be taken out by limiting.

The mechanism for recording the transverse video tracks consists of a two-inch diameter wheel with four magnetic heads spaced 90° apart (see Fig. 3). The tape is curved along its width by means of a vacuum shoe which holds it in a perfect arc about 113 degrees long. Details of the assembly are shown in Fig. 4. The arc distance between program audio and control tracks is about 100 degrees. The plane of head wheel rotation is perpendicular to the motion of the tape so that as the wheel rotates at 14,400 rpm (240 rps) and the tape is pulled through at 15 inches per second, transverse tracks are recorded with a pitch of 0.0156 inches (15.6 mils). The width of the head and hence the width of the track is 10 mils with a 5.6 mil blank space between. The length of one TV line along this track is about 5.5 degrees of arc or 0.1-inch; therefore, a total of 18.4 TV lines is recorded on each transverse track. While the number of TV lines used on playback is only 16 or 17 depending upon their position on the track, 18.4 lines are recorded in order to allow suitable overlap of information for reliable switching between heads during the horizontal blanking interval. One TV frame (525 lines) comprises 32 transverse tracks or one-half inch of tape motion. The distance between vertical blanking periods is 16 tracks or ¼ inch.

The magnetic video head is a tiny assembly held together by two much larger non-magnetic clamping blocks. A highly magnified sketch of the assembly is shown in Fig. 2. The recording/playback gap is formed by a 100 micro-inch spacer held between the alfenol pole tips. The flat area formed by the top of both pole tips is 0.010-inch wide and 0.060-inch long.

The main tape guide posts do not rotate; instead, air is forced through very small holes in the post so that the tape rides over the post without touching it, except at the edges where flanges are used to guide the tape. The advantages of this method are that the tape is very accurately guided, and only a minute amount of guiding pressure is required, protecting the edge of the tape from damage.

Equipment and System Design

The complete color video tape recorder is contained in six standard cabinet racks as diagrammed in Fig. 8. The tape transport panel is conveniently located at eye level between the control panel and oscilloscope on the

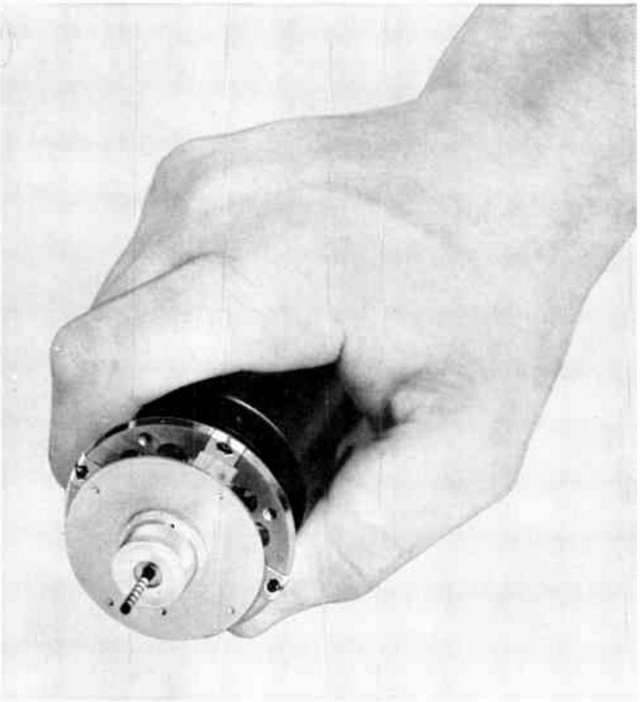


FIG. 3. Mechanism for recording the transverse video tracks. Slip-rings provide connections to the four magnetic heads.

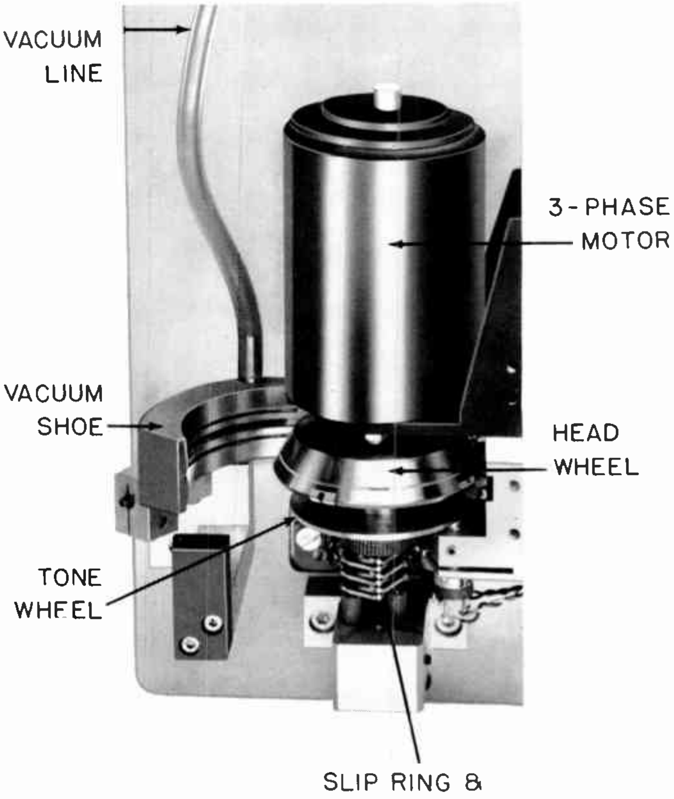


FIG. 4. View showing details of the tape panel assembly.

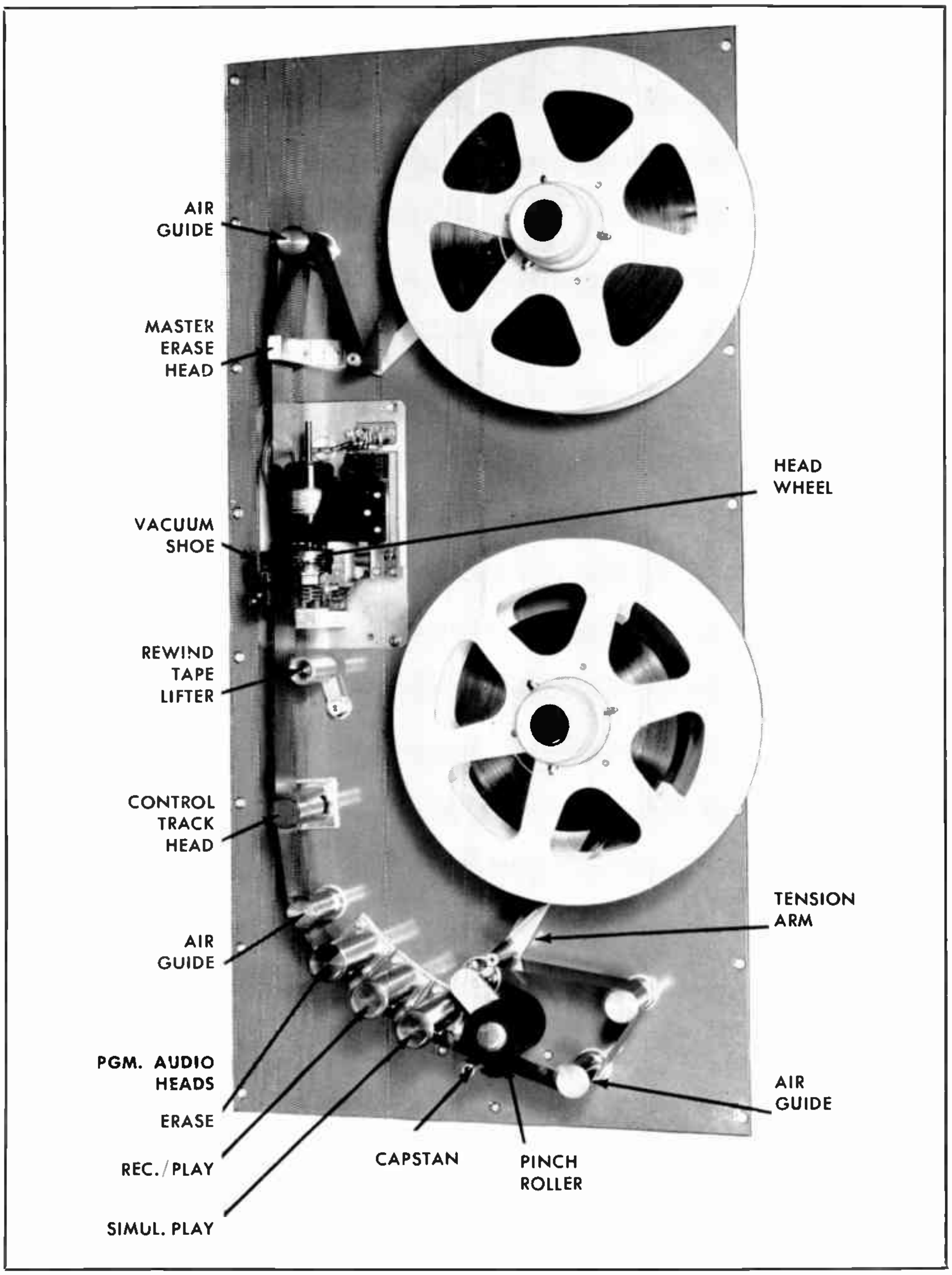


FIG. 5. Tape Transport Panel.

right, and the picture monitor on the left. These three racks associated with the tape transport must remain together; however, the other three racks containing the color processing equipment, servo amplifiers and power supplies can be remotely located. Also, operating control can be delegated at the master control panel to a remote control panel if desired.

To provide a high degree of operational flexibility during recording and playback, signal monitoring facilities in the form of meters, waveform oscilloscope and picture monitor presentations have been built in. A CRO switcher permits selection of a number of important signals for display on the oscilloscope. Similarly, other switches allow display of video input, monochrome output and color output pictures on the monitor.

Figure 6 is a simplified block diagram of the complete video tape recorder. The functions of the block referred to as the "video system" are diagrammed in Fig. 10.

Recording Cycle

In following this description of the recording cycle, reference should be made to Fig. 6 which indicates the functions of several of the various assemblies of the recorder. It should be assumed, of course, that the two switches which are drawn in the "play" position are changed to "record."

The principle function of the supply and take up reels during the record cycle is to provide proper tape tension; the tape is actually driven by the capstan assembly. Supplied with a constant amplitude 60-cycle voltage, the capstan motor drives the tape at a constant rate of 15 inches per second. At the same time, the speed of the head wheel is controlled by the head wheel motor and servo to 14,400 rpm or 240 rps. This is accomplished by comparing the frequency and phase of the 240-cycle tone wheel pulse with a reference 240-cycle pulse. If there is an error in the tone wheel signal, the servo amplifier adjusts the head wheel motor speed so as to remove the error. As the diagram shows, the 240-cycle reference pulse is actually derived from video. How the reference generator and the editing pulse are used to facilitate tape splicing is described in a later paragraph.

The tape is held in an arc by the vacuum shoe and the 4 magnetic heads in the wheel scan across the tape at the rate of 960 scans per second. The linear scanning speed of the heads is nearly 90 miles per hour. Good head-to-tape contact is maintained by virtue of the fact that the head pole tips extend about .004 inch above the wheel rim and are caused to protrude into the tape.

Before the tape gets to the head wheel it first passes over the master erase head which cleans the entire two inch width. The clean tape then passes between the vacuum shoe and head wheel where the video signal on its FM carrier is recorded. The motor shown connected to the vacuum shoe is not active during record. the shoe being locked in position. The tape next passes over the control track head where a 240-cycle sawtooth signal is recorded. This signal will be used later during playback to insure that the video heads scan along their recorded tracks. The 30 cycle frame pulse, which is only about 100 microseconds wide, is merely added to the sawtooth. This does not interfere with the subsequent tracking operation but is used later for tape splicing.

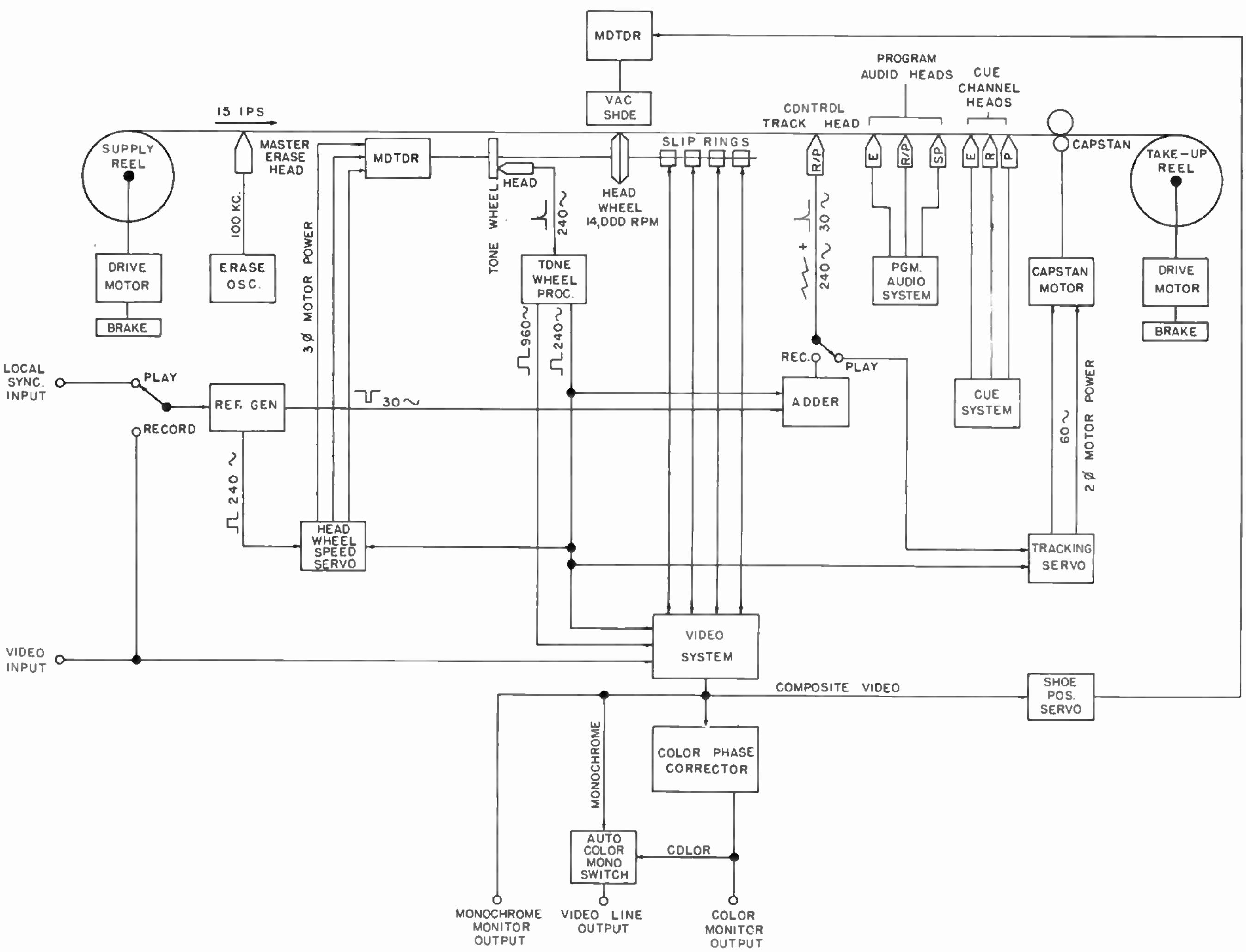


FIG. 6. Functional block diagram of color tape recorder.

Next, the program audio track is recorded, the area first having been erased by a separate erase head which is a little wider than the following record head. The simultaneous playback head which is right next to the record head allows the operator to monitor the signal being recorded.

On the other edge of the tape the cue channel record head provides a means for recording suitable cue information. This can be in the form of verbal cues or some form of signal which could later be used for control of the tape machine in an automatic programming operation. A special feature of the cue channel is that it can be either in the record or playback mode regardless of the mode of operation of the tape machine. This allows the recording of cue information while playing back or previewing the video signal.

As mentioned previously, the composite video signal is on an FM carrier which is recorded on the tape. With reference to Fig. 10, the incoming video signal goes directly to a frequency modulator whose carrier frequency is about 30 mc. The resulting FM signal is heterodyned with a 35.5 mc local oscillator which results in a final FM signal having a carrier frequency of about 5.5 mc with a deviation from roughly 5 to 6 mc. (For simplicity, the carrier frequency is referred to as 5.5 mc. Actually, there is no "center frequency" since the modulator is clamped. That is, the tip of sync always corresponds to an instantaneous carrier frequency of about 5 mc regardless of the duty cycle of the video signal. Similarly, peak white corresponds to a frequency of about 6 mc.) It is this FM signal which is recorded on the tape. The magnetic head and tape response is such that the actual playback pass band is roughly 1 to 7 mc. Obviously this results in a vestigial sideband FM system.

FIG. 7. Control panel of video tape recorder.

The FM signal goes to a record amplifier which essentially drives all four video heads in parallel through a slip ring/brush assembly. Therefore there is no need for head channel switching during the comparatively simple record cycle.

In the playback mode, the head wheel again rotates at 240 rps by virtue of the same servo control. The only difference is that the timing reference is now local sync. The 240 cycle tone wheel pulse is the main timing signal for the rest of the machine. The most important servo function during playback is that of the tracking servo. Its function is to assure that the control track signal passes over the control track head in exactly the right phase so that the video heads are reading right on top of the transverse video tracks. To accomplish this the 240 cycle tone wheel signal phase is compared with the phase of the control track sawtooth. The speed of the capstan motor is controlled by the servo amplifier so as to cause the proper phase relationship to be maintained.

Video Playback Functions

FM signals being picked up by the four heads in the wheel are fed through the slip ring/brush assembly and the play/record switch to the video system diagrammed in Fig. 10. As seen by the diagram, these signals are fed to a four-channel amplifier and then to a four-channel equalizer. This equalizer essentially adjusts the frequency response in each channel so that the four channels are identical.

These signals are then fed to a 4 x 2 switcher. The 240-cycle tone wheel signal operates this electronic switcher so that signals from heads No. 1 and No. 3 feed out channel A, while those from heads No. 2 and No. 4 feed out channel B. Because of the 90-degree spacing of the heads, No. 1 and No. 3 never read signals at the same time, and therefore can share channel A. The same is true for heads No. 2 and No. 4, and they share channel B. There is a two TV line overlap in the transverse track signals which means that just before head No. 1 leaves the tape, head No. 2 has entered and is reading the same information as head No. 1 (except that it is near the other edge of the tape). Simularly, there is overlap between heads No. 2 and No. 3, No. 3 and No. 4, and No. 4 and No. 1. It is the function of the 2 x 1 switcher to select the final signal during these overlap periods. This is accomplished by the 960-cycle gate which identifies the overlap interval in combination with horizontal sync pulses derived from the video signal itself. The demodulator feeds the video signal back to the switcher for this purpose. The switch is made during the horizontal sync period which of course is during the horizontal blanking interval.

The composite video signal out of the demodulator goes to a sync restorer which merely clamps the signal, removes the 2 x 1 switching transients, and provides three parallel outputs. By referring to Fig. 6, it can be seen that one of these goes to the color phase corrector and another goes to the automatic switcher which in-

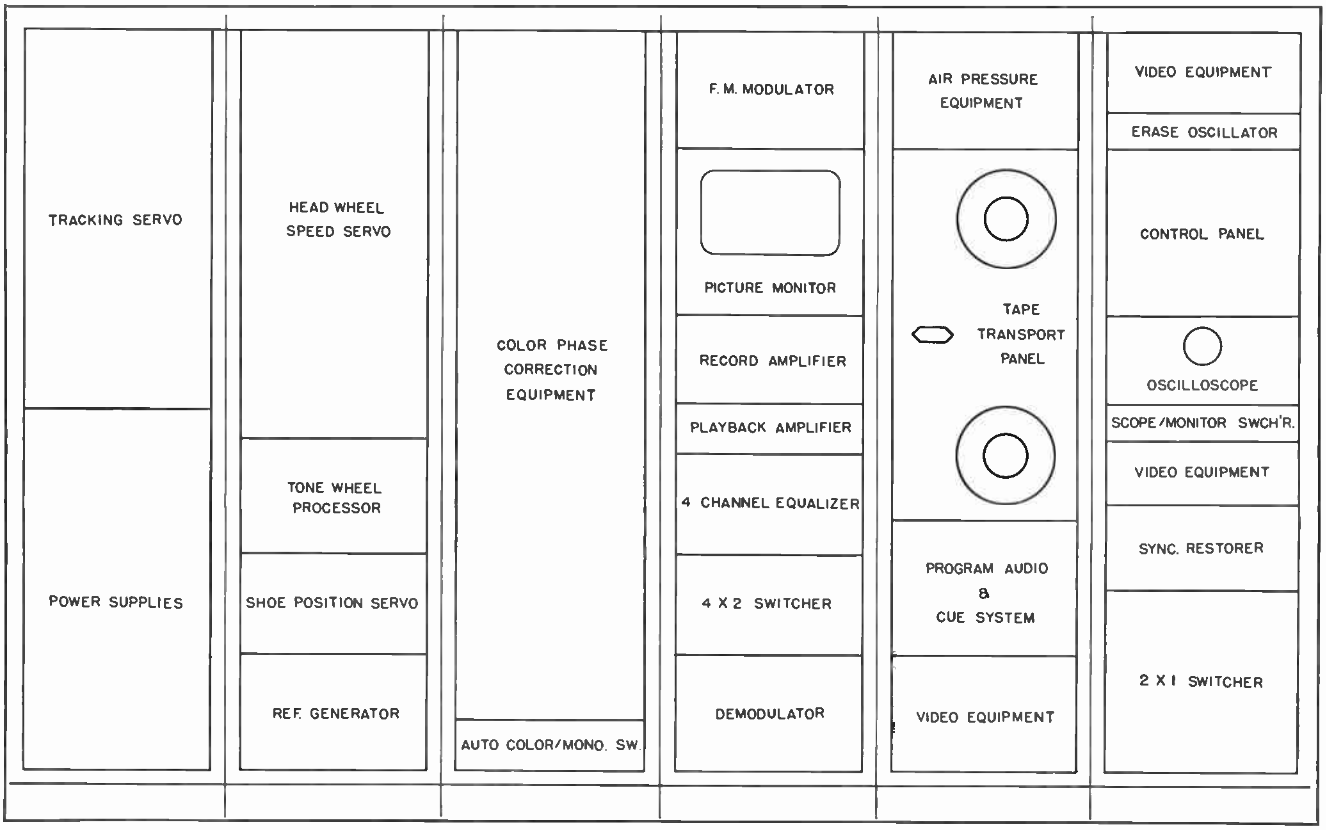


FIG. 8. Diagram showing typical layout of color tape recorder equipment in standard cabinet racks. Racks containing color processing, servo amplifiers and power supplies can be located remotely.

stantaneously selects the proper line depending upon whether the signal coming off tape is color or monochrome. This switching chassis then provides a 75 ohm sending-end terminated program line feed.

Tape Splicing

Special provisions for tape splicing have been included in the video tape recorder. As mentioned earlier, the reference generator of Fig. 6 has a 240-cycle pulse output which is derived from the incoming video signal. This pulse in conjunction with the head wheel servo causes vertical sync to always be recorded in the same position on the transverse tracks on all machines. A 30 cycle frame pulse is recorded on the control track directly below alternate vertical sync intervals, i.e., at the beginning of each frame. Actually, the frame pulse will be positioned between the two transverse tracks containing vertical blanking which is nominally 17 TV lines long. When a splice is to be made, the tape is pulled out of the head wheel/shoe assembly and the edge of the tape

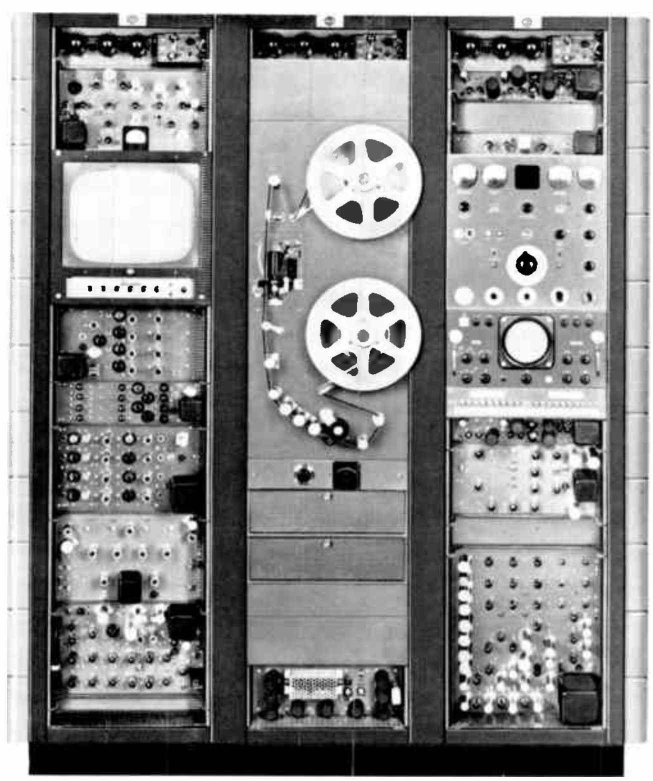


FIG. 9. Photo of the three racks shown on the right side of the diagram above.

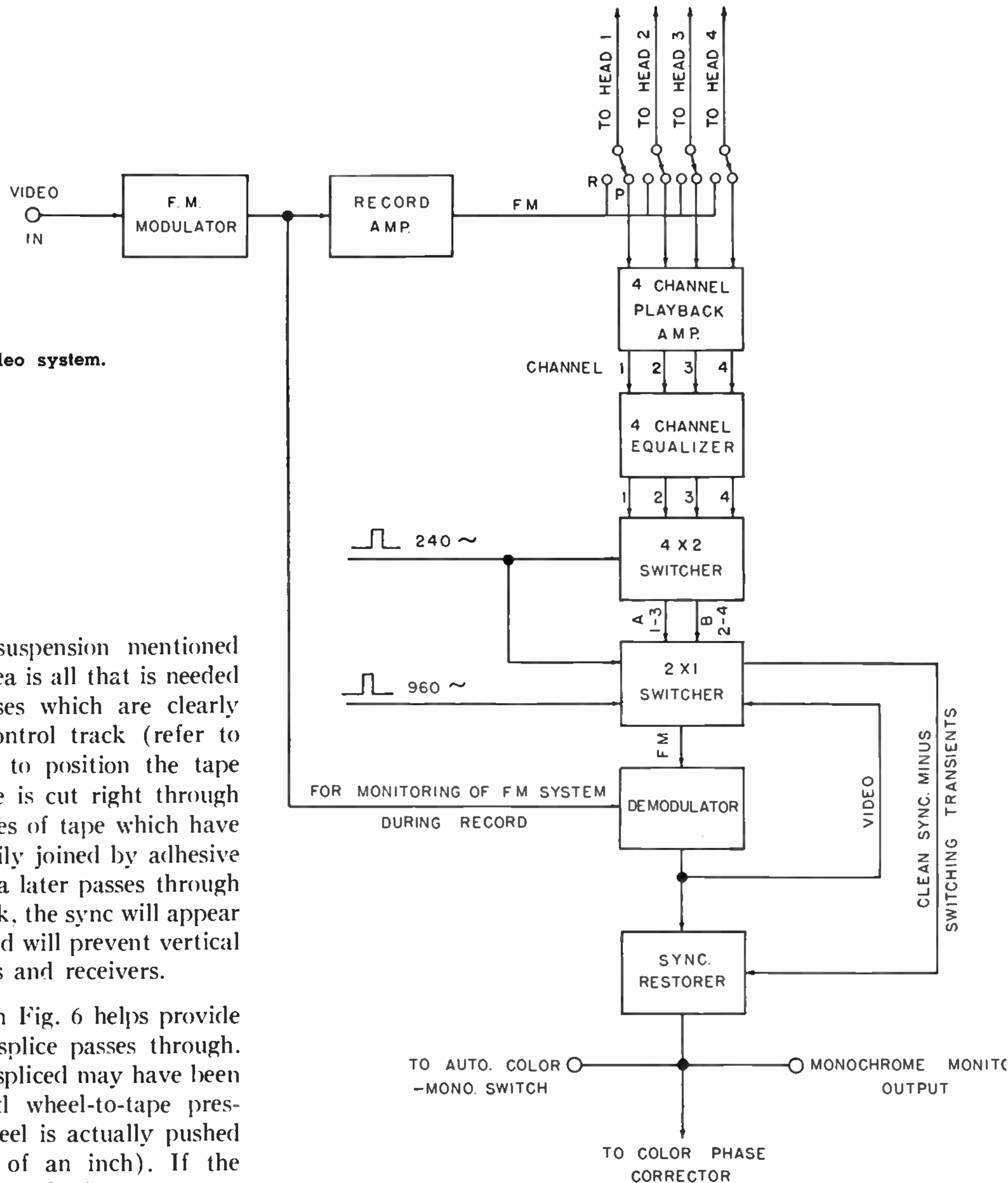


FIG. 10. Block diagram of recorder video system.

sprayed with the carbonyl iron suspension mentioned earlier. An inch or so of sprayed area is all that is needed to easily identify the editing pulses which are clearly visible every ½ inch along the control track (refer to Fig. 1). The frame pulse is used to position the tape in a simple cutter so that the tape is cut right through the vertical blanking interval. Pieces of tape which have been cut in this manner can be easily joined by adhesive splicing tape. When the spliced area later passes through the head wheel assembly on playback, the sync will appear essentially as a continuous signal and will prevent vertical rolls from occuring in TV monitors and receivers.

The shoe position servo shown in Fig. 6 helps provide a continuously usable signal as a splice passes through. The two pieces of tape which were spliced may have been recorded at slightly different head wheel-to-tape pressures (remember that the head wheel is actually pushed into the tape a few thousandths of an inch). If the transverse tape stretch (due to head wheel-to-tape pressure) is slightly off tiny jogs will appear in vertical lines in the picture. These jogs can be removed by correcting the transverse tape stretch by adjusting the head wheel-to-tape pressure. This is what the shoe position servo does by slightly moving the position of the vacuum shoe, depending upon the presence of an error signal which is derived from the playback video signal.

Color Processing

The equipment requirements for reproducing color TV signals from magnetic tape are more stringent than they are for monochrome TV signals. First, the response at the high end of the video channel must permit the chrominance information to pass. Second, a tight phase relationship between the average subcarrier burst frequency and phase and the hue modulated subcarrier must be present in the transmitted color signal.

In the RCA TRT-1AC Color Video Tape Recorder the speed of the head wheel when reproducing a recorded signal is maintained sufficiently constant to introduce very little phase shift in the color subcarrier during any given TV line. However, the phase relation in a succession of color subcarrier bursts is subject to spurious shifts due to slow, minute variations in head wheel speed and small errors in the quadrature relation of the playback heads. If, as is usually the case in color TV receivers, the local subcarrier oscillator is locked to the incoming subcarrier bursts in a manner that averages many bursts, the demodulated color signal would display hue errors as a function of the timing inaccuracies. At the present state of the speed control art, the resulting picture would be unusable.

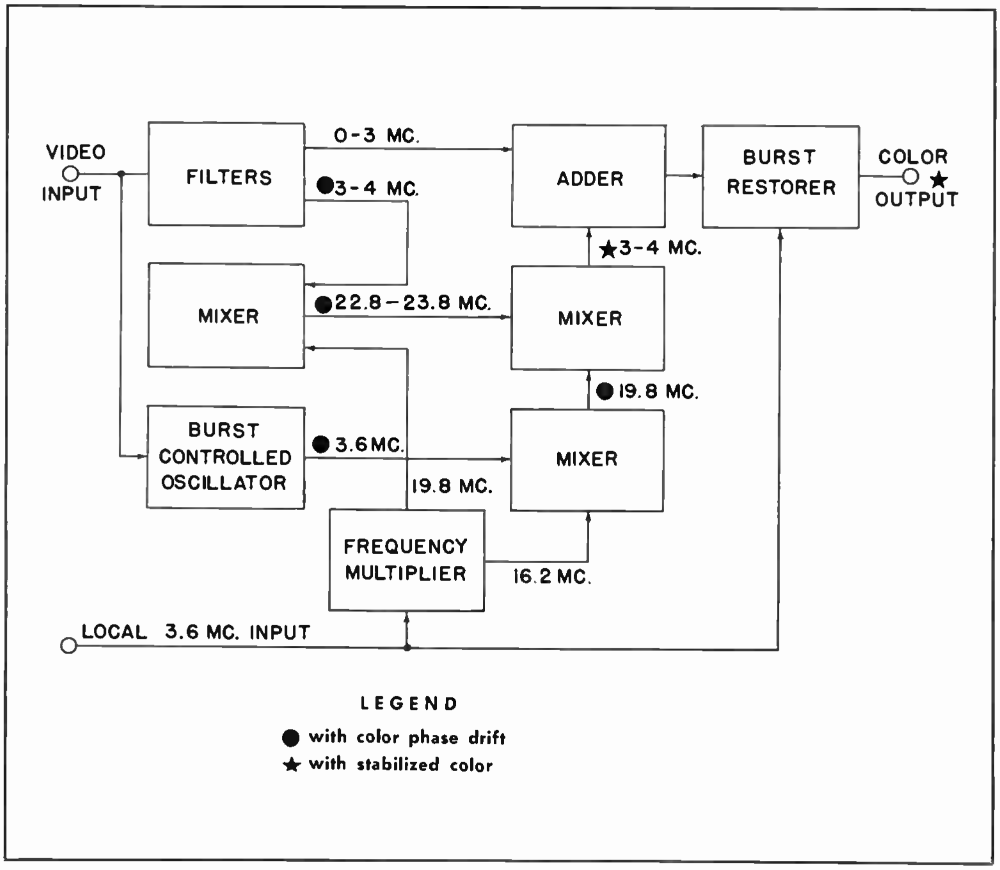


FIG. 11. Simplified block diagram of color processing circuits.

The system shown in the simplified block diagram, Fig. 11, is used quite successfully to correct for the small timing errors and thus eliminate the related color distortion. The basic technique is to cancel out color phase drift in the chrominance signal by translating this signal to a higher frequency spectrum, and then heterodyning this translated signal with a signal which also contains the phase drift and is of such a frequency that the difference signal frequencies fall back into the original frequency band. If this signal is derived from a signal recorded on the tape, it will contain the same phase-drift effects as those in the translated chrominance signal, but the difference signal obtained by heterodyning will be free of phase drift because errors have been cancelled by subtraction.

The video input signal (see Fig. 11), which contains color phase drift is divided into two frequency bands by filters. The higher frequency band contains the chrominance information. This 3 to 4 mc band of signals is translated to a 22.8 to 23.8 mc band by mixing it with a 19.8 mc signal. The 19.8 mc signal is obtained by multiplication of a local crystal subcarrier oscillator. The signal in the 22.8 to 23.8 mc band still contains the color phase drift.

The reference signal is the color subcarrier burst which conveniently is an inherent part of the color video signal. However, the subcarrier burst must be used to precisely control a local oscillator that can provide a continuous subcarrier. By using a burst-controlled oscillator which is synchronized by each burst and sustains the oscillation for the remainder of the TV line, the output subcarrier is effectively step modulated a line at a time in accordance with the color phase drift present. This signal is translated to 19.8 mc by mixing it with a 16.2 mc signal which is also obtained by multiplication from the local color subcarrier signal (see Fig. 11). Next, the 22.8 to 23.8 mc signal is mixed with the 19.8 mc signal. Both signals contain color phase drift. A difference sideband signal of 3 to 4 mc in which the phase drift has been cancelled is produced. The color stabilized 3 to 4 mc signal is then added to the 0 to 3 mc luminance signal to reconstitute the color video signal. A burst-restorer unit reinserts a new subcarrier burst to insure a clean, well-shaped burst on the output color signal.

The output signal resulting from these color-processing techniques is a composite color signal ready for transmission.

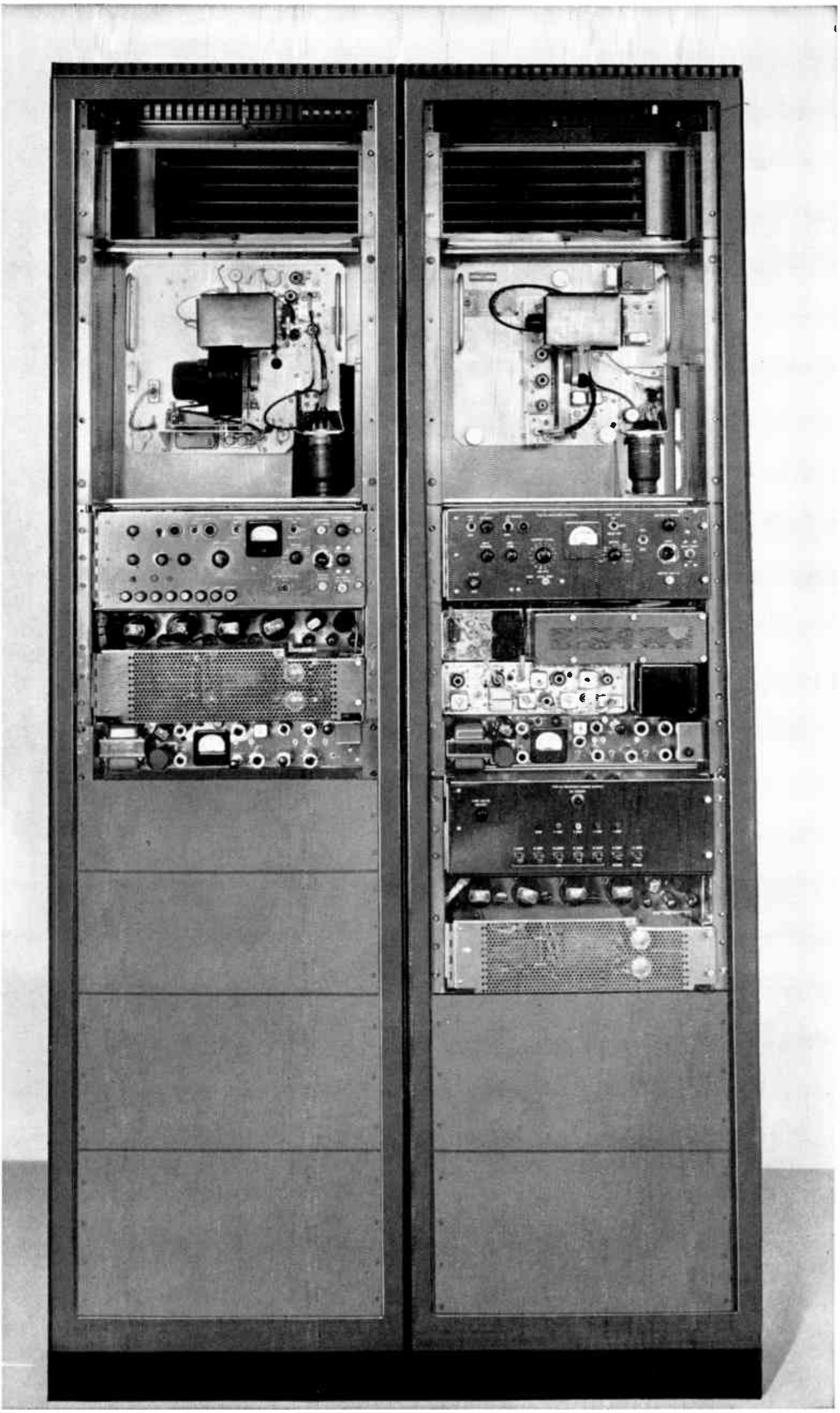


FIG. 12. TVM-1 Microwave Relay Equipment mounted in two standard cabinet racks. Transmitting equipment is installed in the rack on the left, and receiving equipment in the one on the right.

TVM-1 Microwave Relay Equipment

The TVM-1 Microwave equipment comprises a complete microwave transmitting and receiving system especially designed to provide a high quality link for color as well as monochrome television signals. It is a unique system which fulfills the rigid requirements of a fixed, unattended microwave repeater, as well as those of a compact portable station. In addition, the TVM-1 incorporates several features in styling and mechanical design. Chassis type units of the system can be mounted in standard racks for fixed operation, or in portable cases for field use.

Performance features of the system include: a transmitter nominal output of one watt (10,000 watts ERP with a six-foot parabolic antenna); six-megacycle bandwidth; provision for multihop operation; optional transmitter AFC and transmitter picture monitoring; and remotely controllable ON-AIR/standby operation.

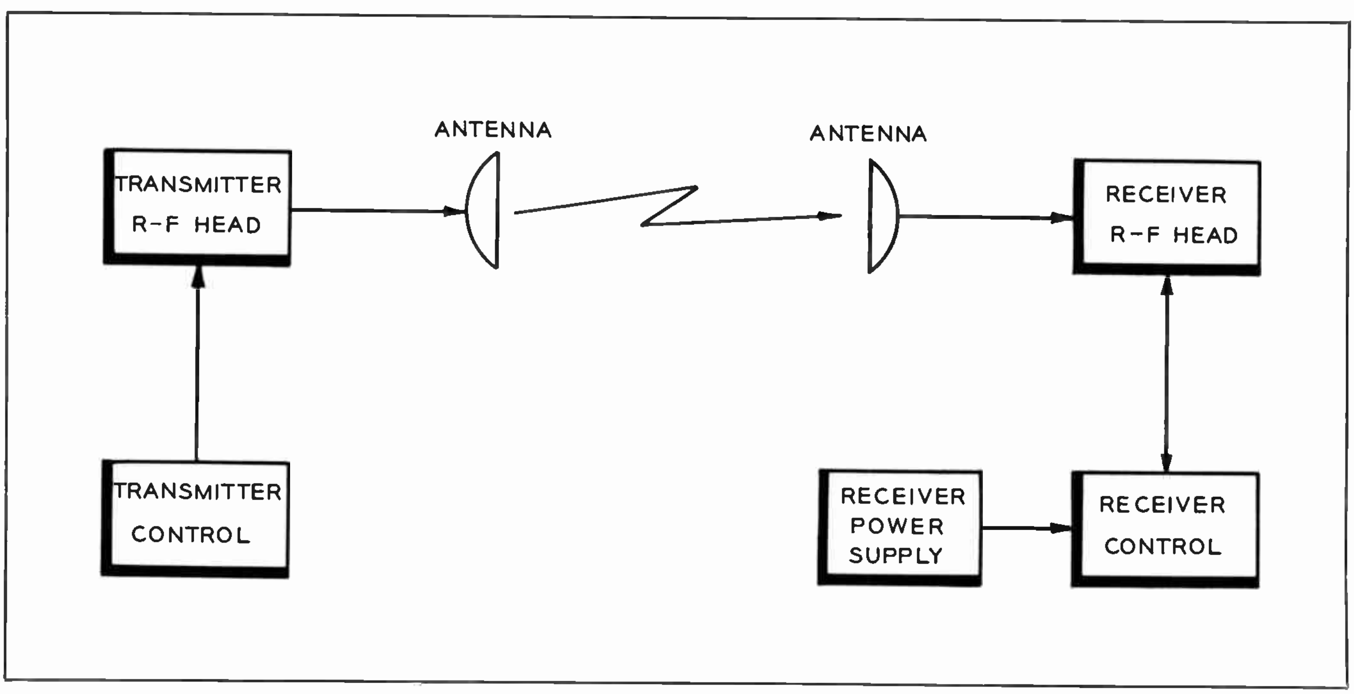
Figures 14, 15 and 16 illustrate typical applications of the TVM-1 equipment as (1) a permanent microwave relay link such as for STL service; (2) a repeater station of a multihop link; and (3) a single hop portable system for relaying field pickups to the transmitter or studio. Complete accessories are available to facilitate any of these applications. It should be mentioned that several factors enter into the planning of systems involving more than one hop or long hop distances. For a detailed discussion of this subject, reference should be made to the systems planning information presented in the latter part of this section.

The TVM-1 consists basically of five compact chassis units: transmitter r-f head; transmitter control; receiver r-f head; receiver control; and receiver power supply. These units are shown rack-mounted in Fig. 12, and a block diagram of a typical system is shown in Fig. 13. The transmitter and receiver r-f chassis can be mounted either in standard 19-inch cabinet racks or in weather-resistant, aluminum, portable cases. The cases are suitable for mounting out-of-doors on the rear of a parabolic reflector or on a tower or building wall. The control chassis and power supply chassis mount directly in either a 19-inch rack or carrying cases.

Accessory equipment, which will extend the service of the system, is also available. The accessories include: a transmitter sound modulator, a transmitter picture monitor, a transmitter AFC unit, a remotely controlled transmitter radiation switch, a receiver sound demodulator, and a wavemeter usable in either the transmitter or the receiver. In addition, a wide variety of waveguides, fittings, antenna mounts, and other mounting accessories are available as optional equipment.

All units of the TVM-1 are divided into plug-in sub-chassis which are available individually when spares are deemed necessary. All connections between units are made

FIG. 13. Block diagram of a television microwave system.



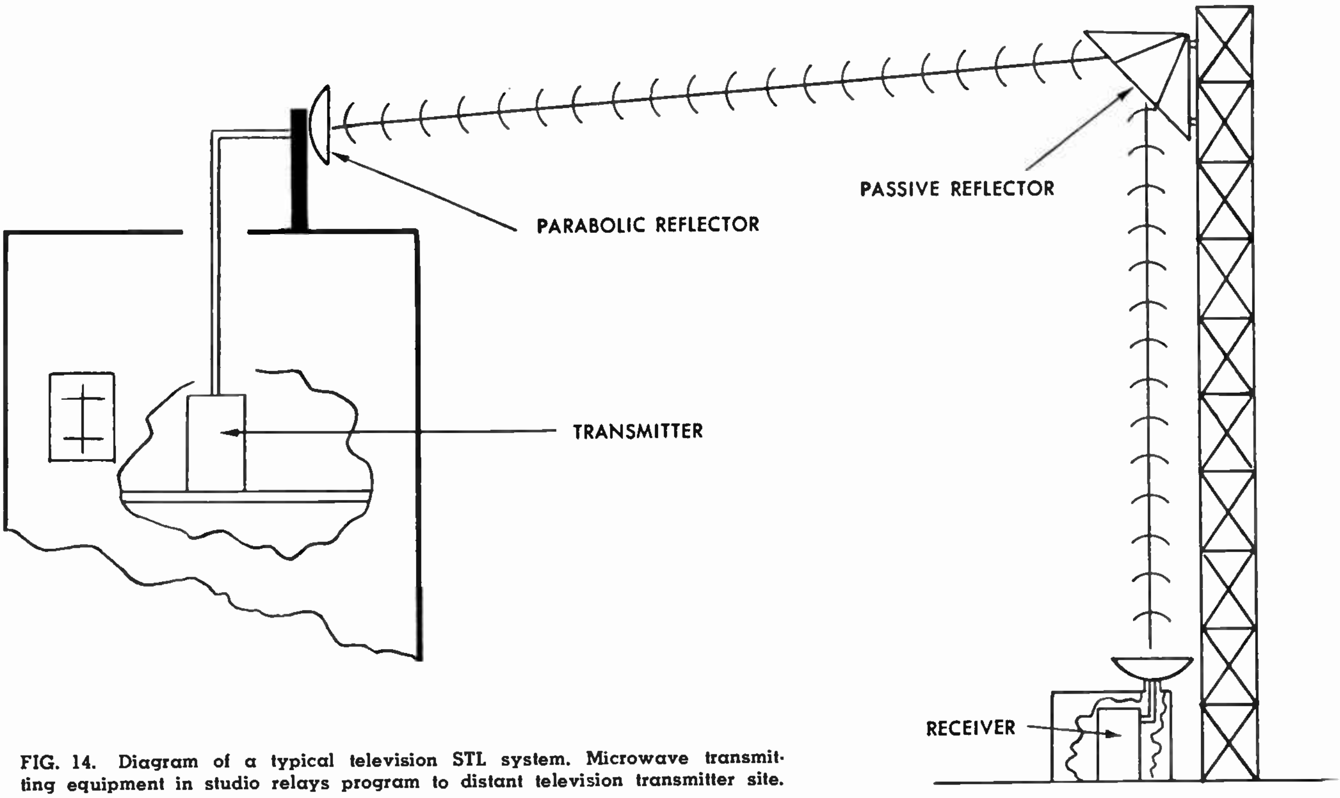


FIG. 14. Diagram of a typical television STL system. Microwave transmitting equipment in studio relays program to distant television transmitter site.

through audio, uhf, or multiconductor connectors which are supplied completely wired. No additional wiring is required for either portable or fixed operation.

Permanent System Installations

The TVM-1 system is ideally suited to fixed installations serving as video relay links between studios and television transmitters or serving small city television stations and community antenna systems. When distance or intervening obstacles necessitate multihop operation, the TVM-1 will serve as a repeater station. Because distortions in a multihop system are cumulative, the extremely high standards of its specifications contribute to the successful operation of the equipment in this application.

In fixed installations, the receiver or transmitter r-f head can be mounted on the rear of a parabolic reflector which is mounted on a tower or at the base of a tower below a passive reflector. The control units and receiver power supply are mounted in racks at a convenient location. In a more elaborate installation, but one that offers cost savings in maintenance and emergency service as well as savings implicit in reduced "off-air" time, the entire system is rack mounted.

The antenna can be mounted in any suitable manner, however, it must be rigidly supported. A gimbal ring mount is recommended for this application. The mount allows horizontal and vertical adjustment up to 7½ degrees from its center axis. When the microwave relay r-f head is not attached to the reflector, an antenna mounting plate and an antenna waveguide flange are required to support the antenna. Waveguide connection from the antenna to the r-f head can be made with brass or aluminum waveguide. Choke flanges with rubber gaskets, or flat flanges may be used. Any length up to ten feet bent or twisted can be supplied with flanges. For long waveguide runs, pressurization is recommended. A nozzle, through which compressed nitrogen or dry air may be applied, can be provided at any point on the waveguide.

A pressurized window is required at the r-f head end of the waveguide. The terminating cap on the antenna waveguide will provide a pressure tight seal for up to 10 psi pressure. Usual pressure is 2 to 3 psi.

Transmitter waveguide longer than approximately ten feet requires the use of an isolator to prevent reflections in the waveguide from shifting the klystron frequency during modulation. The isolator is a waveguide section which contains a ferrite material to allow only one-way transmission through the waveguide.

In those installations where protection is desired for the antenna and waveguide, four-foot and six-foot plastic domes are available for mounting directly to the reflector. Passive reflectors, 4 x 6, 6 x 8, 8 x 12, and 10 x 15 feet are also available.

In certain applications it may be necessary to transmit a microwave signal in two directions from a single transmitter. In order to accomplish this, a power splitter is required. This is a directional coupler which divides the input energy in a predetermined ratio. The ratio required will be governed by the particular application commonly used ratios are 1 : 1, 10 : 1, and 100 : 1.

In other applications, it may be desirable to put two or more transmitters and two or more receivers on a common antenna. Similarly, for two-way systems it may be desirable to put a transmitter and receiver on a common antenna. These alternative methods can be accomplished as desired through use of ferrite circulators and waveguide filter sections.

Automatic Switching—Diversity—Fault Location

In applications where utmost reliability is desired, standby transmitting equipment, diversity receivers and automatic facilities for switching and fault reporting should be employed. Equipment performing these functions will increase the reliability of a system far beyond that to be expected when human supervision is employed. And experience indicates that the use of space or frequency diversity will increase the propagational reliability of a path by a factor of ten or more. (See "Planning Television Microwave Systems" at the end of this section. page 185).

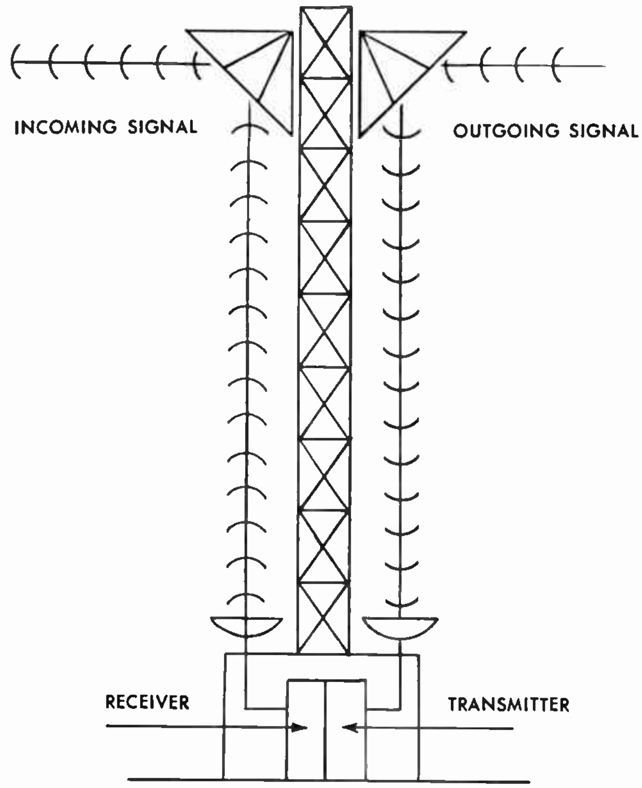
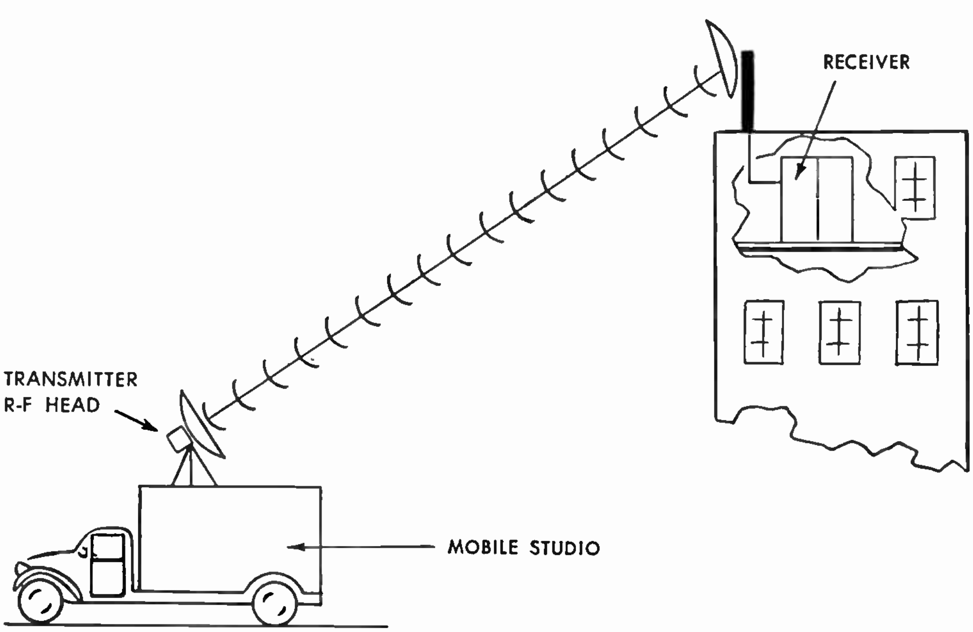


FIG. 15. Diagram showing use of microwave repeater to extend length of system. This makes possible a multi-hop system.

FIG. 16. Diagram showing a single-hop portable system for relaying field pickups to the studio or transmitter.



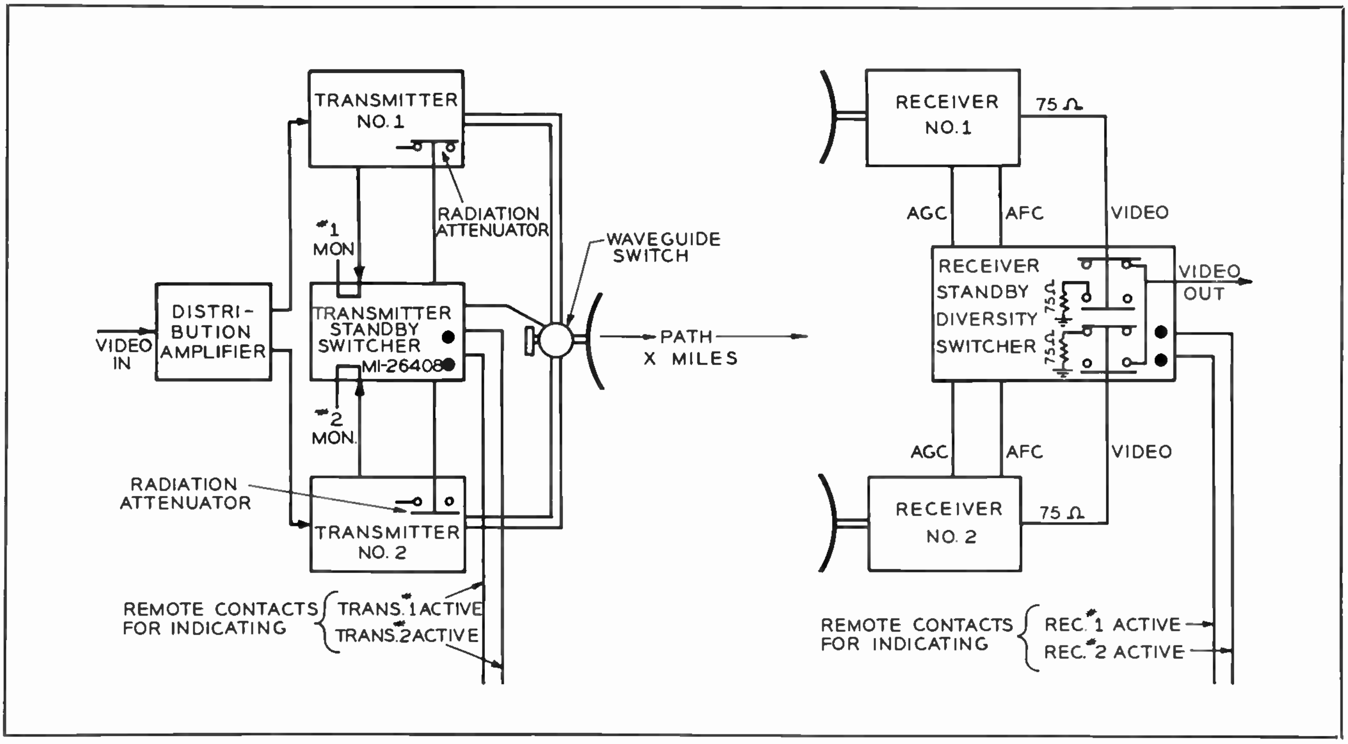


FIG. 17. Block diagram showing diversity and automatic switching units employed in a single-hop microwave link. Although space diversity is illustrated, equipment can be rearranged for frequency diversity as well.

All necessary facilities for automatic switching and fault reporting are included in the RCA Fault Indicating and Fault Reporting Equipment. This equipment, as an extension or accessory to the TVM-1 microwave relay system, is designed to serve the rigid requirements of a permanent, unattended microwave station. Units in the system automatically perform several functions: Locate faults arising in the microwave system and provide indications of the existence and locations of these faults; report to a remote station the nature and location of an equipment failure simplifying correction of the fault; provide automatic switching to a standby transmitter or receiver at any station in the system, while reporting the failure to the remote station; provide transmitter shutdown at a remote unattended location; and provide remotely-controlled reversal of the direction of microwave transmission, among other functions. Although the sensing units are self indicating at the station in which they are installed, they provide reporting information which can be transmitted over any medium such as a class D commercial telephone line, separate microwave system, or over a sound-diplexed subcarrier.

Typical Systems

Basic units in a complete fault indicating and reporting system include a Receiver Diversity Switch; Transmitter Standby Switch; Video Failure Indicator; Low Power, Low-Signal Level Indicator; Video Presence Detector; Indicon Encoder and Decoder; Data Transmitter and Data Receiver; and a Delay Timer. Whether or not all of these units are employed depends upon the complexity of the system and the individual requirement.

It is possible to use fault sending and fault reporting facilities without employing any standby equipment. Such a system may have either an attended or unattended sending terminal, from one to ten unattended repeater stations and an attended receiving terminal. In this type installation, microwave equipment is automatically shut down when trouble develops in order to comply with FCC regulations. Reporting facilities enable the operator to quickly locate and repair failures and thus restore the system to operation.

Figure 17 presents a one-hop microwave system employing standby, automatic switching and diversity reception. The equipment is shown set up for space diversity, although it can be rearranged for frequency diversity as well. Two transmitters are used at the sending terminal and montioring outputs from each are fed into a Transmitter Standby Switcher. Failure of video or power output from the in-use transmitter causes the switcher to transfer rf output connections to the standby transmitter, thus restoring the circuit. At the receiving terminal, video outputs from diversity receivers are fed into a Receiver Diversity Switcher. This unit, in the event of a fade in signal or failure of the in-use receiver, automatically switches the video output line to the non-faded receiver. Contacts in the transmitter and receiver standby switchers provide a means for local or remote indications of equipment performance. A system of this type may have either an attended or unattentted terminal and from one to ten unattended repeater stations.

A block diagram of a two-hop system employing standby, diversity, fault sensing and fault reporting equipment is presented in Fig. 18. Also included in this system are the accessories for relaying fault information from the microwave repeater and from the unattended transmitter terminal to the receiver terminal.

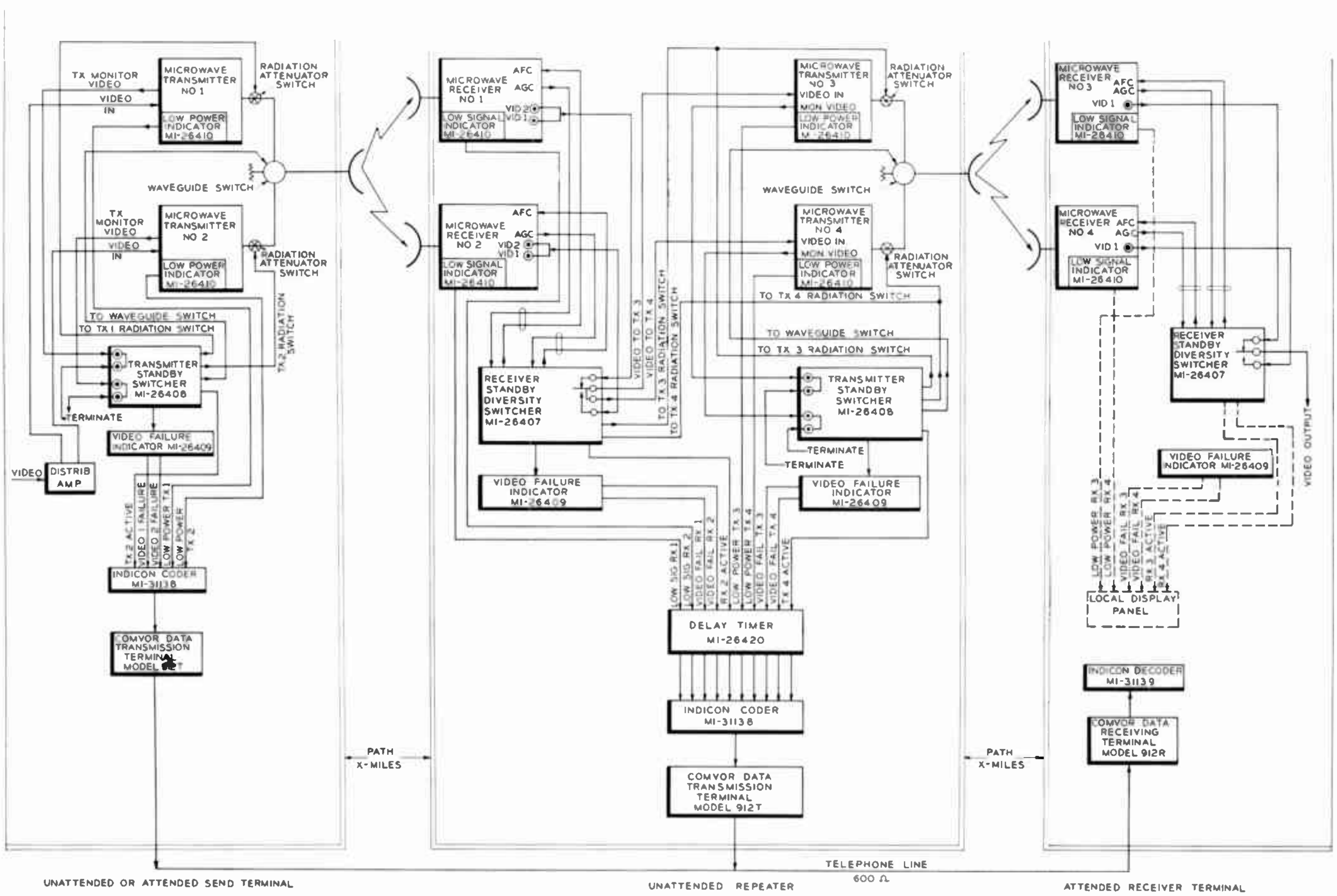
At the sending terminal in Fig. 18, which may be attended or unattended as shown, monitoring outputs from each transmitter are looped through the transmitter standby switcher. Video is sampled and rectified. Failure of video or output from the radiating transmitter causes the switcher to transfer rf connection to the standby transmitter, and simultaneously feed video fault sensing signals to the Video Failure Indicator. Power output failure indications are supplied by the Low Power Indicators in each transmitter; fault indications are fed through the Indicon Coder to the Comvor transmitter for transmission over a telephone line or radio circuit to the Comvor receiver in the attended receiving terminal. Display of these indications is provided at the Indicon Decoder.

Receivers in both the repeater and receiving terminal utilize Receiver Standby Switchers which select the non-failed or non-faded receiver outputs, and provide automatic indication of failed units. Indications of loss of rf signal input are provided by the Low Signal Indicators. Just as in the send terminal, video failure indicators are used in the repeater and receiving terminal. In the repeater, however, fault signals are fed to the Indicon Coder through a Delay Timer. An initial fault starts the timing cycle, and upon completion of the cycle the Indicon transmits the faults as usual. Time delay is variable, and is set in multiples of 20 to 25 seconds for each repeater. In this plan fault and sensing indications are provided locally, and contacts used to activate remote indicators are delayed by the Timer to prevent interference with fault signals from an earlier station.

Fault Reporting Systems

Fault reporting can be accomplished easily and economically by a party telephone line when such is avail-

FIG. 18. Block diagram of a two-hop microwave system with full application of automatic switching, fault sensing, and provision for the relaying of fault information.



able; this medium offers the most positive control of fault reporting and switching information. It also has considerable advantage in systems where it is desired to transmit fault information and switching control in both directions on the system. However, where telephone lines are not available or the cost of local lines is prohibitive, an alternative method is to employ at each site a companion low cost microwave system that will transmit the required data and provide voice circuits as well for maintenance and communication purposes. Frequencies are available for this use.

A third alternative is possible for fault reporting in microwave systems employing standby equipment. Briefly this method employs an additional sound-diplexed sub-carrier channel on each TV relay circuit; this channel carrying the fault information. In the event of a transmitter or receiver failure at some point in the primary relay circuit, automatic switching transfers the TV video, audio programming and fault reporting to the standby system. This method employs the RCA TSD-3 Sound Modulator and Demodulator units illustrated in Fig. 23.

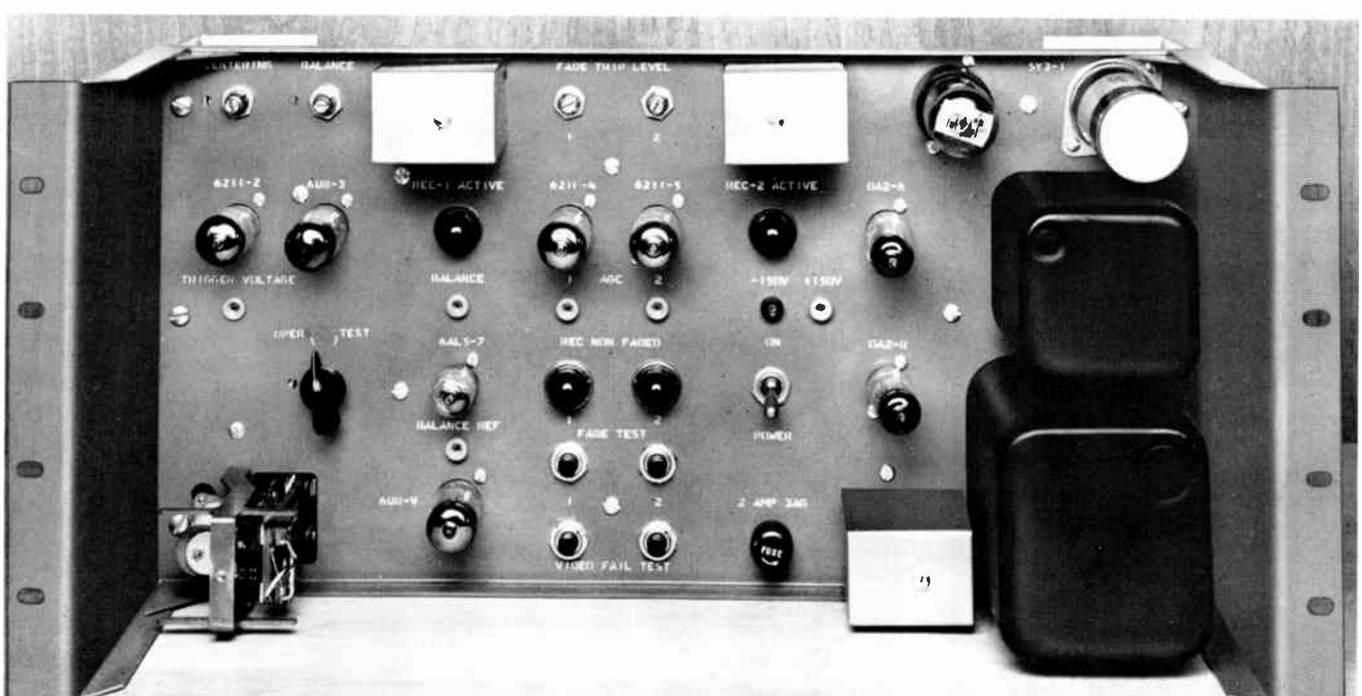
Description of Units

Receiver Diversity Switch (MI-26407) is designed primarily for use as an automatic switching device in either space or frequency diversity systems, wherein two receivers are continuously in use for common programmng. This unit, all components of which are mounted on a 7-inch recessed type chassis, automatically selects the output of the receiver having an rf input signal above a preset level. Thus, if a deep fade is experienced at the receiver in use, and if the rf signal to the other receiver is above the required level, the diversity switch will select the output of the second receiver. In the unlikely event that the second receiver is also faded below the usable level, no switching occurs. Also, no switching occurs between receivers because of higher input signal levels, as long as both receivers are above the preset level.

In addition to the diversity function which operates from the receiver AGC circuits, the switcher also operates as a receiver standby switch. If the video output of the primary receiver fails, switching occurs to the second receiver. An optional connection provides that, should both receivers fail or experience simultaneous fades at an unattended repeater station, the associated transmitter radiation switch will be operated, preventing the transmission of a noise modulated signal. This feature also permits remote shutdown of the rf output of a series of unattended repeaters by turning off the radiation at the sending terminal transmitters. Switching time of the diversity switch is approximately five milliseconds, or less than one picture frame.

Transmitter Standby Switch (MI-26408) permits the simultaneous use of two transmitters either one of which functions as the in-use transmitter. In the event of power output or modulation failure in the operating transmitter, the standby switcher immediately switches the rf circuits to the second transmitter. Contacts in the switcher open the radiation attenuator in the transmitter in use and close the attenuator on the unused

FIG. 19. Receiver Diversity Switch.



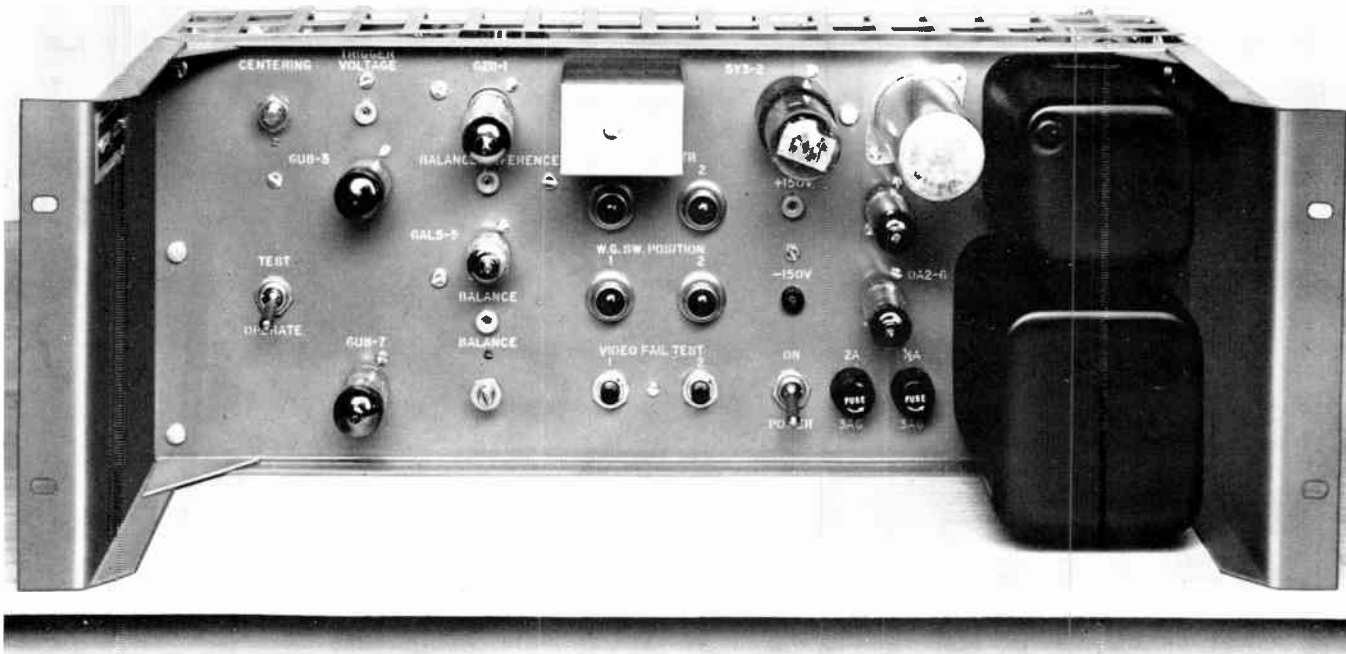


FIG. 20. Transmitter Standby Switch.

transmitter, permitting both transmitters to be continuously "hot" without interference to the received microwave signal. Switching occurs only when the in-use transmitter fails, and not because of higher transmitter output power. Switching time is 100 to 150 milliseconds. Contacts are available for operation of a waveguide switch in the transmitter output circuit. Signal lamps indicate the position of the waveguide switch. The transmitter switcher is mounted on a 5¼-inch recessed chassis.

Video Failure Indicator (MI-26409) is designed to give local indication of loss of video signal at either a microwave transmitter or receiver, and to give remote indications of video failures when used in conjunction with fault-reporting equipment. It is designed for use as a companion unit to the receiver and transmitter standby switchers, since both power and input video information are obtained from these units. The indicator incorporates an indicator lamp as well as contacts for operating remote fault reporting equipment. All components are on a 1¾-inch recessed chassis.

Video Presence Detector (MI-26419) is similar to the Video Failure Indicator except that it is designed for local or remote alarm of video failure in locations where no transmitter or receiver switcher unit is available; thus, the unit requires no interconnection to a transmitter or receiver switching unit as does the video failure indicator.

Low Power/Low Signal Level Indicator (MI-26410) is designed to give alarm signals when the power output of a transmitter or the signal level to a receiver falls below an adjustable preset level. The unit, which is constructed on a 3¼-inch by 9⅞-inch subchassis designed to mount on the transmitter or receiver rf chassis, incorporates an indicator light and contacts for operation of remote fault reporting equipment. Accessories are available to permit rack mounting of the unit if desired. Power is obtained from the transmitter or receiver rf head.

Delay Timer (MI-26240) prevents simultaneous transmissions of fault indications in the event of coincident failures. This unit is required in a fault reporting system where faults are to be reported from two or more stations over a common system such as a telephone line or separate microwave system. The timer also serves as a junction point for all fault reporting circuits within a station. The unit is designed for rack mounting and requires 5¼ inches of rack space.

Indicon Encoder (MI-31138) is a precision instrument capable of providing 15 digits of binary code for indication purposes. A 5-digit code preceding each transmission identifies the transmitting station at all points; the following 10 digits are coded to report the occurrence of any one of ten faults to be transmitted such as: low transmitter output; low receiver input signal; loss of video at receivers; loss of video at the transmitter; tower light failure; illegal entry; low fuel supply at standby or operating power plant; and receiver or transmitter active, and other such functions.

The coded pulse output is used to key either the 912T Data Transmitter or a second subcarrier channel

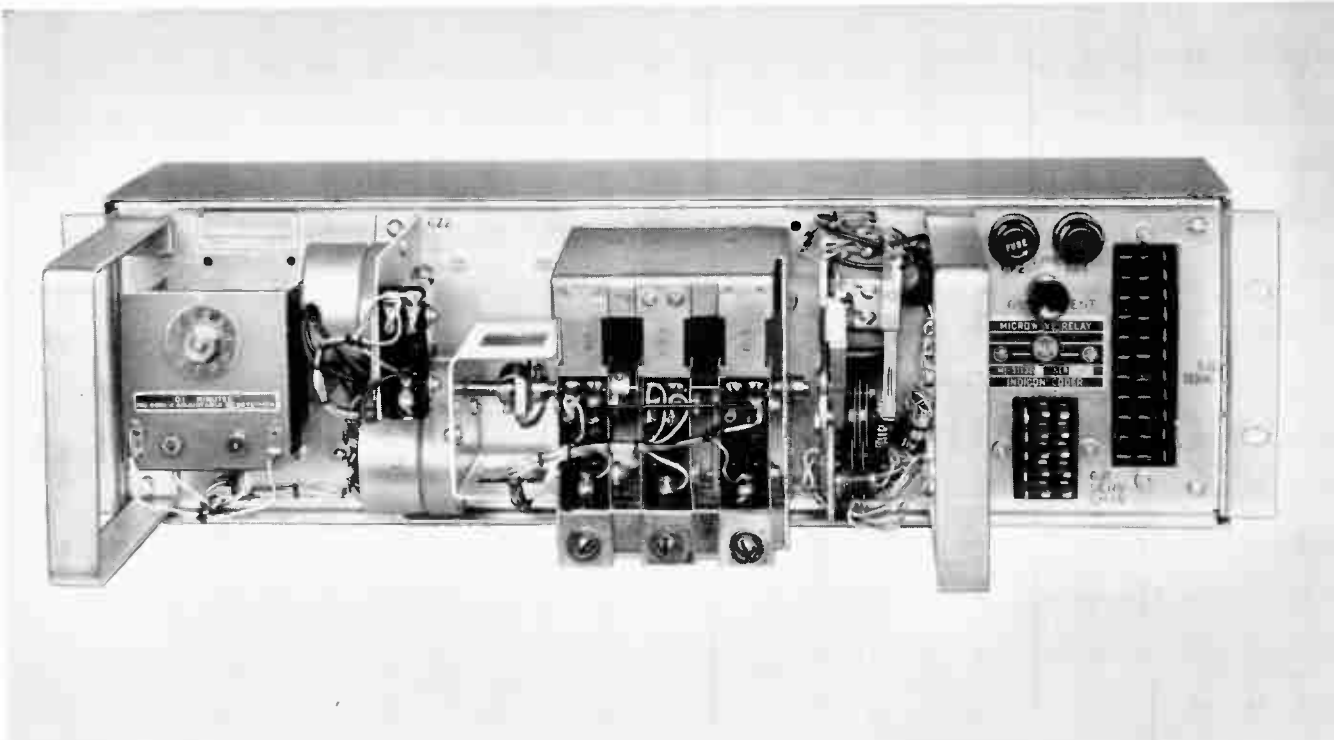
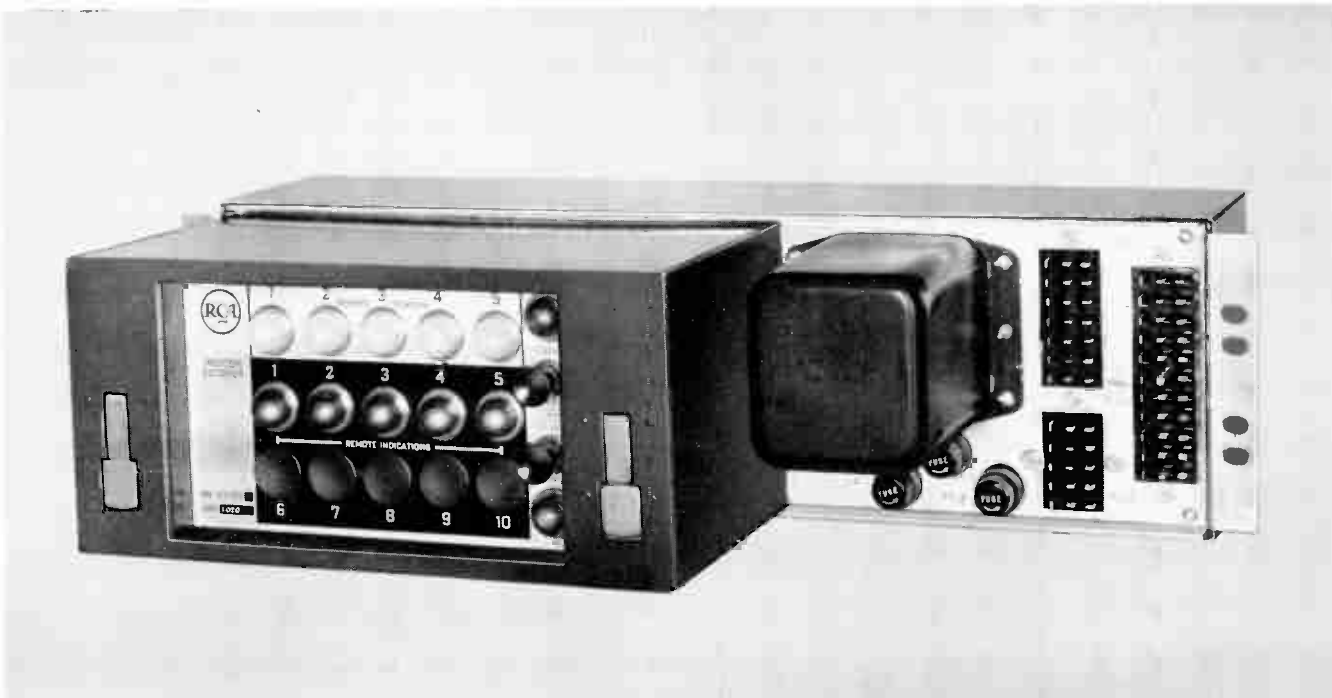


FIG. 21. Indicon Encoder.

FIG. 22. Indicon Decoder and Indicator.



such as the carrier of the TSD-3 Sound Diplexer as previously described. Lockout provisions in the encoder cause each fault indication to be reported in sequence along a major system. The coding sequence and speed is planned to permit audible decoding at unattended repeater stations when an audio monitor is provided for this purpose. The Indicon Decoder (MI-31139) operates in response to incoming coded signals from one or more encoders. A 12-lamp indicator panel presents a visual display of incoming signals; one bank of five lamps identifies the transmitting station, and a second bank of five lamps identifies one of five possible faults being reported by the transmitting station. An additional bank of five lamps can be added to extend fault identification to the ten-fault capability of the encoder. The remaining two lamps are available for identification of local faults at the station. The encoder and decoder are rack mounting, each requiring 5¼ inches of space.

Comvor 912T Data Transmitter is essentially an audio frequency generator which may be operated on any one of 46 audio channels as desired. Output frequencies can be chosen between 300 cycles and 11,000 cycles, with output level adjustable between —30 dbm and —10 dbm. The transmitter is designed for rack mounting and requires 3½ inches of rack space.

The Comvor 912R Data Receiver is the companion unit for the data transmitter. This unit receives the coded audio tone pulses and supplies output contacts to the Indicon Decoder for operation of its lamp indicating system. Input impedance to the receiver is 600 ohms nominal for telephone line use.

Portable Microwave Installations

The TVM-1 may be used in field or portable pickups as a means of transmitting video signals from field pickup cameras or similar sources to the television control point for broadcasting. In this case, the field mounting accessories will ordinarily be used. Fig. 24 shows a complete portable system employing these accessories. The antenna may be located on some high point such as the top of a stadium where a line-of-sight path with sufficient clearance is available. The transmitter control unit will be located with the camera control equipment as, for instance, in a radio booth or in a field truck or mobile unit.

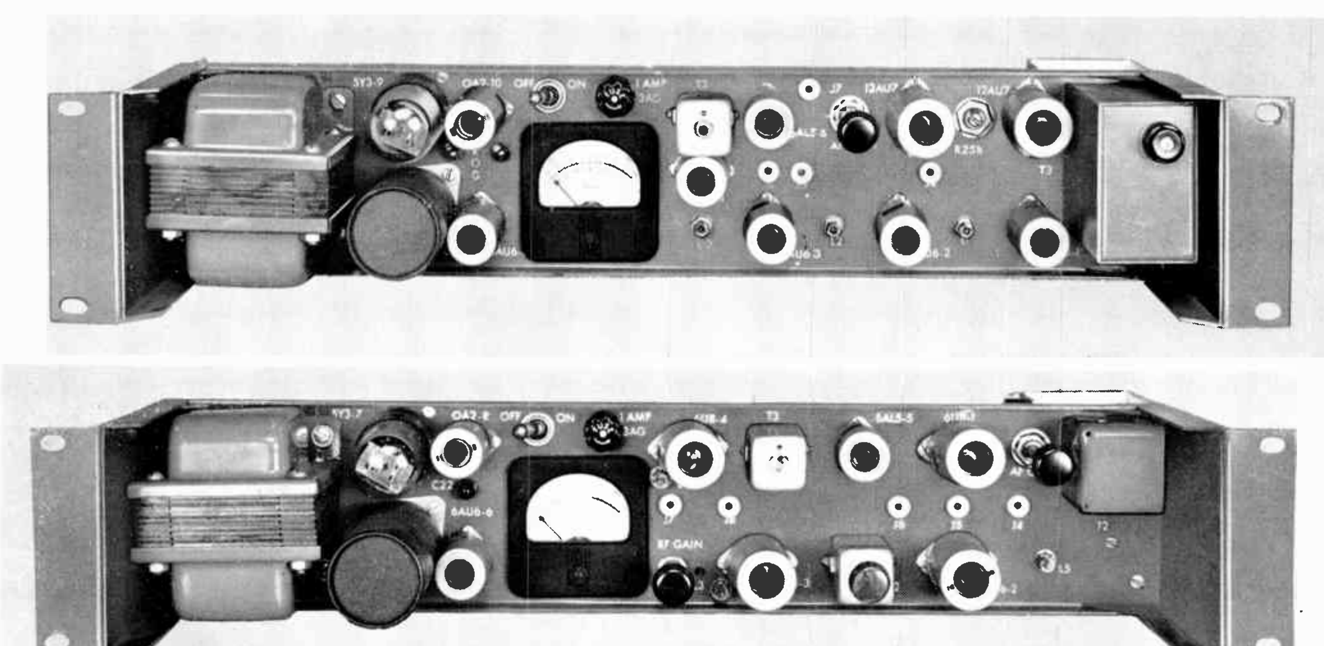
When the TVM-1 equipment is used as a portable link, carrying cases are required for each of the basic units. These cases are functionally designed to be attractive as well as rugged. The controls of each unit are readily accessible through convenient openings in the case.

The r-f head carrying cases are mounted directly on the rear of the parabolic reflectors by means of reflector mounts. The antenna waveguide can be attached directly to the case. The reflector mount fits on a tilt head. This mechanism provides a means of positioning the antenna for maximum signal. A wide vertical and horizontal traverse can be made with accurate control provided by a long lever arm. The tilt head may be mounted on a portable tripod.

If r-f preselection is desired in the case of a single receiver to eliminate interfering high frequency signals, a preselection filter is available for installation in the receiver antenna feed.

An attenuating coupler, available for test purposes,

FIG. 23. TS-3D Sound Diplexer Modulator and Demodulator.



is used to insert either a 55 db or 70 db attenuator between transmitter and receiver. Such attenuation is equivalent to a 7 or 36 mile path in free space using four-foot reflectors.

For applications in which the receiver r-f head is mounted more than 200 feet from the receiver control unit, it is recommended that the i-f connection be made by a length of RG-8/U cable external to the normal camera cable connecting the two units. In this case, an I-F cable kit is available to facilitate the installation. A similar kit is available for use with RG-11/U, for applications where the transmitter is more than 200 feet removed from its control unit.

A remotely controlled rotatable mount is available for use as the transmitting or receiving antenna support for remote pickups. It is completely remote controlled and can be mounted on a platform extension to most towers.

Circuit Description

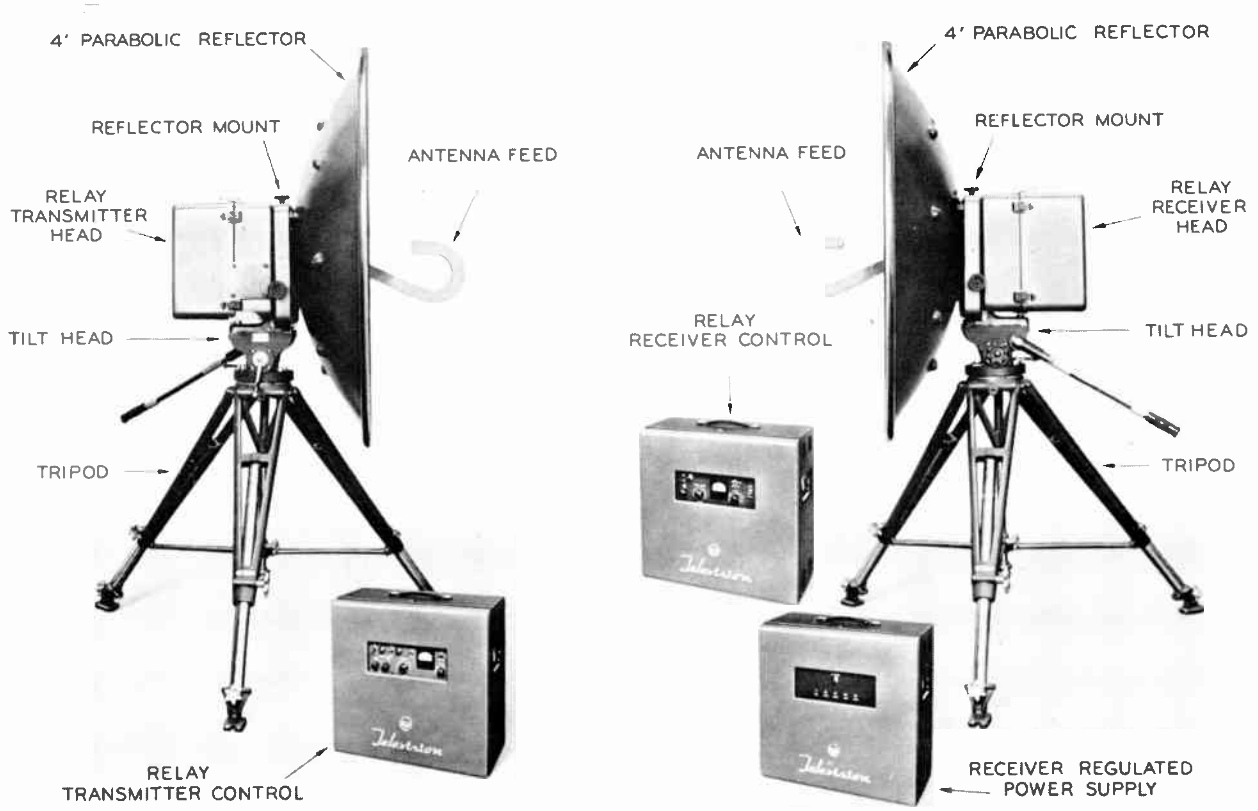
Circuitry of both the receiver and transmitter is designed for relaying color television video and sound signals with a minimum of distortion. These circuits require no critical tuning and a minimum of readjustment of tuning with equipment aging. The tuning and adjustment requirements are a result of much careful planning. Well regulated supply potentials are used throughout. Transmitter and receiver klystrons are of the extremely stable external cavity type requiring no heat oven or temperature compensation. Negative feedback is employed generously in all video circuitry, and an i-f amplifier of ample width (30 mc) is used to allow for drifts due to the tube aging. In addition, premium high gain tubes are used extensively throughout the i-f and video circuitry.

The receiver utilizes a balanced crystal mixer to acchieve the best possible noise figure. This, combined with the one-watt power output from the transmitter, and supplemented by high gain antennas, makes possible the best in propagational reliability over long paths.

The video amplifiers in the TVM-1 employ feedback control to reduce distortion and changes in gain due to tube aging. In the receiver, two 75-ohm sending-end-terminated video outputs are provided by two independent cascode type video amplifiers. Thus switching, etc, can be done on the monitor line without affecting the program line.

One or two sound channels may be transmitted over the TVM-1A by use of the TSD-3A or TSD-2B sound diplexer accessories. For two channels, both units are used. Sound transmission is accomplished by adding a 6.2 mc or a 6.8 mc carrier frequency-modulated by the audio signal, to the video signal in the sound modulator. The composite signal is passed through the system as a standard video signal. The output of the limiter-discrimi-

FIG. 24. Portable microwave transmitting and receiving equipment.



nator in the receiver is connected to the video amplifier input through the sound demodulator, rather than directly. This unit separates the 6.2 or 6.8 mc carrier and the video signal by means of a passive filter, and the audio signal is demodulated from the carrier after amplification and limiting. When used on multiple hops, a modulator is used at the first transmitter and a demodulator at the last receiver.

The signal radiated by the microwave transmitter can be monitored by means of the transmitter monitor accessory. This is accomplished by detecting the video signal at the transmitter output, and amplifying the signal to a nominal 1 volt level in the transmitter monitor amplifier. The unit is a high gain video amplifier which mounts on the transmitter head chassis. Its output is fed to the transmitter unit where it is available for monitoring purposes. Specifications on the transmitter monitor output are the same as those on the receiver output, thus the quality of the outgoing signal can be accurately evaluated.

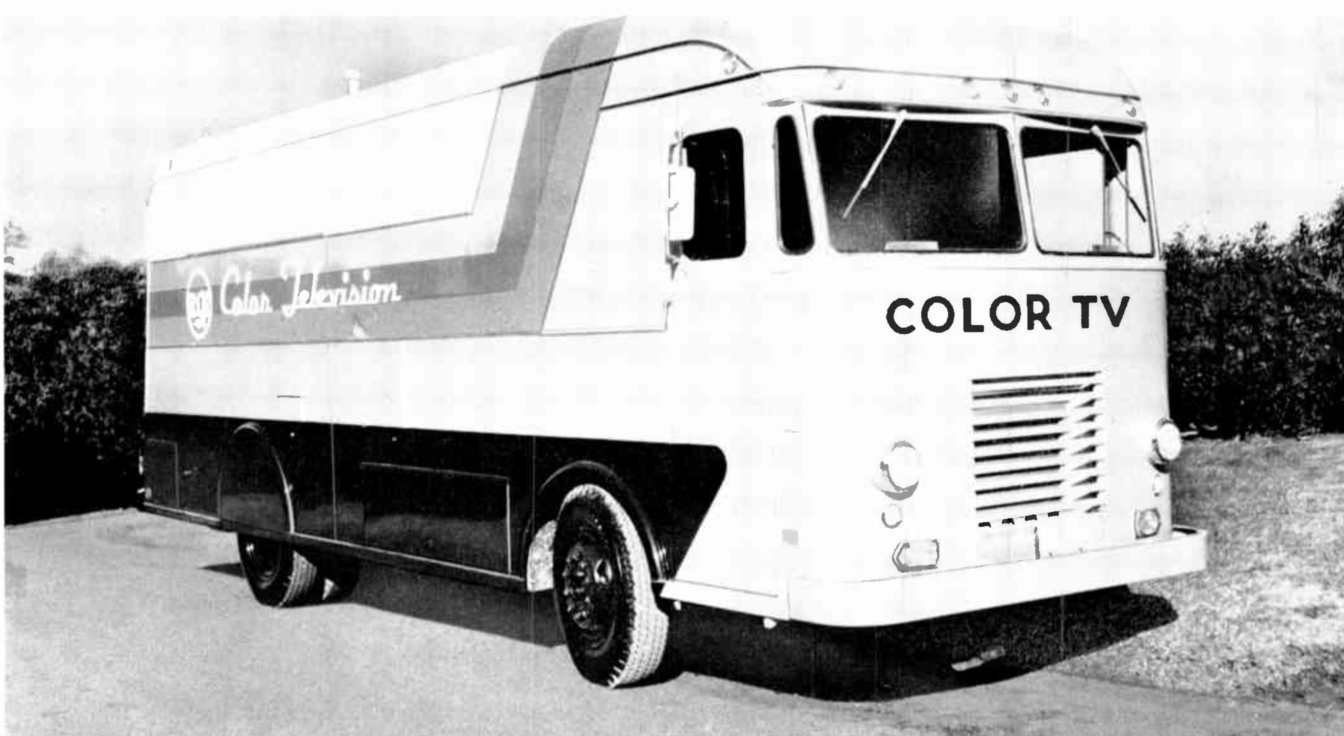
A transmitter AFC accessory is also available to increase the inherent stability of the transmitting klystron by about three to one. This unit derives its error information from the same discriminator that detects video for the transmitter monitor. Error (frequency drift) information is then fed to an AFC amplifier (identical to the receiver AFC amplifier) which provides a correcting voltage for the transmitter klystron.

When the TVM-1 is used as a remote repeater for a multiple-hop system, the transmitter output can be turned on and off remotely by an AFC radiation switch. This unit is 3½ inches high by 19 inches wide to permit mounting in a standard rack. The TVM-1 receiver AGC voltage is applied to the input of the radiation switch where it actuates a trigger circuit to operate a relay that in turn controls the transmitter radiation attenuator. An additional function of the AFC radiation switch is to control the receiver AFC and prevent its reaction to spurious (adjacent channel) signals when the received signal falls below a predetermined level.

Color Television Mobile Units

RCA Color Television Mobile Units are custom built vehicles designed to embody complete equipment facilities for originating remote, local or closed-circuit color programs. These units are also often used as mobile control rooms that can be transported readily to any desired location, and thus extend the usefulness of exist-

FIG. 25. RCA custom-built color TV Mobile Unit.



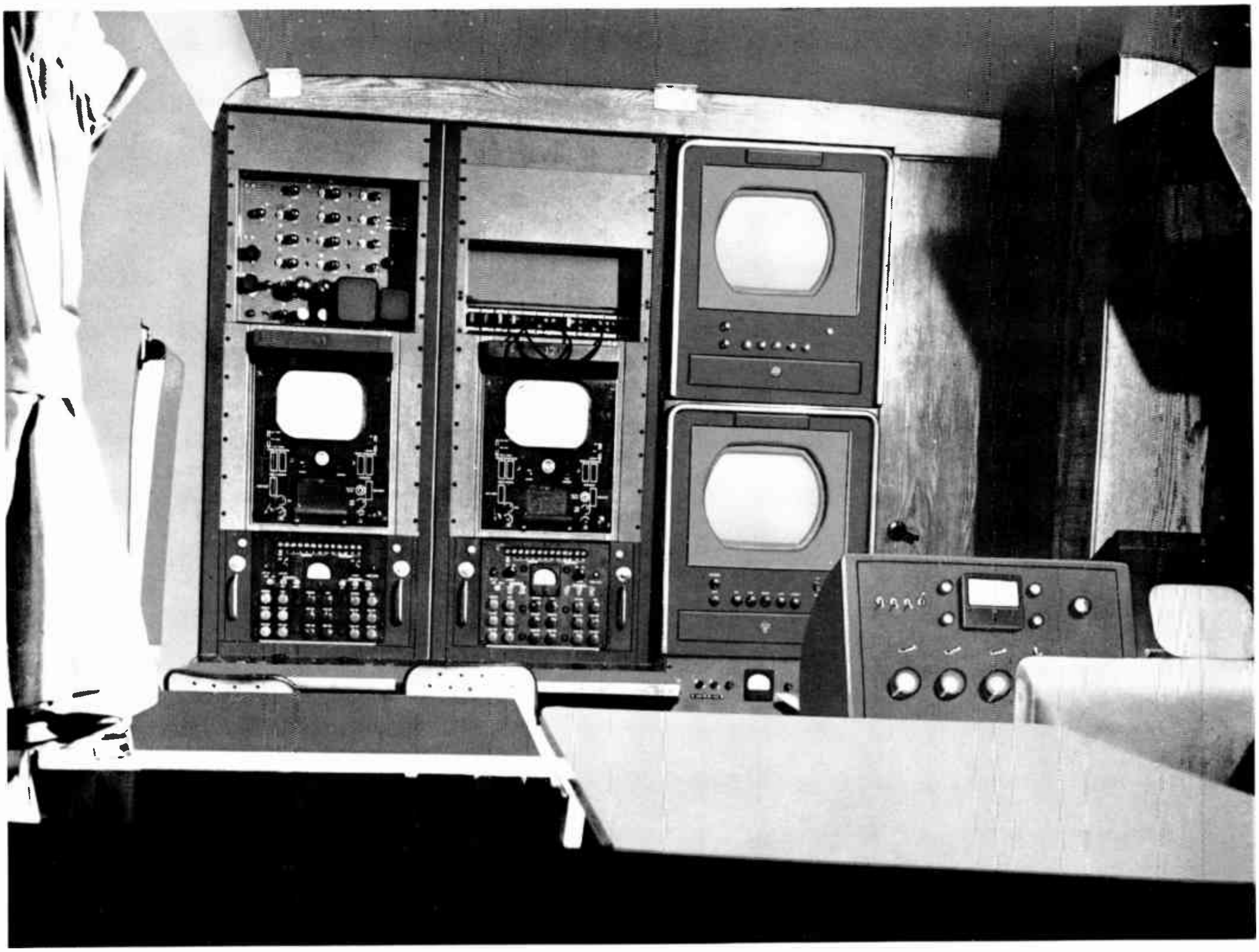


FIG. 26. View of video operating area showing rack-mounted monitoring and control equipment, program director's table (foreground), audio console, and air-conditioner (upper right).

ing studio facilities. Color mobile units can be designed to accommodate anywhere from one to five color cameras, plus other equipment which can include color film and low power transmitting facilities.

The color mobile unit described is a typical two-camera unit. It is designed for two complete color camera chains with a full complement of equipment, and still provide adequate room for convenient and comfortable operation. Equipment is housed in a 28-foot truck which also contains complete heating and air conditioning equipment. The truck is divided into two sections. The front section is the operating area; the rear section is a storage area which also houses many of the components required for operation of the two color cameras.

Complete equipment includes the two color camera chains, a switcher, audio console, sync generator, test equipment, power supplies and cables. Of course, provision is also made to include microwave facilities as previously mentioned.

In the control room are located the video controls for the cameras, the audio console, and switcher. The seating arrangement is such that either one or two operators can use the position. With the back of the seat moved toward the rear of the truck, the seat then serves for transporting passengers. The three equipment racks contain camera control No. 1, camera control No. 2 and color monitoring facilities. A centralized power control panel is mounted directly beneath the monitoring equipment within easy reach of the camera operator.

Microwave and Power Facilities

To facilitate the setup and use of microwave, a large area of the roof of the vehicle has been reinforced with steel plating. Provision is also made on the roof for storage of a parabolic reflector. A sturdy vertical pipe extending from the floor to above the roof provides a convenient anchorage for overhead cables; or it can be used as a socket for a gin pole in lifting equipment to the roof.

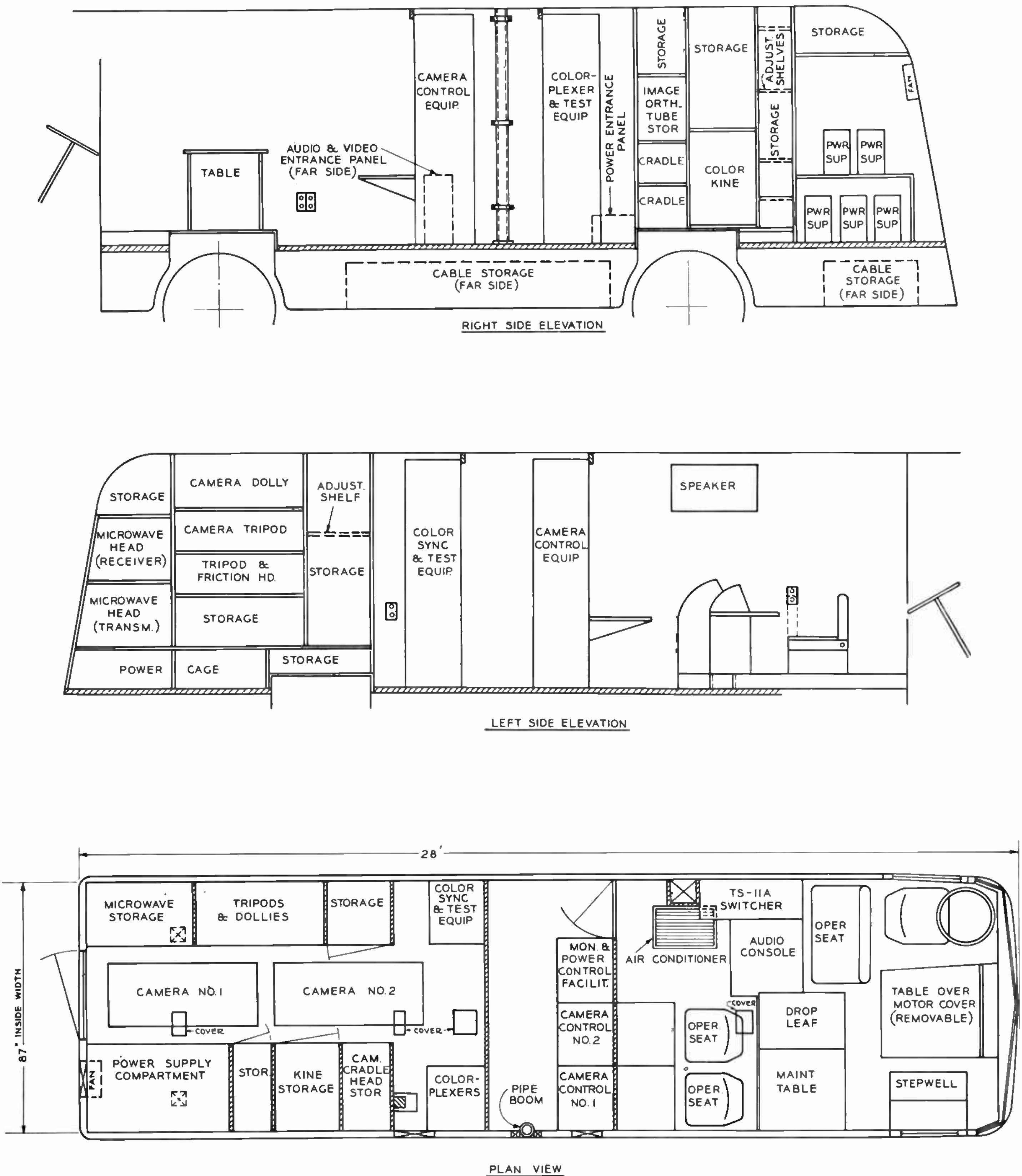


FIG. 27. Plan and elevation diagrams of color mobile unit.

The rear compartment houses five field power supplies. Behind the grill along the floor on the left side are located a 15-kva isolation transformer and a powerstat line corrector. The powerstat line corrector is remotely controlled from the power distribution panel located in the operating section of the truck. The center aisle is used to store the two color cameras.

Test Equipment

Two racks also located in the rear portion of the truck house the colorplexers, color sync equipment and test equipment. The test equipment includes: a color bar generator for alignment of colorplexers and color monitors; calibration pulse generator permitting calibration of all signal displaying devices against a common source; linearity checker; color signal analyzer; and oscilloscope.

Wiring and Terminations

Interconnection of all equipment located throughout the truck is accomplished by wiring through ducts installed underneath the floor. All incoming and outgoing lines terminate at panels located on the curb side of the truck. There are two such panels. One panel is located directly in line with the camera control racks. This panel provides connections for the two camera inputs, three microphones, and one remote audio input, one video input, microwave control output, video and audio outputs.

The power entrance panel located more to the rear of the truck contains four a-c output receptacles and main input power connection. The external source of power required to operate the color mobile unit with two cameras is single phase, 220 volts, 90 amperes.

Access to storage space for the camera and power cables is provided externally in the skirt line of the truck. There are three compartments provided, which are capable of carrying approximately 1,500 feet of camera cable and 100 feet of four conductor No. 4 power cable. Each color camera requires three interconnecting cables, therefore, the 1,500 feet of camera cable mentioned above actually serves the requirement of two cameras. Experience has indicated that cable runs up to 600 feet in length can be used successfully.

Operation

A crew of four men is normally needed to operate the equipment within the truck. Two video operators operate the two color camera chains, each using a color monitor and master monitor to assist him in properly setting up the camera chain. Color monitors also double as preview monitors for the director. Director and audio operator are located to the rear of the camera operators, affording them full view of the monitoring facilities.

FIG. 28. General storage area of mobile unit as seen through rear door.

Planning Television Microwave Systems

Unlike most television equipment, microwave relay systems utilize a transmission path which is only partly controllable by the user. Thus, the performance of the system is dependent not only upon the equipment itself, but also upon the quality of the path over which it must be operated. It is essential, therefore, that the television microwave relay system be carefully planned prior to installation. It is in the initial planning that the station engineer assumes a major role in determining requirements based upon local terrain conditions and microwave principles. The information presented in the following paragraphs is intended as a guide for use by the engineer in planning these systems.

Fundamentals of Microwave Propagation

Microwave energy is popularly assumed to travel from transmitter antenna to receiver antenna in a "beam" similar to that emitted by a searchlight. Actually, the situation is somewhat more complicated since the amount of energy received is affected by:

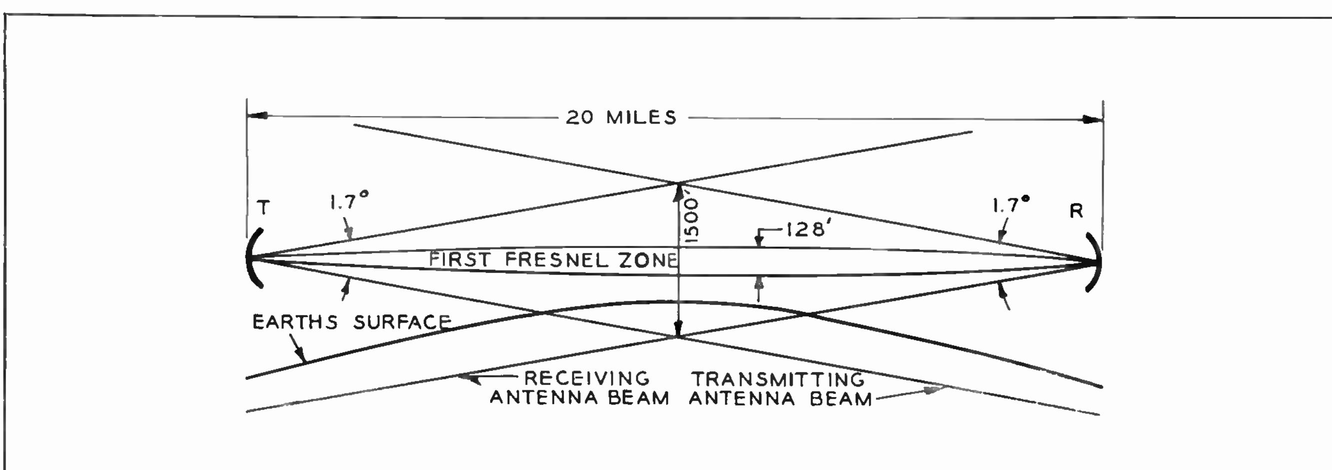
1. The proximity of the earth which diffuses or scatters part of the energy from the beam and which may reduce the signal received, even though a "line-of-sight" path exists between the transmitting and receiving antennas.
2. Reflections from the surface of the earth or from layers of still air which may arrive at the receiver in-phase or out-of-phase with the direct signal, thus reinforcing it or canceling it.
3. Variations in density of the earth's atmosphere which cause the path of the beam to bend and which, under certain conditions, may cause fading.
4. Diffraction over or around obstructions.
5. Foliage, the density of which varies with the seasons, causing diffusion or scattering.
6. Open water or marsh land, which causes varying degrees of reflections.

For optimum results, it is necessary to plan the microwave system so that the effects described above will be minimized.

Fresnel Zone

To minimize loss of signal due to absorption by the earth, it is necessary to provide more than "line-of-sight" clearance. A significant amount of the received energy, in effect, traverses other than a straight-line path. If antennas are properly aligned, the region in which most of the useful radiated energy is concentrated is in the center of the beam radiated by the transmitting antenna. Within this beam is a region called the first Fresnel zone. This Fresnel zone is contained within a fictitious curved boundary, extending as illustrated in Fig. 29, from the transmitter to the receiver. It is the boundary from which any reflected signal would travel an additional half-wavelength in going from the transmitter to the receiver. Because there is a 180-degree phase shift upon reflection, any signal going from transmitter to receiver via this path will arrive at the receiver as an aiding signal. Any reflection from a surface within this Fresnel zone boundary, however, will not have the full added half-wavelength of travel and thus will arrive at the receiver as a partially or totally canceling signal. For this reason, this zone should be kept free of all ob-

FIG. 29. First Fresnel zone shown in approximate relation to transmitted and received beams produced by six-foot dishes spaced 20 miles apart.



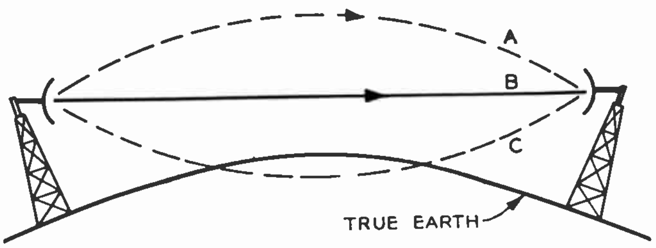


FIG. 30. Diagram illustrating typical microwave paths for three different atmospheric gradients, i.e.: (A) dielectric constant decreasing with altitude (normal); (B) no change in dielectric constant with altitude (homogeneous atmosphere); (C) dielectric constant increasing with altitude (inverse bending).

structions or potentially reflecting surfaces. (Similarly, there is a second Fresnel zone boundary via which the added path travel is one wavelength; a third with added travel of one and one-half wavelength, etc. Reflections from these boundaries are alternately aiding and canceling.)

Figure 30 shows three microwave paths for different atmospheric gradients. Due to the scale used, the change in departure (and arrival) angles at the antenna is greatly exaggerated. Angle change increases with path length and seldom exceeds 0.3 degree. Path A, the normal path, is slightly curved. Because of this it is customary to plot microwave profiles on 4/3 earth radius paper, thus converting the normal path to a straight line. The B and C paths are then both seen as cases of inverse bending, but only the C path is obstructed and thus only this path causes a fade. In practice, it has been found desirable to provide greater clearances for longer paths, while smaller clearances may be used for the shorter ones. Recommended clearances are given in the section devoted to antenna heights.

Owing to the extremely short wavelength of microwave radiation, the surface of the earth is ordinarily a poor microwave reflector. Furthermore, such reflected energy usually is scattered diffusely so that very little of it reaches the receiving antenna. Occasionally, however, the nature of the terrain will be such as to produce a strong reflected signal. This occurs on over-water paths or when the terrain is smooth, highly conducting and free of vegetation (certain desert areas).

Fading

Terrain producing strong reflected signals is always undesirable and should be avoided whenever possible. When the path-length difference between the direct and reflected waves is such that the two arrive out of phase, cancellation occurs and will produce a deep fade. Since the path-length difference may be changing constantly due to changes in atmospheric conditions, such paths are usually subject to severe fading. Special techniques such as high-low siting which is discussed later have been developed to avoid these effects.

If the atmosphere were perfectly homogeneous, energy from the transmitting antenna would travel in a straight line to the receiver. Due to variations in the dielectric constant of air, however, the path of the energy may be refracted or bent. This can result in fading of the whole signal for two principal reasons:

1. The beam may be forced to follow a curved path in order to go from transmitter to receiver. This curve may cause it to intersect the earth and thus be obstructed. A fade due to this phenomenon is said to be due to inverse bending and may be quite prolonged. This is illustrated by path C in Fig. 30.
2. An abrupt difference in dielectric constant at a point within the Fresnel zone may provide a good reflecting surface momentarily. This can result in a canceling signal arriving at the receiver and a dropout in total received signal strength. Such fades are normally of very short duration, but may be rapidly repetitious. They are said to be "multipath" fades.

   If the path of the beam is bent too close to the earth, the earth may provide the reflecting surface for a multipath fade.

Nearly all paths are subject to some fading from atmospheric effects. Therefore, it is customary to make a fading allowance when planning microwave systems. In most parts of the country a standard fading allowance can be used with reasonable accuracy and will therefore be assumed.

In a few regions, particularly those which are subject to frequent periods of humid or stagnant air where wind velocities are less than five miles per hour, more severe fading can be expected. This lack of turbulence in the air allows the building up of conditions conducive to inverse bending, and multipath effects. The presence of ground fog, in particular, is often an indication of fading conditions, though the fades are almost never due to the fog itself. The most prevalent fading regions are found in the tropical and sub-tropical zones. It is desirable to make a special engineering analysis of any proposed paths in such areas.

Use of This Planning Guide

In planning a TV microwave relay link, the engineer must determine fundamentally these questions:

1. What are the electrical and physical factors which will limit system performance?
2. What antenna heights should be used?
3. What antenna or passive reflector sizes should be used?
4. If unusual propagation or antenna-siting conditions exist, what special steps should be taken to insure satisfactory operation? (Problems of this nature should be referred to competent authorities.)

This Guide will permit the user to determine the answer to the first three of these questions except when unusual conditions exist. It can be said that unusual conditions exist:

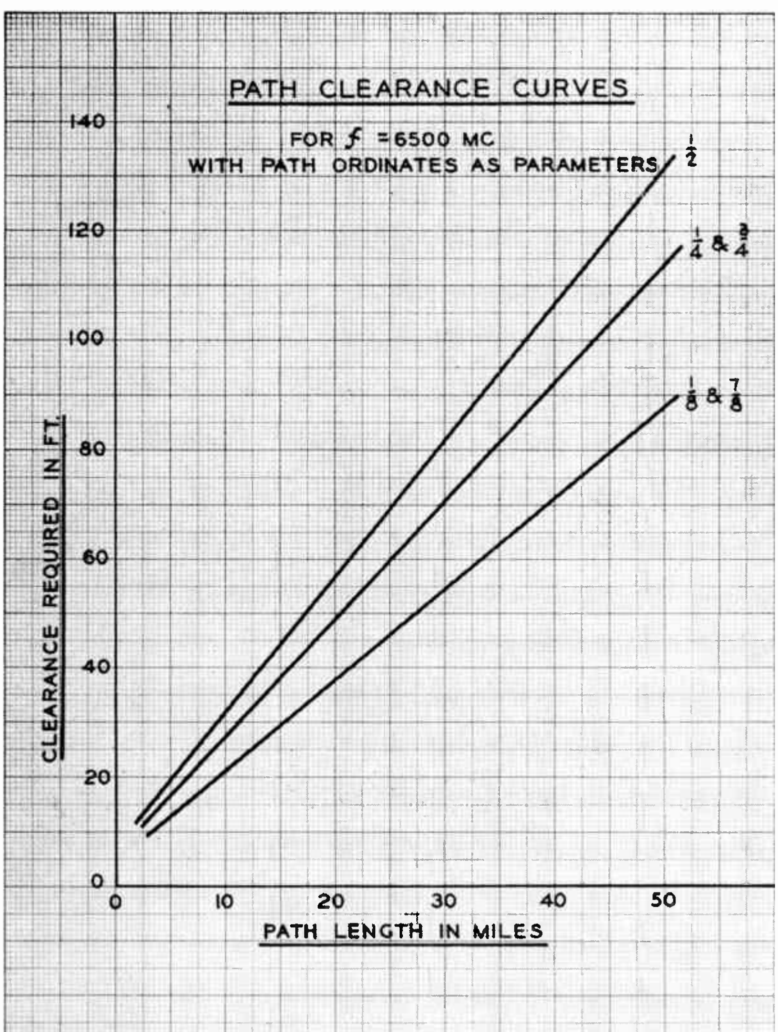
1. Where it is impossible to provide sufficient antenna height to maintain the path clearance indicated in Fig. 31.
2. Where the path is over water or over smooth terrain which might produce strong reflections. The terrain may be considered smooth if variations in height all along the path are less than 75 per cent of the first Fresnel zone radius computed at the center of the path (see Fig. 32).
3. Where the path length is greater than 10 miles and atmospheric conditions are conducive to unusually severe fading as described in the paragraphs on fading (page 186).

Site Selection

Sites for microwave stations should always be chosen to provide adequate line-of-sight transmission paths if reliable operation is to be insured. At the same time, attention must be given to the system requirements and to operational convenience. System requirements will be more fully considered in the section on multi-hop systems.

As a first approximation, sites should be selected which are not more than 20 to 30 miles apart unless the topography of the intervening terrain is such that adequate clearances over a longer path may be obtained. It is also important that there be no long periods of non-turbulent air in the path. Potential sites should be located on a topographic map of the district. A topographic map is a graphic representation of the configuration of shape of a portion of the earth's surface. If more than three stations are to be used in the system,

FIG. 31. Curves showing clearance values over a series of path lengths. Clearances are shown at the ½-point, ¼ and ¾ points, ⅛ and ⅞ points above a 4/3 earth.



the methods outlined in the section on multi-hop systems should be strictly observed.

If the sites selected satisfy these requirements, their merits should be evaluated from an operational standpoint. Preferably, the sites should be level and accessible to vehicles and a commercial power line should be within reasonable distance. Power regulation should be inherent or otherwise provided by automatic devices.

Path Survey

Having made preliminary site selections, the terrain over which the path passes should be analyzed. Where maps are available and are of known accuracy, they may be used for this purpose; otherwise, a rough physical survey of the path must be made. During this survey, a note should be made of the height of any prominent obstacles, either natural or man-made. The general characteristics of the terrain, such as density of foliage, large bodies of water, swampy areas, rocky or sandy soil, should be noted. A physical inspection of the sites should always be made before attempting to erect stations at locations chosen on the basis of map or aerial-survey information.

Calculation of Antenna Height

The first step in the calculation of transmitting and receiving antenna heights is to obtain an accurate profile on the ground level along the transmission path. This can be done by a number of methods. Where accurate topographic maps are available, they provide a simple and satisfactory means of obtaining the terrain profiles.

A bulletin entitled "Topographic Maps" as well as maps for specific areas may be obtained by addressing

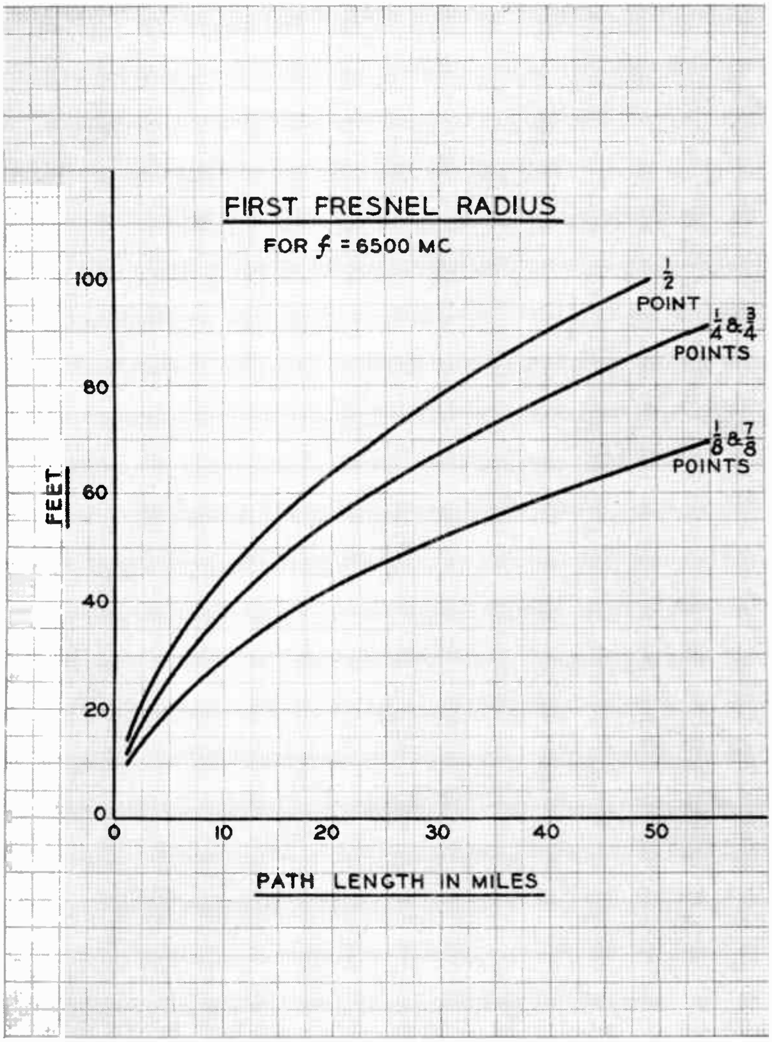


FIG. 32. First Fresnel radius curves for various path lengths.

$$\text{Fresnel Radius} = \sqrt{\frac{N\lambda d_1\ (d-d_1)}{d}}$$

N = 1 (first Fresnel Zone)

= 2 (second " ")

= 3 (third " ")

= 4 (fourth " ")

λ = wavelength

d = length of path

d_1 = distance to point in question

inquiries to the United States Geological Survey, Washington 25, D. C., or to Denver 15, Colorado, for maps of areas west of the Mississippi.

Where accurate maps are not available, a physical survey of the path should be made. This can be done with accurately calibrated sensitive altimeters which are properly adjusted in accordance with the barometric pressure and referred to a known point or bench mark. This is known as the American Paulin system. A line joining the two sites is drawn on a county highway map and the altitude measured at each point where the line crosses a road. Elevations between roads can be estimated but critical obstructions should be measured exactly.

More elaborate methods of surveying may be used including conventional civil engineering techniques or the use of an aircraft-mounted absolute altimeter. However, their expense makes the use of simpler systems desirable whenever possible. The importance of a sufficiently accurate survey cannot be overemphasized and judgment must be exercised to insure that adequate data are obtained.

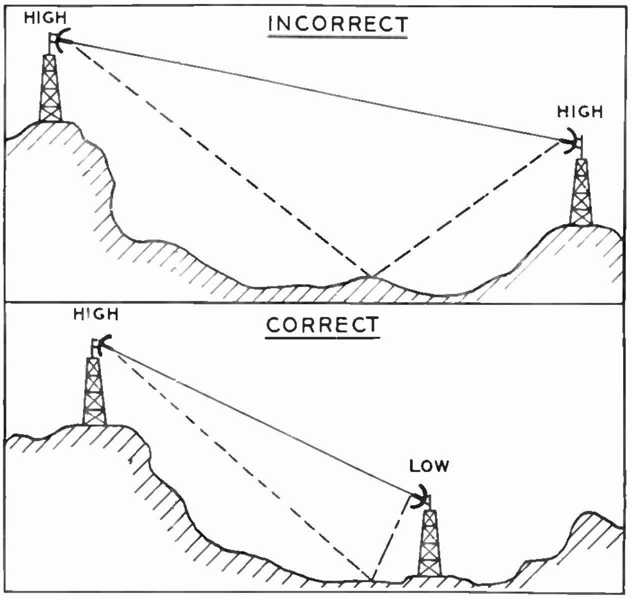


FIG. 33. Siting of stations over smooth terrain.

Multipath Signals

Attention should, at this time, be given to the possibility of multipath signals caused by reflections from the earth's surface. Such reflections are negligible when operating over irregular terrain such as encountered in rolling countryside. They become increasingly objectionable over smooth terrain. If the use of paths over smooth terrain is unavoidable, the expedient of high-low siting of stations should be used whenever clearances permit. The object of this technique is to prevent the location of potential reflecting surfaces at points where the angles of incidence and reflection to the two antennas can be equal. This condition is illustrated in Fig. 33. In some instances, the use of this technique will necessitate an additional repeater station. An economic evaluation may indicate it more expedient to find an alternate transmission path.

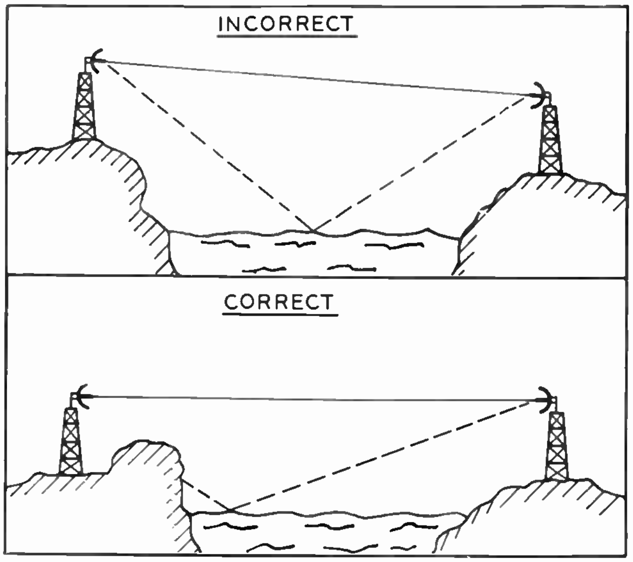


FIG. 34. Siting of stations over water.

Over-Water Paths

Over-water paths should be avoided if at all possible. When such paths must be used, high-low siting of stations may prove useful. Another technique which is sometimes useful is to take advantage of the natural screening provided by terrain obstructions or by buildings.

Using an obstruction to reduce the reflected signal requires careful analysis, since the angle of approach of the reflected and direct rays is very small. This is not too apparent on the distorted scales used in preparing path profiles.

In case the path length is short enough to assume very little beam bending, the direct ray obstruction loss will be negligible. However, as the distance increases, this loss will become more significant due to the greater dif-

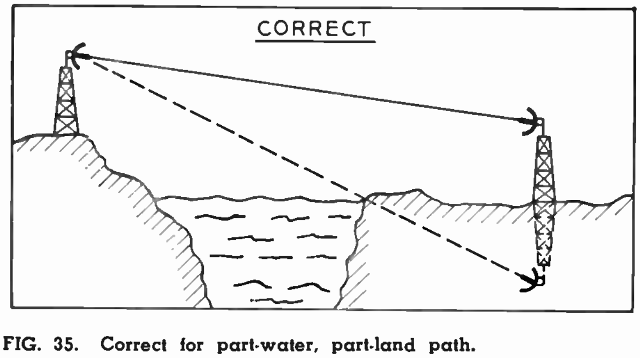


FIG. 35. Correct for part-water, part-land path.

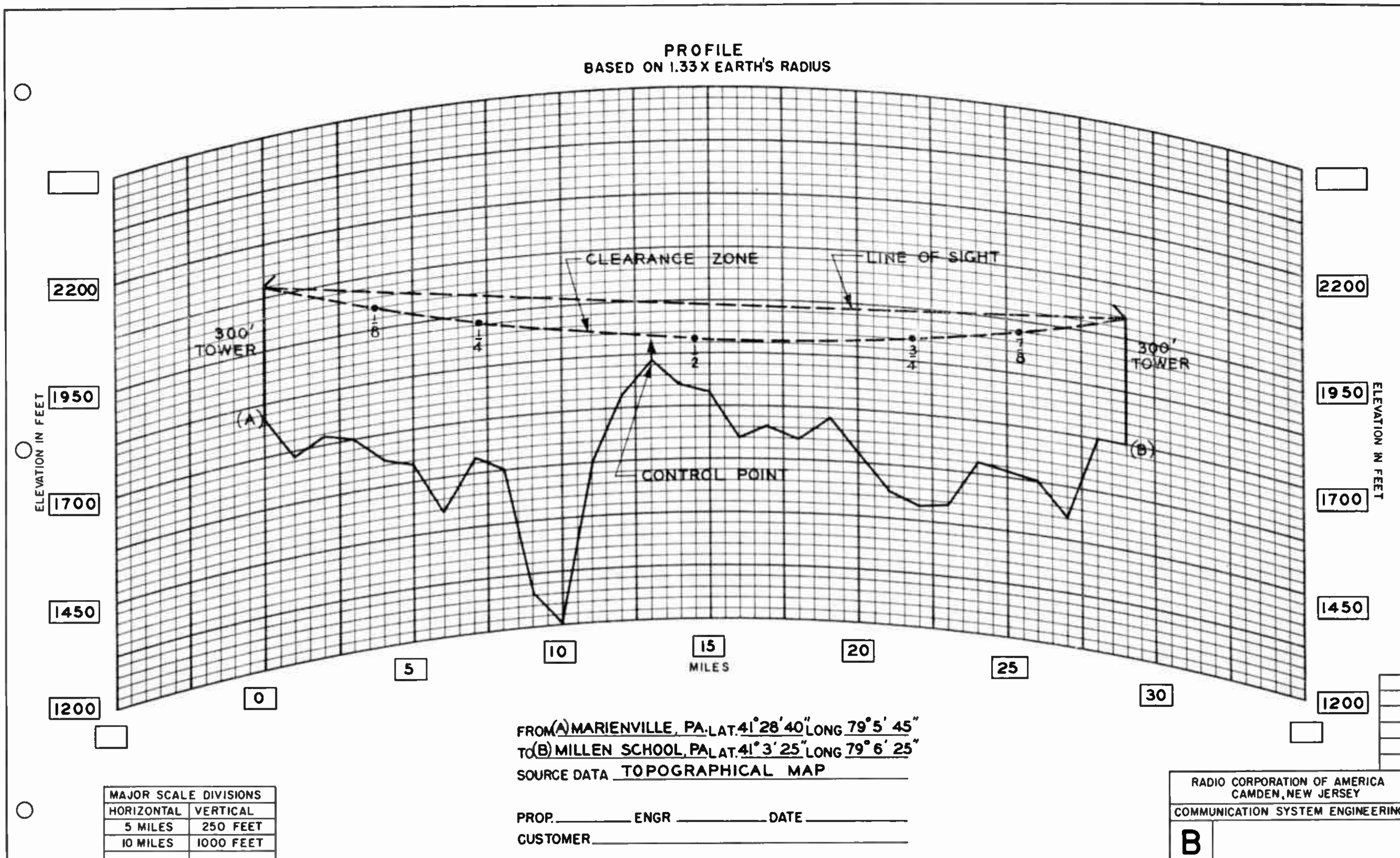


FIG. 36. A typical microwave path drawn on profile paper.

fraction medium. This results in a lower net gain, but fading stability can be improved. Figure 34 shows a typical instance in which protection is available.

Circuits working over a path which is part land and part water should have station sites so located that the multipath point of reflection is located on the land portion of the path and as near to one station site as possible. This condition is illustrated in Fig. 35. The multipath point of reflection can be determined with reasonable accuracy by extending the beam to the image of the antenna and noting the point where it enters the earth's surface.

Path Clearance Requirements

As a final consideration before drawing the clearance zone on the path profile, an assessment should be made of the prevailing weather conditions over the various routes in the system.

According to the anticipated weather and general features of the terrain, the values for the clearances, as obtained from Fig. 31, should be multiplied by a factor which can be obtained from the tabulation given in Table I.

As a general guide, it may be assumed that the terrain which the microwave path crosses is "broken" if the variations in profile height all along the path are greater than 75 per cent of the first Fresnel zone radius computed at the center of the path. (Refer to Fig. 32, first Fresnel Radius.)

In the broken terrain, ground reflections will not cause excessive interference with the direct signal providing that the profile irregularities are located at random intervals along the path.

Having determined the required correction factor for the path clearance ordinates, the corrected zone may be drawn on the path profile.

Path Profile

The elevations, including the height of obstructions, should now be drawn on special 4/3 earth's-radius graph paper. This earth radius paper is used because the atmosphere is normally such that the microwave path will be curved when plotted over true earth as illustrated in A of Fig. 30. By use of 4/3 earth, the path can be considered a straight line.

If 4/3 profile paper is not available, it can be constructed from rectangular coordinate paper using the following formula:

$$h = 0.5 d_1 d_2$$

where: h = bulge of earth in feet at distance d_1 miles from near end, and d_2 miles from far end of path.

For the true earth profile, this formula becomes:

$$h = 0.677 d_1 d_2$$

TABLE I

PATH CLEARANCE CORRECTION FACTORS

Path Length	Nature of Terrain	Weather	Multiply Path Clearance By
Up to 18M	———	————	1.0
18 to 28M	Broken	Normal Air Turbulence	1.0
18 to 28M	Smooth	Normal Air Turbulence	1.25
29 to 40M	Broken	Normal Air Turbulence	1.25
29 to 40M	Smooth	Normal Air Turbulence	2.0
18 to 28M	Broken	Ground Fog Prevalent	1.25
18 to 28M	Smooth	Ground Fog Prevalent	1.5
29 to 40M	Broken	Ground Fog Prevalent	1.75
29 to 40M	Smooth	Ground Fog Prevalent	2.25

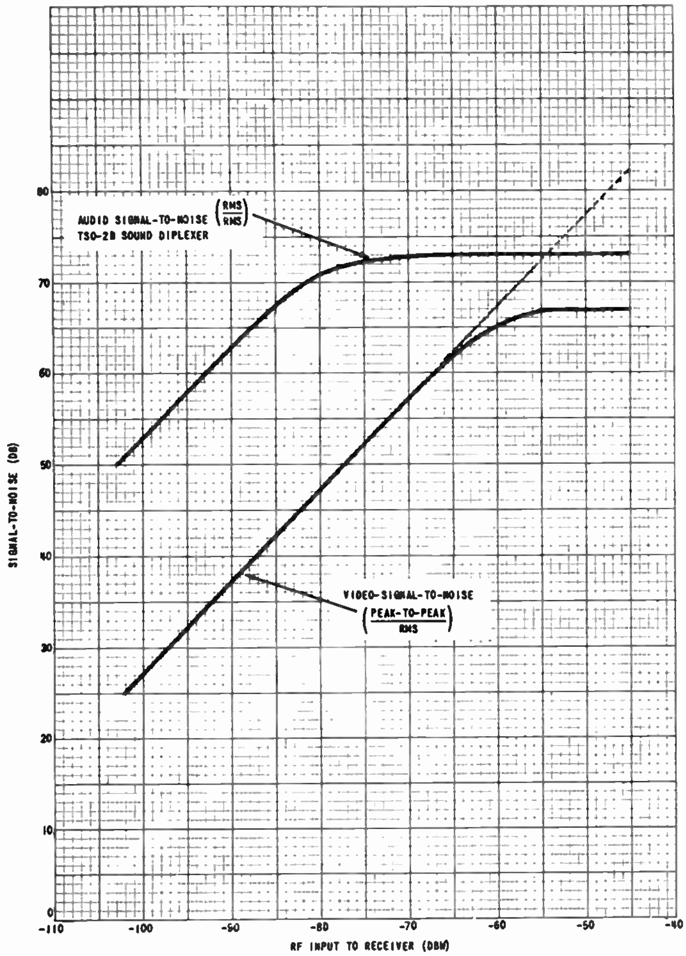


FIG. 37(a). Signal-to-noise ratio.

Figure 36 shows a typical microwave path drawn on profile paper. In the absence of more specific information, a fixed allowance of 50 feet should be made in rural areas for trees, low buildings and other obstructions when these are not known. In urban or metropolitan areas, suitable allowance must be made for tall buildings. This can ordinarily be done by visual inspection.

When plotting elevations on this paper, note that only one vertical scale can be used with a given horizontal scale. Suitable pairs of values are shown at the bottom of the graph. Also note that the middle of the path should be located at the center of the graph. At the end of each path, insert vertical lines to scale to represent the chosen antenna tower and join the tops of the lines with a straight line to represent the direct radio path. Divide this path into sections representing 1/8, 1/4, 1/2, 3/4 and 7/8 of its total length. At these points, measure at right angles distances representing the clearance appropriate to the path length.

At this point refer to Fig. 31 and note that the graph shows the required clearances at these section points for paths of varying lengths. The path clearance zone may be drawn by completing the curve delineated by the section clearance points as illustrated in Fig. 36.

Path Length

The range of a microwave relay system is determined by the propagational reliability required and by the permissible signal-to-noise ratio. Calculation of these items for a given path involves consideration of antenna size,

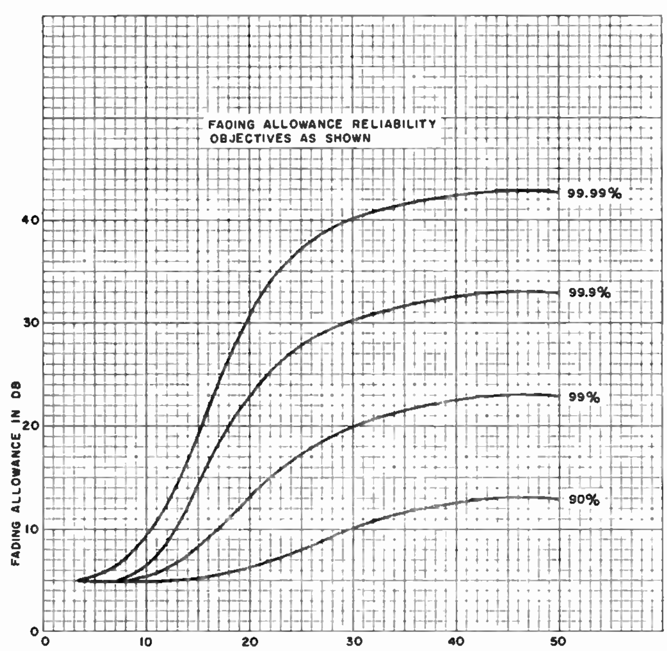


FIG. 37(b). Fading allowances.

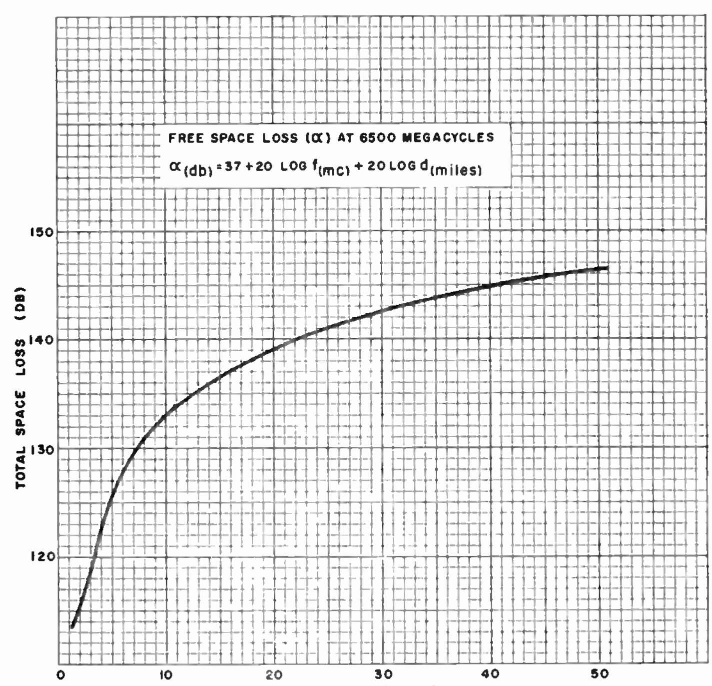


FIG. 37(c). Free-space loss.

HOW TO DETERMINE PARABOLIC AND PASSIVE REFLECTOR SIZES FOR A GIVEN SYSTEM PROPAGATIONAL RELIABILITY

Example:

Assuming propogation reliability of 99.99 per cent is to be expected.

A profile plot has been made and adequate clearances obtained as described in the preceding pages of this section.

Path length=20 miles.

Distance from passive reflectors to parabolic reflectors mounted on the ground=150 feet.

Refer to Fig. 37(b) and note that for a reliability of 99.99%, a fading margin of 31 db is required. Add 28 db to this number to get the non-faded s/n ratio $\left(\frac{p/p}{rms}\right)$ required. This is 59 db.

Refer to Fig. 37(a) and note that to obtain a non-fade s/n ratio of 59 db, an r-f power input to the receiver of —68 dbw is required. If some safety margin is to be allowed for tube aging, antenna misalignment, etc., (3 db is usually ample), add this figure to the r-f power input of the receiver. This makes the power input —65 dbw.

Refer to Fig. 37(c) and note that the free space loss between isotropic antennas separated by 20 miles is 139 db. The TVM-1 transmitter has a one-watt power output. Thus, it can be seen that the r-f power delivered to the receiver will be —139 dbw using isotropic radiators. The power input required is —65 dbw; therefore, the antenna system used must provide a combined gain of 139 minus 65, or 74 db.

The required antenna gain may be provided at any desired proportion at the transmitter and the receiver. Examination of Fig. 38(a) will show that a four-foot parabola used with a 6 ft. x 8 ft. reflector mounted at a height of 150 feet will provide a gain of 37 db. Using any two such combinations providing the same net gain will be equally acceptable.

transmitter power, path length, transmitter-modulation, receiver noise figure, system bandwidth and other factors.

Figure 37(a) is a plot of signal-to-noise ratio which can be expected from the TVM-1 equipment operating normally with varying receiver inputs.

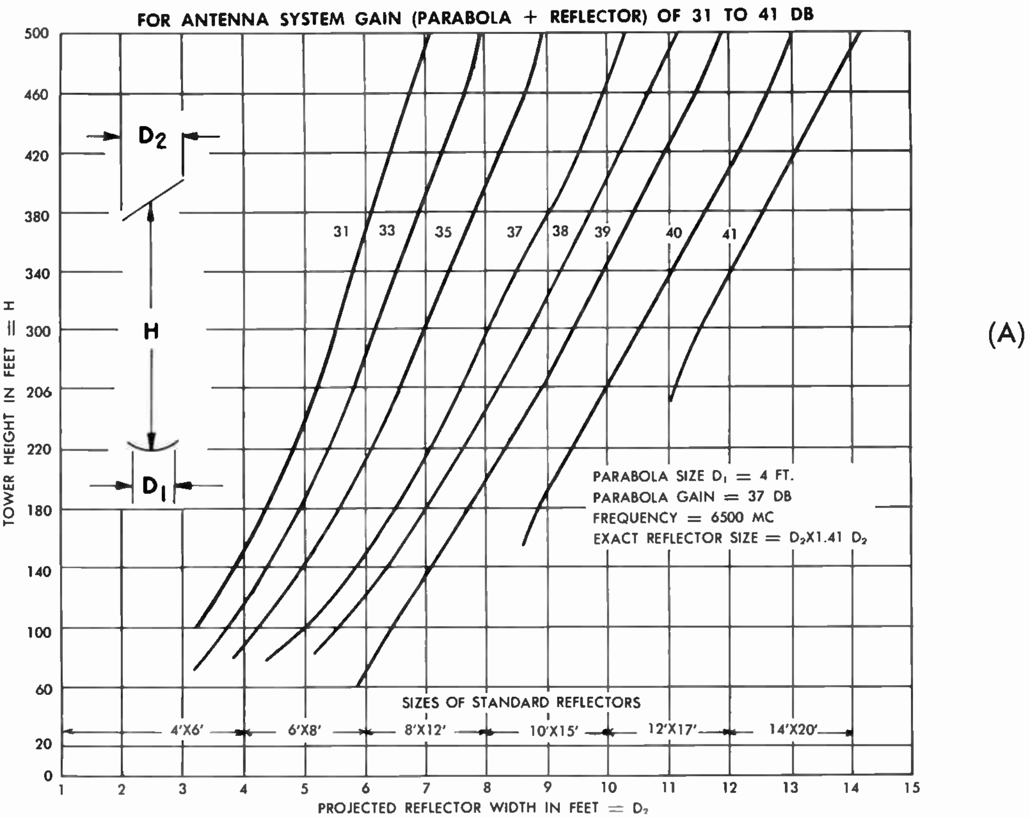
The receiver input power is determined from the net path loss between transmitter and receiver. This is calculated by determining the free-space loss between transmitter and receiver from Fig. 37(c), and then subtracting the antenna gain at each end of the system. The resulting figure indicates in dbw how far the receiver input level is below that of the one-watt transmitter. Reference to Fig. 37(a) will then give the signal-to-noise ratio to be expected from the receiver under non-faded conditions.

Noise indicated in Fig. 37(a) is random noise only and does not include ac hum or any other periodic tone. Such noises are independent of path length.

Propagational Reliability

In most practical cases the possible range of the equipment is determined by the reliability of the transmission path required. The reliability figure expresses as a percentage the amount of time in which the signal-to-noise ratio will be better than a prescribed minimum. This minimum is taken at 28 db p/p picture to rms noise* which, according to tests, the average observer will tolerate only for a short time.

* NOTE: The minimum acceptable signal-to-noise ratio of 28 db, under fading conditions, is based on numerous subjective measurements made by RCA and others (*Perception Television Random Noise* by P. Mertz, Journal of SMPTE, January 1950; *Quality Rating of Television Images* by P. Mertz, A. D. Fowler, H. N. Christopher, Proceedings of IRE, November 1950). Under this condition the noise will be visible but not sufficiently severe to destroy the commercial usefulness of the picture. While a higher signal-to-noise level is required for normal non-fading conditions. The minimum level as shown can be tolerated for short periods of time.



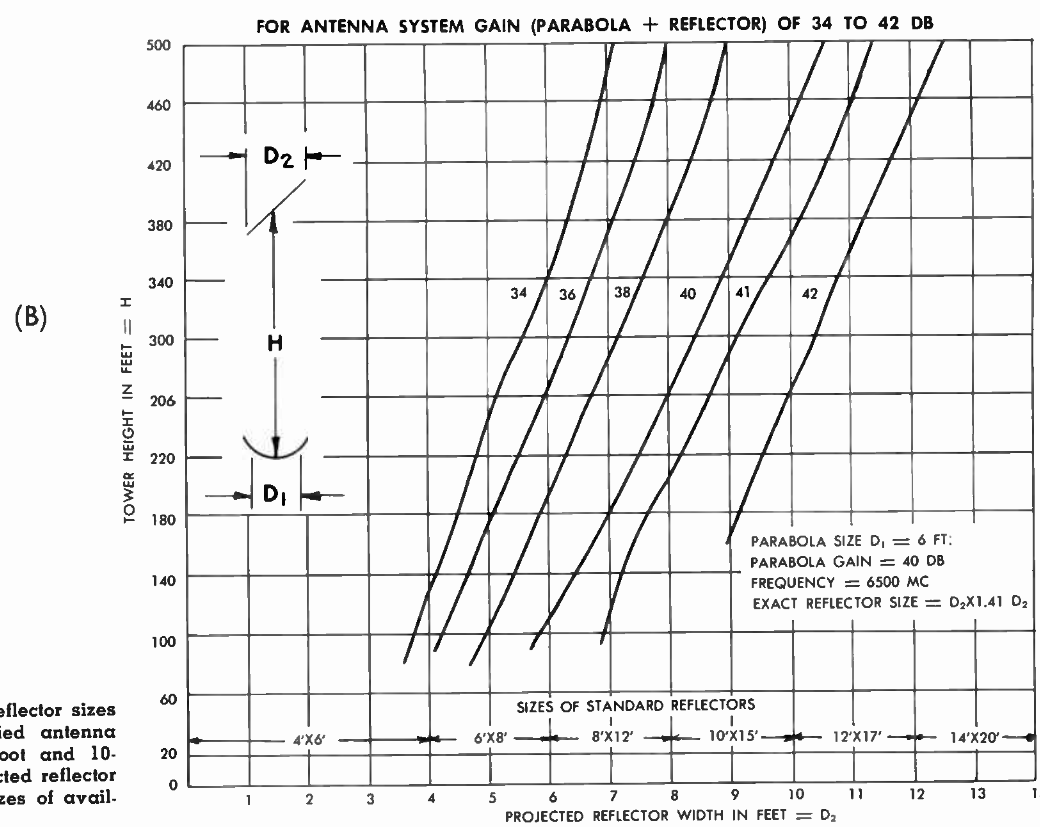
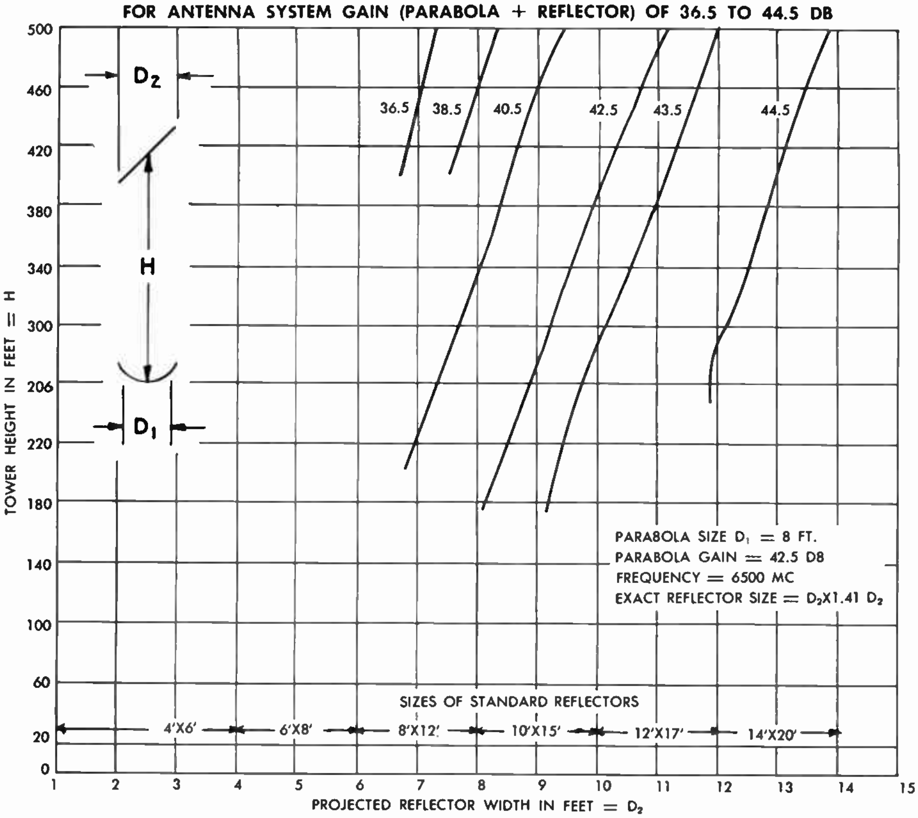


FIG. 38. Curves showing required reflector sizes and tower heights to obtain specified antenna system gains from 4-foot, 6-foot, 8-foot and 10-foot parabolas. Curves indicate projected reflector widths, or the smallest dimension; sizes of available standard reflectors are given.

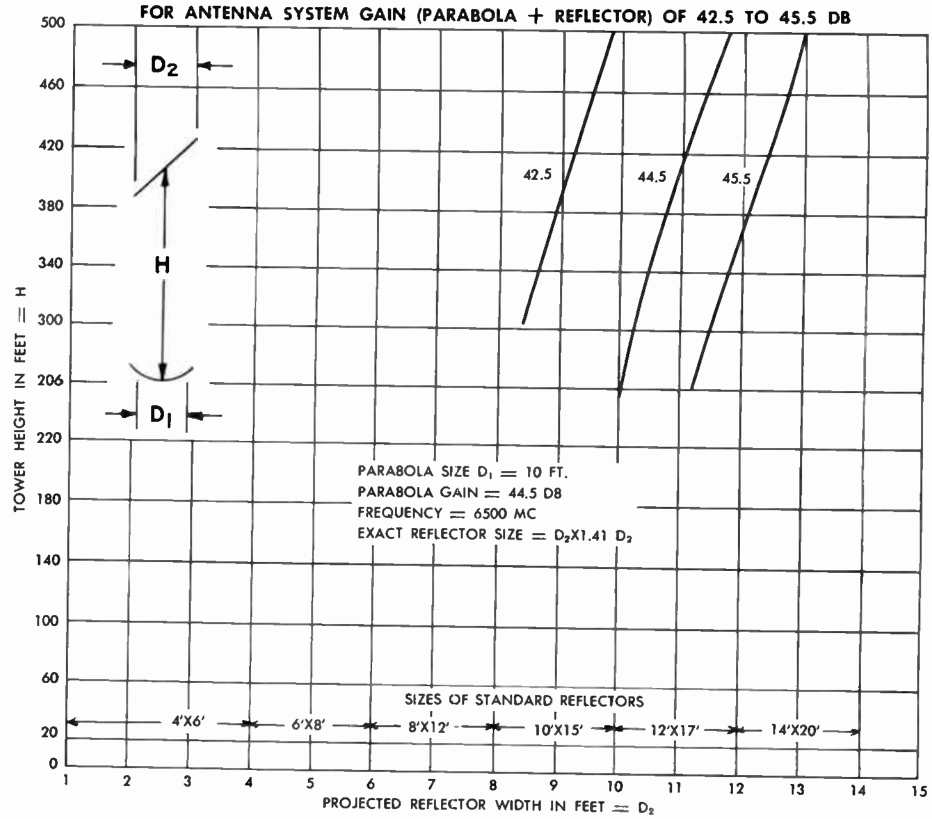
FOR ANTENNA SYSTEM GAIN (PARABOLA + REFLECTOR) OF 36.5 TO 44.5 DB



(C)

FOR ANTENNA SYSTEM GAIN (PARABOLA + REFLECTOR) OF 42.5 TO 45.5 DB

(D)



Reliability percentage is read from Fig. 37(b), after first determining the fade margin provided. The fade margin is the number of db by which the non-faded signal to noise ratio exceeds the 28 db minimum tolerable. It can be seen from the curves of Fig. 37(b) that longer hops require greater fade margins to provide a given reliability.

The reliability percentages are tabulated below to show the corresponding number of hours of outages per year, based on a full 8700-hour year. Ordinarily, most of these outages occur during the 3 to 4 hour intervals of calm atmosphere about during sunrise and sunset.

Per Cent Reliability	Hours Outages per Year
99.0	87.6
99.9	8.7
99.99	0.87

Diversity

The propagational reliability figured for a path can generally be improved by a magnitude of ten or more by using space or frequency diversity. By employing diversity, a 99.9% path becomes 99.99% or better. In space diversity the receiving antennas must be separated vertically by a distance which is determined by the path geometry. It is normally about 100 to 200 wavelengths (15 to 30 feet). In frequency diversity common antennas may be used on both paths. and a frequency spacing of 200 mc or more is desirable. Diversity switching equipment is available for use with the TVM-1.

Multihop Systems

The high power, stability, excellent transmission characteristics and operational features of the TVM-1 equipment make it well suited for use in multihop systems of moderate length. This section is devoted to a description of the engineering principles which should be followed in planning such systems.

Location of Multihop Sites

Unlike single hop systems where the transmitter and receiver location are ordinarily fixed by the terminals of the circuit, the intermediate relay points in a multihop system can frequently be selected to take advantage of the natural terrain features. This flexibility increases the responsibility of the designer, since the choice of optimum sites requires a careful study of construction costs, land costs, site accessibility, power availability, and other factors.

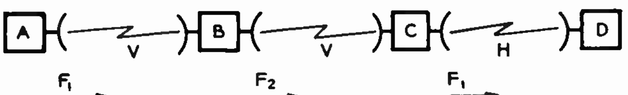


FIG. 39. Multi-hop microwave system using alternate frequencies and polarization to avoid interference.

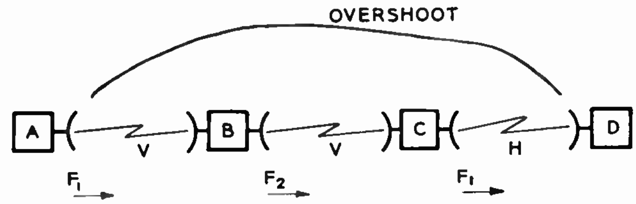


FIG. 40. System of Fig. 30 showing possibility of interference due to overshoot.

Because outage time due to fading is cumulative in a multihop system, it is usually desirable to use shorter paths than the longest which could be employed in a single hop system. If the path lengths are too short, on the other hand, the possibility of outages due to equipment failure and signal distortions are increased because of the large number of hops required. Path lengths in the order of 20 to 30 miles are recommended for the TVM-1 microwave equipment in multihop service as a compromise between these requirements.

Certain obvious physical considerations must be kept in mind in selecting sites. These include accessibility under all types of weather conditions, availability of power, CAA restrictions and the suitability of the soil for tower foundations and guy anchors.

In a system containing more than two hops it is customary to use two transmitting frequencies with the same frequency being used on alternate hops as shown in Fig. 39. This is required because of the possibility of the signal from the repeater transmitter entering the receiver at the same location.

Although a line-of-sight path would not ordinarily exist over the distance covered by a multihop system, certain atmospheric conditions may cause abnormally long-distance transmission to occur. If the sites are in line, this might cause interference known as overshoot as shown in Fig. 40. In such cases it is advisable to locate site D so that a line drawn showing the A antenna path is at least 4 degrees from a line drawn along the D antenna path. This condition is shown in Fig. 41.

Antenna Polarization

Polarization of antennas in a microwave relay system is an effective means of reducing the possibility of interference. With opposite polarizations approximately 20 db of rejection can be obtained. This would involve, for example, using horizontal polarization for the A transmitter and vertical polarization for the C transmitter. See Figs. 39-41.

The unwanted overshoot signal is now considerably attenuated since less power is radiated in the direction of the station subjected to interference. In addition, the gain of the receiving antenna at the station will be reduced when receiving an off-beam signal.

For a high-grade circuit, the level of the overshoot signal should be at least 40 db below that of the desired signal. This amount of protection can often be obtained by the judicious use of terrain features, even when the stations are virtually in a straight line, provided that the overshoot path A to D in Fig. 40 is not less than 50 miles in length.

As a safe rule, however, it is wiser to obtain the required protection by means of antenna directivity since the overshoot signal is subject to erratic propagation conditions. The signal may, during periods of abnormal propagation, arrive at D comparable in strength to the direct signal transmitted from C.

System Reliability

Statistics of the local power utility should be studied to determine if the frequency of storm or other outages is higher for a given area than over a potential alternate route. It is desirable to keep a record of the occurrance of such outages and their duration if an accurate estimate of the performance of the microwave equipment alone is to be made.

Preventive maintenance will be essential to maintain the equipment in first-class working condition. With present equipment designs, metering facilities are built in or are conveniently accessible with a multi-purpose instrument. Therefore, such maintenance is neither difficult nor expensive.

Propagation Reliability of Multihop Systems

In a multihop system, if the signal-to-noise ratio on any of the hops drops below the minimum acceptable value, the signal-to-noise ratio of the entire circuit will, of course, be below the minimum.

To calculate the total time for the entire system, conservative design practice requires the assumption that none of the individual hop outages will occur simultaneously. This means that the over-all outage time is the sum of the outages of the individual hops. Thus, if a system has three hops each with a reliability of 99.9 per cent, the individual outage time would be 0.1 per cent. Therefore, the total outage time would be 3 times 0.1 per cent or 0.3 per cent and the over-all system reliability would be 99.7 per cent.

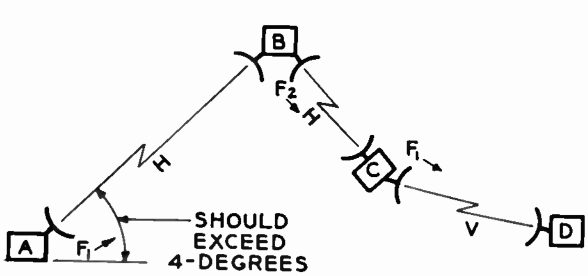


FIG. 41. Locating multi-hop sites, and polarizing antennas to avoid overshoot interference.

Signal Distortion

The extremely low signal distortion of the TVM-1 microwave system makes it particularly suitable for multihop service. Each link in a multihop system may add distortion to the signal. This is particularly true with respect to amplitude frequency response, differential gain distortion and differential phase distortion.

Conservative design practice requires the assumption that the over-all distortion of the system may be as great as the sum of the distortions specified for single hops. For example, the specified tolerance on differential phase shift for the TVM-1 equipment is 1 degree. Thus, the possible differential phase shift error for a three-hop system is three degrees. In practice, the total distortion will probably be less since there is the possibility of the distortion cancelling. Also, it is unlikely that all the equipments will be operating at the limit of their tolerances.

Multiple Hop Applications

Since most relay points are unattended, a number of special equipment problems arise which will now be considered.

Radiation Switch

FCC policy requires that the carrier be turned off during periods when no modulating signal is present. It is preferable, however, to leave the transmitter operating continuously in order to improve tube life, increase the system stability and reduce the possibility of equipment failure. To solve this problem, the TVM-1 microwave equipment is provided with a radiation switch consisting of an attenuator inserted in the waveguide feed which makes it possible to shut off the transmitter. For unattended points, this switch can be actuated by a relay controlled by the AGC voltage of the receiver at the same location. In this way, the entire system can be turned on and off from the transmitting end of the circuit.

Stabilizing Amplifier Use

Locating a stabilizing amplifier at the receiving terminal of a multi-hop system is recommended procedure. This is good practice in single hop systems and is even more useful in a multihop system. The stabilizing amplifier will greatly reduce any hum introduced by the system and will also minimize transient surges which may occur during periods of rapid fading.

Towers

The selection of the proper tower for the support of the antenna system involves several factors of major importance, of which tower twist and deflection rigidity are paramount. The factors of safety, wind and ice loading, load supporting ability, lighting, grounding system and painting must also be considered. The specifications as given in the RETMA* Tentative Standards Proposal on Microwave Towers and Mechanical Characteristics for Microwave Antennas and Passive Reflectors are recommended as a basis for determining tower requirements.

The height of the tower and the obstructive area of the parabola and/or reflector will be determined by the path calculations. Additional information relative to the climactic conditions and the nature of the soil will be necessary. The normal single-hop TV relay will ordinarily use the existing facilities of the broadcast station. However, the unattended repeater station tower requirements will always require individual analysis.

Automatic Tower Light Control

Unless the tower lights are to be left on continuously and are observed by a responsible individual and the failures reported locally to the CAA, a photoelectric cell control relay must be provided to turn the lights on and off. The controls for these lights must have contacts which initiate a failure-alarm signal to some attended location. Before finally choosing a site, a check should be made with the nearest CAA office to determine the specific local requirements for lighting.

Buildings

The buildings can be any of three basic types: prefabricated steel; poured concrete; or cinder block. The building must be well ventilated, yet waterproof and verminproof. Automatically operated vent fans help to maintain proper operating temperatures inside the building.

The concrete building and the cinder block building are more expensive than the prefabricated metal building, but they do have the advantages of being tighter, provide better heat insulation and are sturdier in appearance. They provide better protection from hunters and vandalism and the slab concrete roof is excellent protection against falling ice.

Whatever type building is chosen it should be large enough to accommodate a work table and those items of test equipment likely to be needed in servicing in addition to the permanently installed equipment.

When a gasoline-driven generator is installed, it is recommended that the building be provided with a firewall between the power room and the equipment room. The firewall provides protection in case of gasoline fire and also prevents corrosive battery fumes from entering the equipment room.

Auxiliary Power

Every effort should be made to locate the relay station close to a good source of commercial power. However, even the best power lines, especially those in rural areas, are subject to interruption. Therefore, if utmost reliability is necessary, an auxiliary power unit will be needed.

A gasoline-driven power unit of ample capacity is desirable for unattended repeater stations. This will provide power for the TVM-1 equipment, interior lights, test equipment, soldering iron and tower lights.

The generator must be provided with an automatic transfer panel to sense the loss of the main power, crank the gasoline engine, transfer the r-f equipment's power leads to the auxiliary generator and return the equipment back to its normal source of power after the source has been restored for at least 15 minutes.

If the time required for switching of this type cannot be tolerated, then a continuous power unit having an a-c motor, an a-c generator and a gasoline engine connected to it with a solenoid-operated clutch can be provided.

In locations where no primary power is available, two motor-generator sets with automatic changeover facilities are usually installed.

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* Now known as Electronic Industries Association.

PART 12

Color Test Equipment

High quality test and monitoring facilities are important and necessary to the color television station in maintaining desirable standards of performance and to insure compliance with FCC regulations.

Equipment used for *monitoring* color transmission is almost the same as that used for monochrome, except for the TM-21 Color Monitor and the high quality demodulator needed for color. The TM-21 sets the standard of system performance, serving not only in monitoring functions but also as a vital unit of test equipment. In contrast to modest monitoring requirements, however, color operation has introduced new *test and measuring* techniques, as well as a number of test equipments developed especially for color use.

Test equipment for the color station can be listed in two general categories: (1) equipment needed to evaluate the studio installation; and (2) equipment required to test transmitter performance. Since requirements differ still further, depending upon whether the station originates color or merely participates in color network shows, two additional lists are possible. To assist the reader in visualizing the equipment in each case, typical test equipment lists are presented in Tables I and II. Equipment groups selected for these tables are capable of providing sufficient information to insure that the installation will meet the operating standards established by the FCC.

Color Studio Test Equipment

Most color video signal tests can be performed by use of standard monochrome test items such as wideband oscilloscope, sweep generator and suitable test charts, in conjunction with a linearity checker, color signal analyzer and color bar generator. Detailed information on

TABLE I
STUDIO TEST AND MEASURING EQUIPMENT

EQUIPMENT	PURPOSE
	(a) For Network Participating Stations
Linearity Checker	Differential Gain Measurement
Color Signal Analyzer	With Linearity Checker Provides Differential Phase Measurement
Color Stripe Generator (Optional)	Provides Color Test Signal for Home Receiver Adjustment
	(b) For Color Originating Stations *(All items listed above plus the following equipment)*
Color Bar Generator	Provides Standard Color Signal for Aligning Colorplexers and Monitors
Calibration Pulse Generator	Provides Standard Signal Voltage for Calibration of Waveform Monitors and Setup of Processing Amplifier

TABLE II

TRANSMITTER TEST AND MEASURING EQUIPMENT

(For Color Originating and Network Participating Stations)

EQUIPMENT	PURPOSE
Linearity Checker Color Signal Analyzer	Measuring Transmitter Amplitude and Phase Response
VHF or UHF Sideband Response Analyzer	Measuring Frequency Response of Transmitter
VHF or UHF Sideband Demodulator	Checking and Monitoring Characteristics of Transmitted R-F Signal
Square Wave Generator	Adjustment of Phase Equalizer
Dummy Load and Wattmeter	Power Output Measurements

the use of this equipment in measuring the transfer charracteristics of color television equipment is presented in Parts Eight and Ten of this manual. Reference should be made to these sections and to the test equipment instruction books for actual procedures to be followed in making measurements.

WA-9 Calibration Pulse Generator

The WA-9 Calibration Pulse Generator produces a precise video signal voltage of either 0.7v or 1.0v amplitude. These voltage standards can be used for setup of the processing amplifier in film and live camera chains, as well as for accurately calibrating waveform monitors so that video signal amplitudes can be established. The 0.7 volt output serves as a reference standard for noncomposite video signals, and the 1.0 volt output for composite signals. It is common practice to make these voltages available at jack panels and in switching systems so that the entire distribution system can be aligned conveniently for proper levels.

The WA-9 provides a square pulse at horizontal frequency. The output impedance of approximately 0.6 ohms is sufficiently low to permit feeding several circuits with negligible change in level. In addition, the square wave is timed so that it appears as a positive half-cycle centered between horizontal sync pulses. Thus, the signal will readily pass through any clamp circuits in the system without disabling them. Horizontal drive from the sync generator is amplified and used to trigger a stabilized, cathode-coupled multivibrator which places the calibrated pulse between the horizontal sync pulses. The output pulse is produced by a square wave multivibrator. Output of this stage is clipped by a current-regulating circuit controlled by a voltage reference tube, and the resultant calibrated pulse drives a feedback amplifier with highly stabilized gain.

Circuits of the generator, shown in the simplified block diagram of Fig. 1, feature extreme stability. With line voltage changes from 110 volts to 125 volts, output level will vary no more than 1%. Output voltage variations are held to 0.5% in changing from no termination to one 75-ohm termination, or from one to two 75-ohm terminations. Pulse width is 31.75 microseconds, with a rise time of less than one microsecond and tilt less than 1%.

All components of the WA-9 are mounted on a recessed type chassis designed for standard rack mounting. Controls are located on the front of the chassis for the following functions: pulse position; pulse width; voltage calibration; 0.7/1.0 v selector; and power switch. Output can be controlled by a locking-type screwdriver adjustment.

WA-1 Color Bar Generator

The WA-1 Color Bar Generator supplies a synthetic signal which permits precise alignment of the colorplexer and provides a standard for measuring color camera

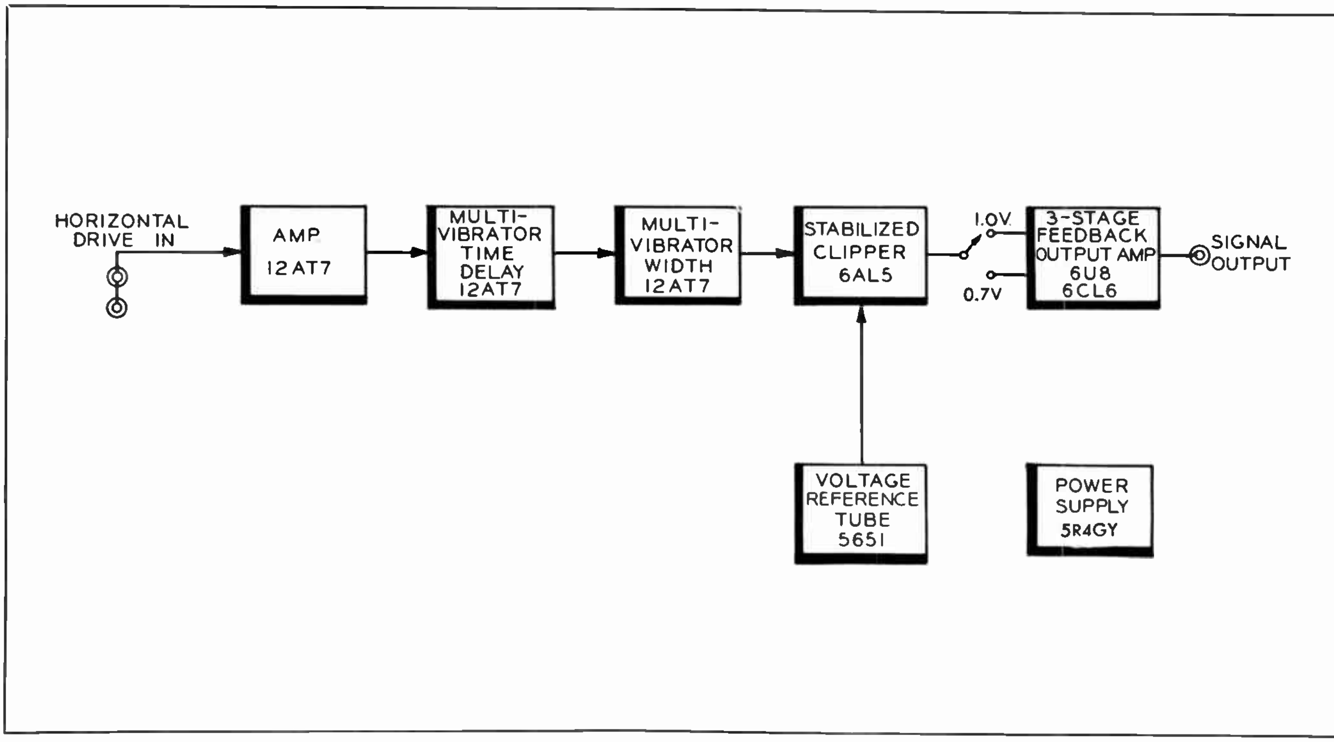


FIG. 1. Block diagram of WA-9 Calibration Pulse Generator.

FIG. 2. Components of the WA-9 are mounted on a recessed chassis.

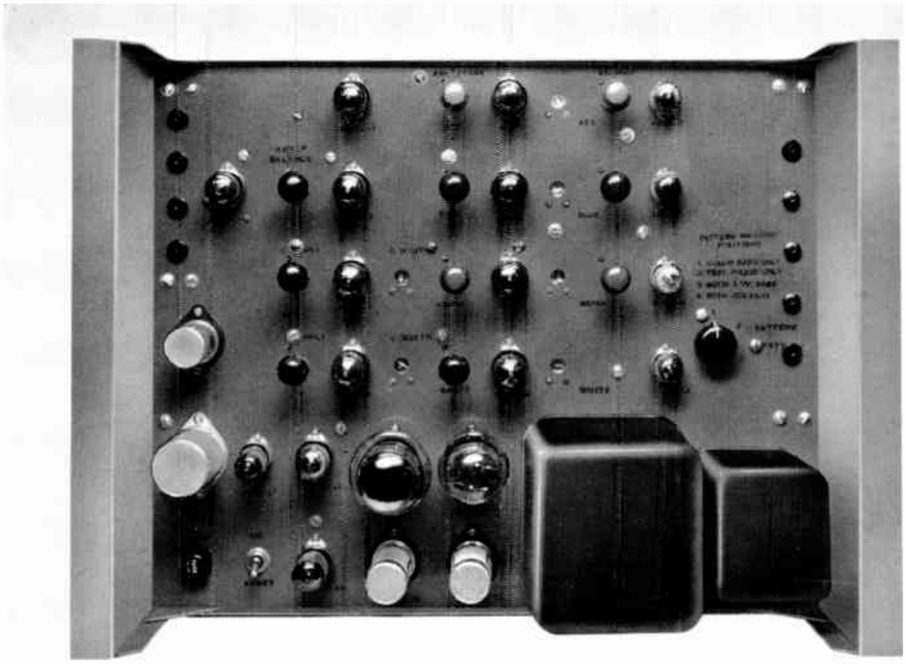


FIG. 3. WA-1 Color Bar Generator.

performance. Use of this signal in the color system is analogous to the use of the monoscope camera in monochrome operations.

The WA-1 generates rectangular pulses which when fed to the red, green and blue input circuits of the colorplexer produce a color bar test signal at the output of the colorplexer. In addition, the generator is capable of providing a split-field color bar pattern on the color monitor, displaying standard color bars in the upper half of the raster and a white bar together with the Q and I test bars in the bottom half of the raster, as recommended by the Electronics Industries Association. This standard pattern is illustrated in Part Four of this manual which describes use of the color bar generator in aligning the colorplexer.

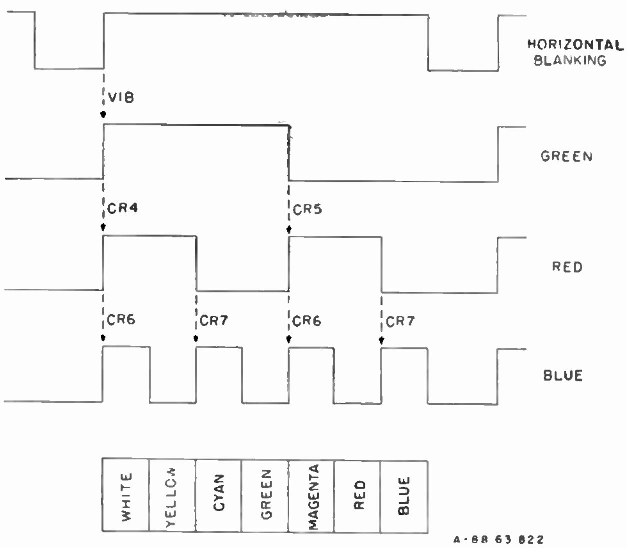
Circuits of the color bar generator are shown in the simplified block diagram of Fig. 5. All components are mounted on a recessed type chassis designed for standard rack mounting. An integral regulated power supply and conservative circuit design assure stability in operation. Limiting action insures constant output level of 0.7 volt or 1.0 volt peak-to-peak for all of the color bar signals.

In operation, the trailing edge of the horizontal blanking pulse triggers the green multivibrator which is adjusted to produce a pulse long enough to include the first four bar intervals. The green multivibrator triggers the red multivibrator from both its leading and trailing edges, so there are two red pulses per line period, each one-half as long as the green pulses. The red multivibrator in turn triggers the blue multivibrator from both its leading and trailing edges to produce four pulses, each one bar interval wide.

Formation of the Q, I and White pulses is as follows: The trailing edge of the horizontal blanking pulse initiates the I pulse; the trailing edge of the I pulse triggers the the white pulse; and the trailing edge of the white pulse triggers the Q pulse. The manner of triggering as well as the amplitude and time relationships of these pulses are shown in the diagrams of Fig. 4.

WA-6 Color Signal Analyzer

The WA-6 Color Signal Analyzer is designed to permit the study of the composite color video and subcarrier signal. The WA-6 facilitates adjustment of the colorplexer, and when used in conjunction with the color bar generator and an oscilloscope, permits accurate measurement of phase relationships existing between the subcarrier burst reference and various components of the composite color signal. The instrument is also used in



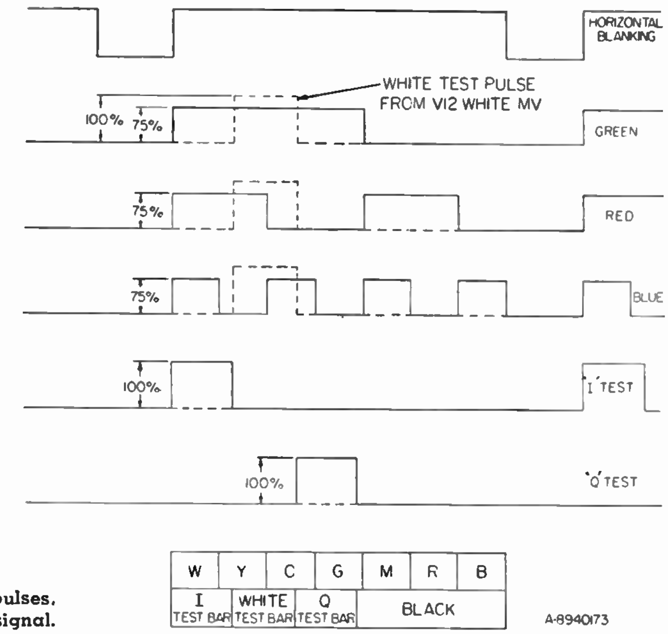
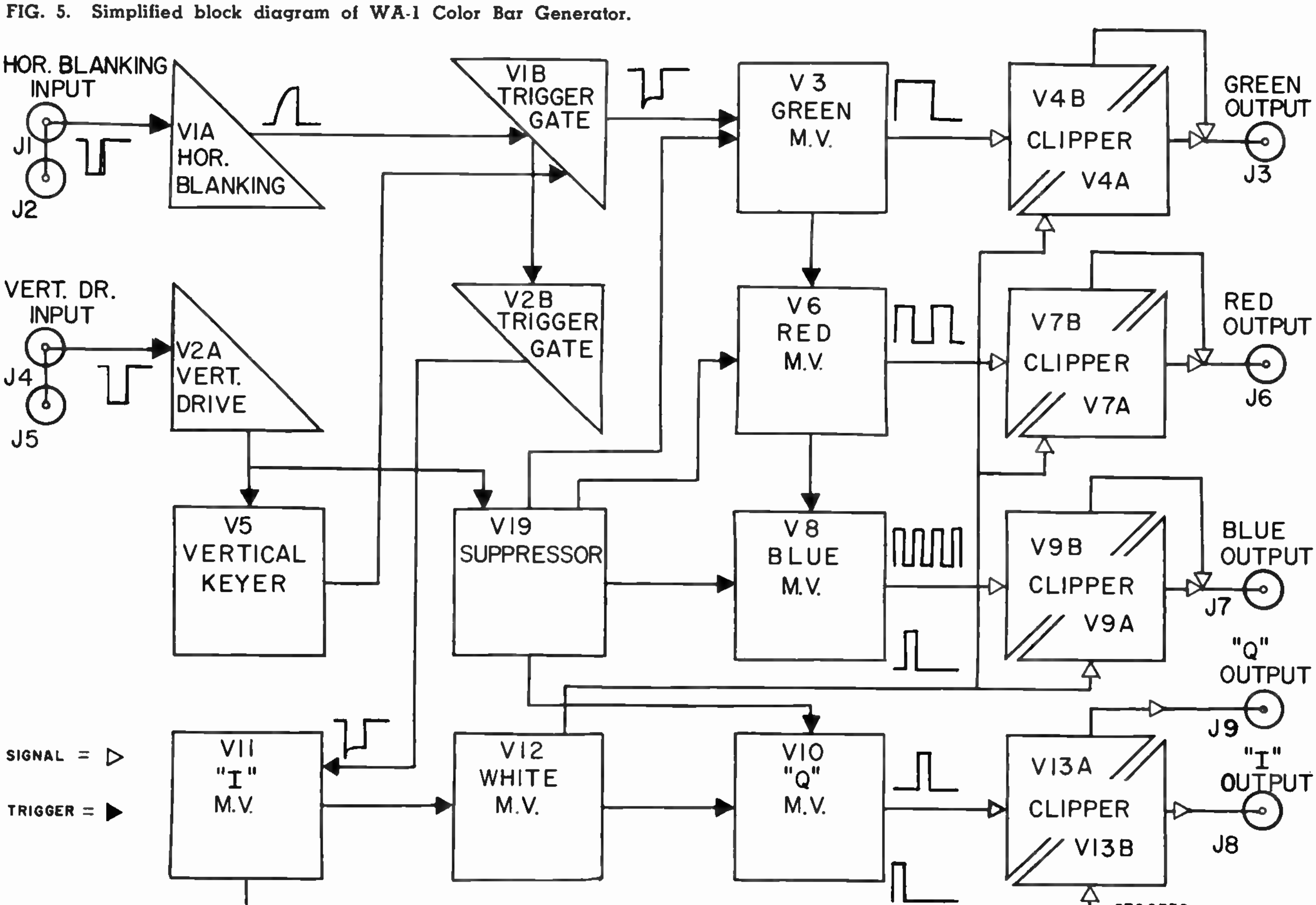


FIG. 4. Diagram showing deriviation of R, G and B color bar pulses, and time and amplitude relationships in the composite bar signal.

FIG. 5. Simplified block diagram of WA-1 Color Bar Generator.



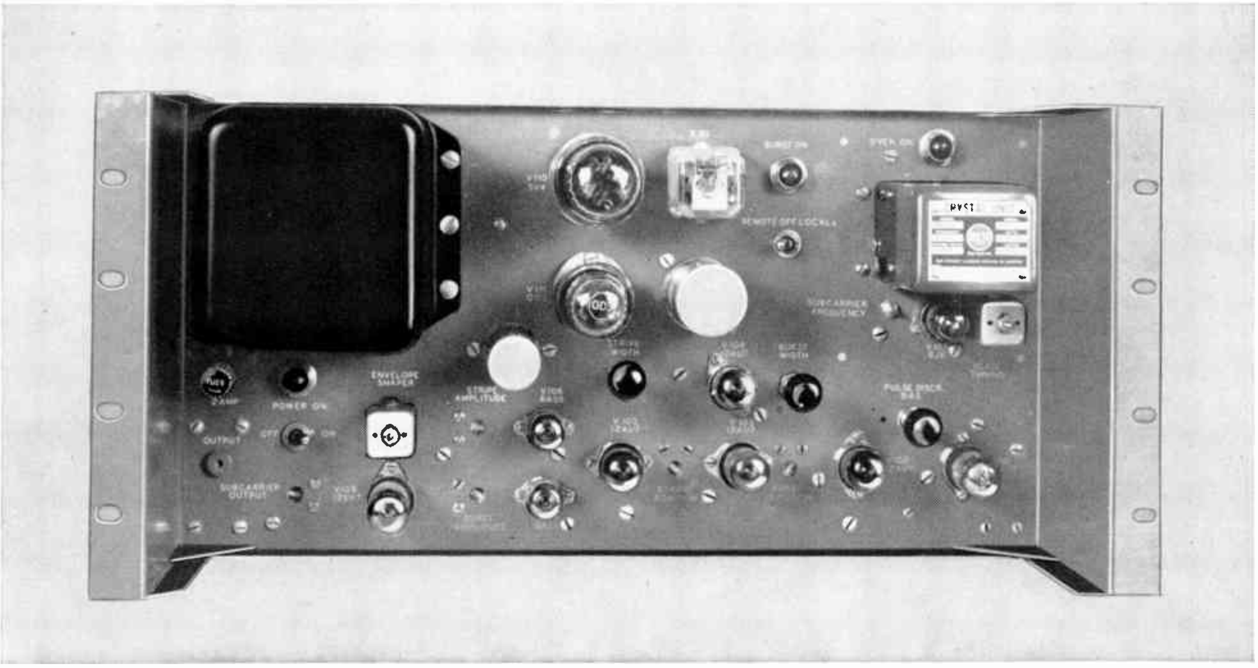


FIG. 6. WA-8 Color Stripe Generator.

conjunction with the linearity checker for making differential phase (phase intermodulation) measurements. Use of the WA-6 in making these measurements is described in Part Ten.

In all cases a source of subcarrier is required in the operation of the color signal analyzer. This can be obtained from the linearity checker which contains a generator for this purpose, or it can be obtained from the output of the frequency standard. The color signal analyzer is a null-indicating type instrument for measuring phase at subcarrier frequency. It contains self-calibrating facilities and is capable of measuring phase differences of the order of 0.5 degrees.

WA-8 Color Stripe Generator

The WA-8 Color Stripe Generator is an inexpensive color signal generator designed to produce a color test stripe on color home receivers. Use of the generator makes it possible for the viewer or receiver service personnel to determine that a particular color receiver installation is capable of reproducing color programs, even though at the time only monochrome programs are being broadcast.

Any station which is equipped to transmit network color can use the color stripe generator to add a narrow color stripe to the monochrome signal. The stripe signal is normally unnoticeable on either monochrome or color receivers; but the technician installing a color receiver can use the signal to produce a stripe of yellow-green color (when color reception is normal) by making a deliberate temporary misadjustment of the horizonal deflection oscillator. The generator is loosely coupled to the video line feeding the transmitter in such a way that normal system operation is not changed.

Information added by the stripe generator to the composite monochrome signal consists of two bursts of 3.58 mc subcarrier frequency. The first burst is positioned immediately following horizontal blanking, or 9.2 microseconds (+0.6, —0.0) following the leading edge of horizontal sync. In this location, it is just outside the period normally "sampled" by the burst gate of a receiver, so it does not activate the color circuits in the receiver. If the horizontal phasing circuits of the receiver are deliberately misadjusted, however, the burst sampling pulse can be moved over to pick up the first burst of the stripe signal. When this happens, the color receiver responds as if the signal had a normal color sync burst (i.e., the color circuits are activated). The second burst is positioned so that its leading edge is three microseconds preceding the leading edge of horizontal picture blanking. This burst produces the color on the kinescope of a properly adjusted color receiver. Since these signals are devoid of any luminance component, they are positioned on the average of the luminance value present in the monochrome signal at the time. When a color program is broadcast, however, the stripe generator should be turned off so as not to cause color interference.

Circuitry of the color stripe generator is shown in the block diagram of Fig. 7. The purpose of the sync separator is to strip sync from the composite monochrome signal. The "burst eliminate" circuit prevents the separation of pulses during the vertical sync and equalizing pulse intervals. No bursts or stripes should appear for

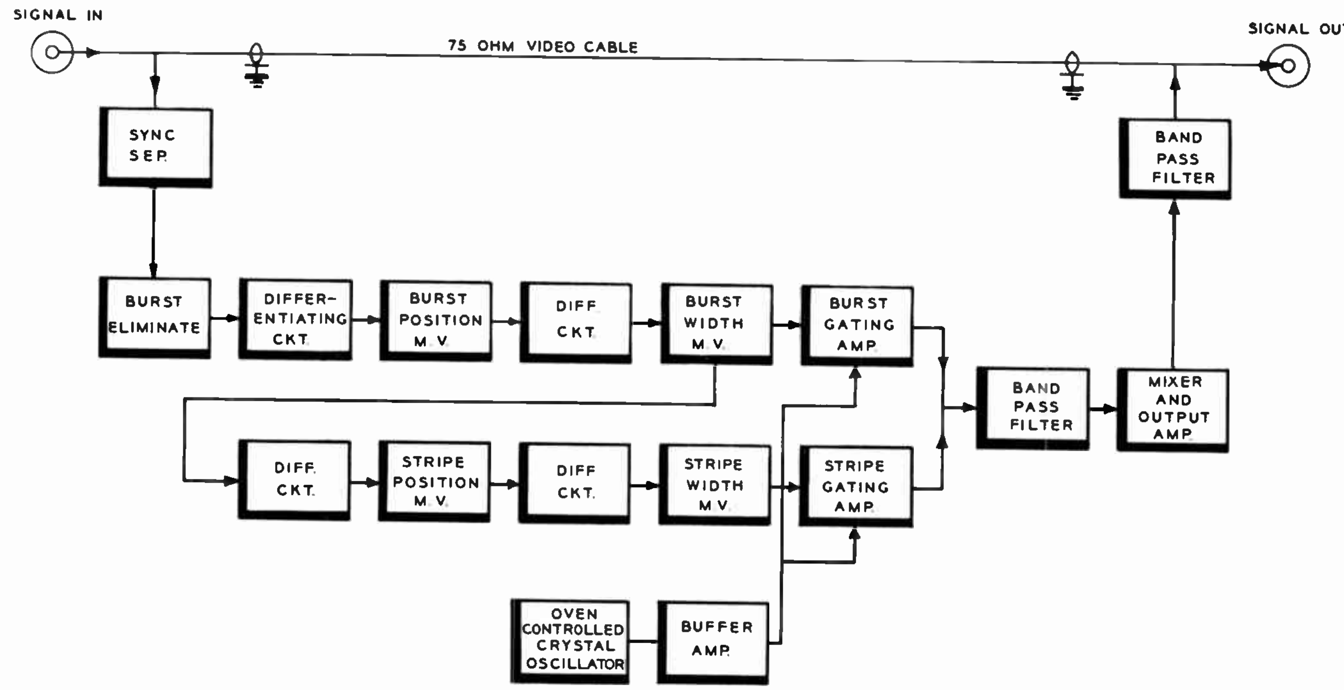


FIG. 7. Block diagram of Color Stripe Generator.

nine lines during the vertical blanking interval. The output of this stage, therefore, is a series of pulses at horizontal rate with a nine-line gap during the vertical interval. This information is differentiated and applied to the burst position mutivibrator which in turn drives the burst width multivibrator. Its output is the positive pulse necessary to trigger the burst gating amplifier. A second output drives the stripe position multivibrator which in turn drives the stripe width multivibrator. Its output is also a positive pulse necessary to trigger the stripe gating amplifier. The subcarrier signal at 3.579545 mc is produced by a stable oven-controlled crystal oscillator. Its output is supplied to the gating amplifiers. The gating amplifiers feed the mixer and output stage, which in turn feeds back to the video line. Thus, the video line is never broken. If failure of the stripe generator should occur the monochrome signal would not be affected. Coupling of the output signal to the video line is so loose that the monochrome signal is essentially unaffected, but the color bursts or envelopes are added or superimposed on it.

All controls for the generator are accessible from the front. Front panel controls consist of the Remote-Off-Local switch which applies +B to the subcarrier oscillator and mixer output tubes in the remote and local positions and removes it from the tubes in the off position; pulse discriminator bias pot for adjusting the clipping level so that under all values of picture information

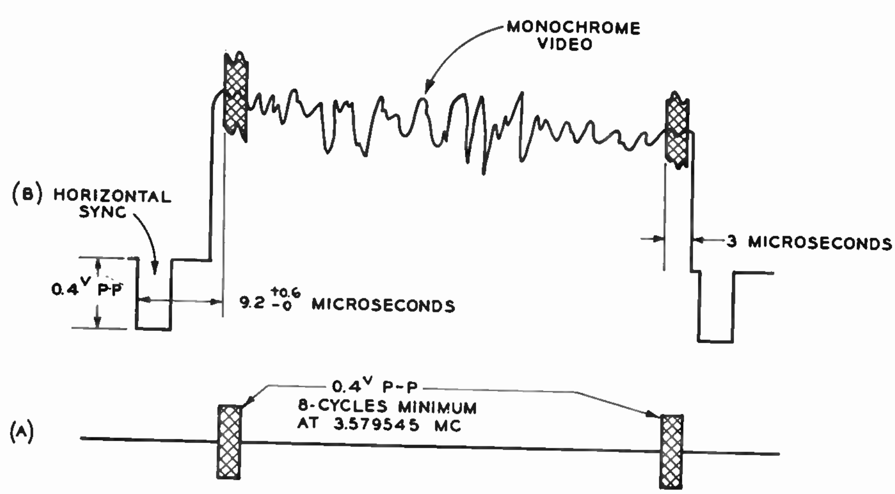


FIG. 8. Diagram showing signal produced by the Color Burst Generator. Line (A) represents color bursts of subcarrier frequency, and line (B) is the composite signal from the Color Stripe Generator.

nine lines of bursts are eliminated during the vertical blanking interval; subcarrier frequency control—a trimmer to adjust the oscillating frequency of the oven controlled crystal to exactly 3.579545 megacycles; subcarrier output control—a level setting control common to both burst and stripe for adjusting their amplitudes with respect to the monochrome signal; three separate controls associated with the color burst for adjusting its width, its amplitude and its position with respect to sync; envelope shaper control—essentially a control to adjust a bandpass filter (a low Q resonant circuit) for best shape of the burst and stripe envelopes; oscillator plate tuning—an inductance control for adjustment of the crystal oscillator plate circuit for maximum stability; and the on-off power switch.

WA-7 Linearity Checker

The WA-7 Linearity Checker generates a test waveform consisting of a staircase signal with provisions for superimposing a 3.58 mc sine wave on the steps, and for varying the average picture level of the signal. Differential gain measurements can be made in video amplifiers, transmitter circuits and transmission systems by use of the linearity checker alone. Differential phase measurements can be made by employing the linearity checker together with the color signal analyzer to serve as a phase detector to analyze the signal after passing through the device under test. Another important use of the linearity checker is in the adjustment of white stretch to compensate for the non-linear transfer characteristics of grid modulation in the transmitter. This is described in Part Ten which covers transmitter adjustments.

The linearity checker includes a Hi-Lo filter which is used at the input to the oscilloscope. By switching the filter between high, low and normal positions, the subcarrier, step wave, or composite signal can be viewed separately, and the waveforms interpreted accordingly. The instrument incorporates a subcarrier frequency generator.

Burst Controlled Oscillator

The burst-controlled oscillator is an accessory for the color signal analyzer for use in special cases where differential phase measurements are to be made over a studio-to-transmitter link, or in any other circumstances where the test signal source is at a distance from the point of measurement. The oscillator provides a continuous subcarrier frequency of 3.579545 mc. Output is locked in frequency and phase to the color synchronizing bursts which are part of the incoming signal being measured.

This item is not necessary if the studio and transmitter are at the same location, or if test procedures are not carried out at a point remote from subcarrier signal sources.

Signals for Grating and Dot Patterns

Signals to produce grating and dot patterns useful in the adjustment of scanning linearity and beam convergence can be obtained from the TG-2 Sync Generator. Circuits built into the TG-2 provide a stable pattern of 13 x 17 bars, white on black background with blanking added. A selector switch in the grating circuits allows choice of horizontal bars, vertical bars, both horizontal and vertical bars, dots at the intersections of the bars, or a test position where sync and blanking are mixed for observation of the front porch.

FIG. 9. WA-7 Linearity Checker.

Transmitter Test Equipment

Equipment required for test and monitoring of the color transmitter is listed in Table II which appears at the beginning of this section. The burst controlled oscillator, although not listed, may be required if the studio and transmitter are not at the same location, as previously stated.

In addition to the linearity checker and color signal analyzer, transmitter tests require use of the BW-5 Sideband Response Analyzer. BW-4 Visual Sideband Demodulator and a suitable r-f load and wattmeter.

Use of this equipment in making measurements is described in Part Ten of this manual. The sideband response analyzer provides for the display on an oscilloscope of the entire frequency and sideband response capability of the transmitter and sideband filter without laborious point-to-point curve plotting. The unit is used in the adjustment of video amplifiers and modulators as well. The analyzer includes a video sweep oscillator making it unnecessary to provide separate video sweep generators for measurement purposes.

The visual sideband demodulator produces a signal for monitoring and checking transmitter output. It provides information on waveform characteristics such as wave shape, sync percentage, depth of modulation, resolution and transient response, as well as a composite picture of the signal for checking compliance with FCC standards.

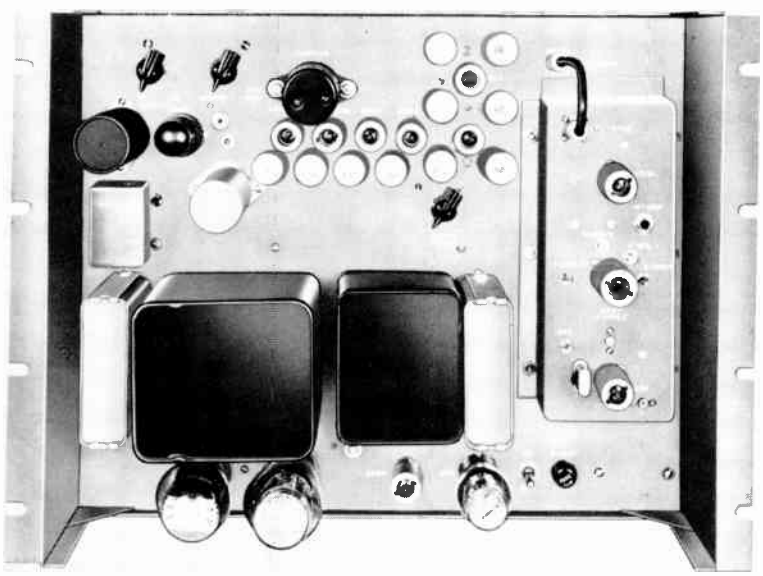


FIG. 10. BW-4 Visual Sideband Demodulator.

FIG. 11. BW-5 Sideband Response Analyzer.

TS-40 TRANSISTORIZED VIDEO SWITCHING SYSTEMS

RCA TS-40 Transistorized Switching Equipment introduces a new concept in the design of video switching systems for color and monochrome television. It provides the broadcast engineer with several important technical advantages, plus a degree of flexibility not found in conventional switching systems.

Aside from the significant reduction in the power and space required, transistors inherently provide extremely rapid switching transitions, greatly eliminating the chance of visible disturbance to the picture. They are immune to dust which often affects the performance of relay switchers; they provide excellent cross-talk isolation; and their life expectancy is almost unlimited. By virtue of the short lead lengths involved, the compact switching assemblies made possible by transistors have excellent video performance.

Modular Design

Modular design and plug-in construction are employed in the TS-40 because of the additional flexibility obtained, and for the convenience these features offer in servicing and in future expansion of facilities. By combining the modules, virtually any size switching system with up to 24 inputs and 10 outputs can be tailored to specific requirements. Taper-tab, taper-pin, and edge-type connectors eliminate most soldering operations and simplify modification or enlargement of the system. Built-in protection circuits protect key components from accidental damage, and etched wiring is used extensively to assure uniform performance.

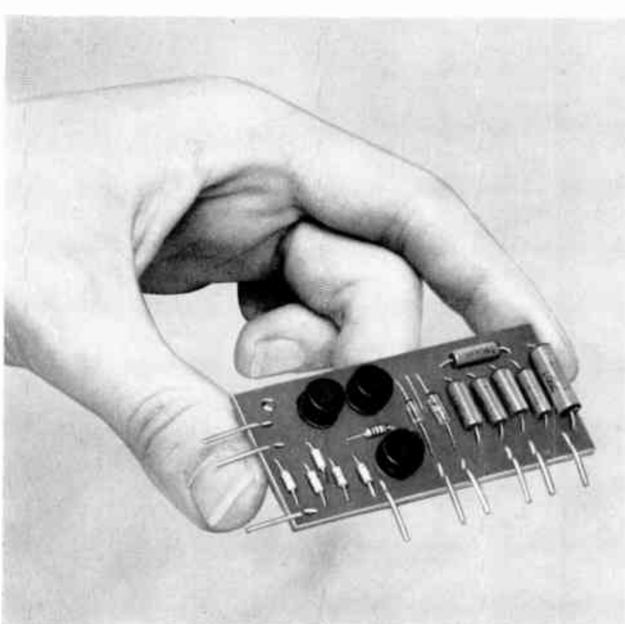


FIG. 1. The Cross-point, basic switching element in the TS-40 Transistorized Switching System.

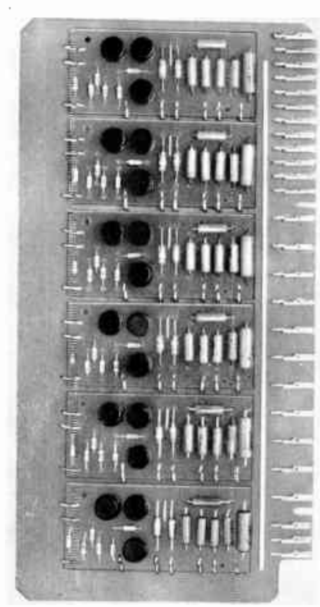


FIG. 2. A Cross-point Group is made by assembling six cross-points on a special plate.

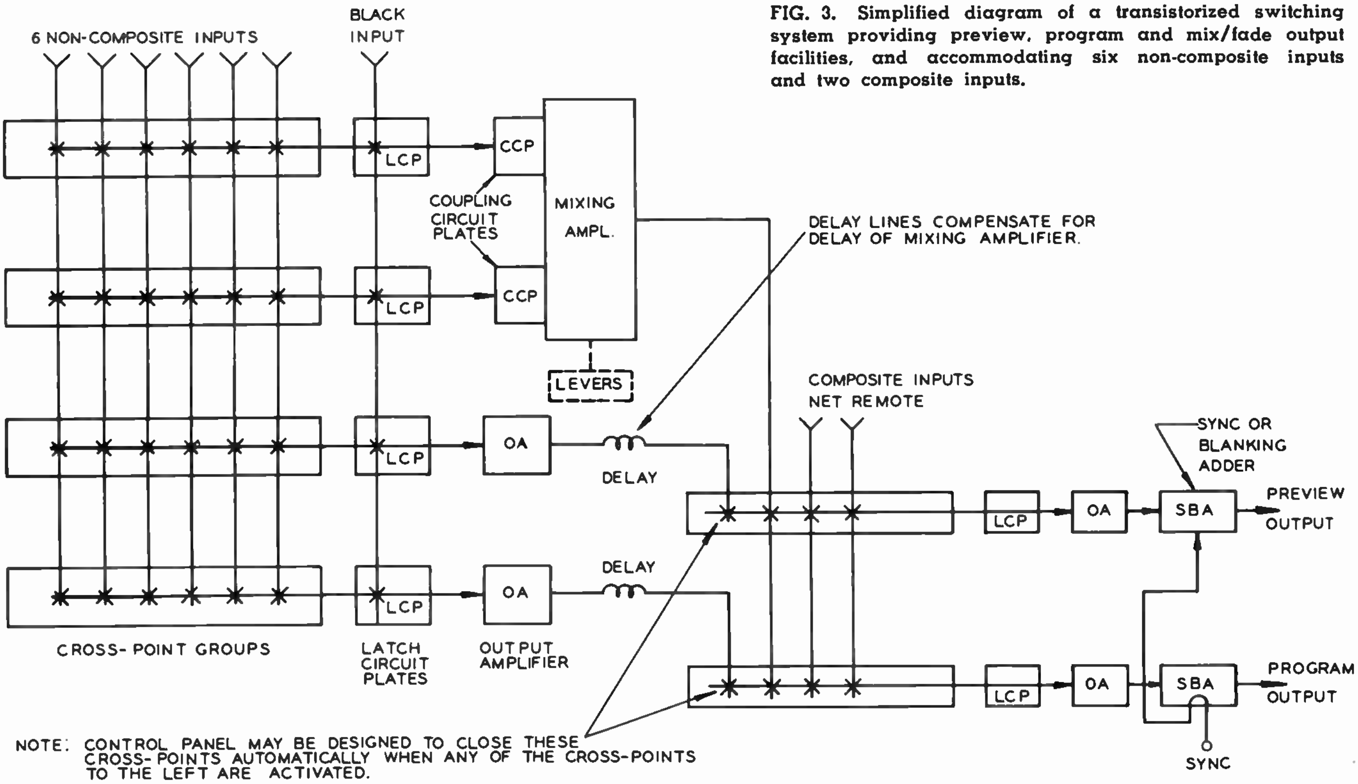


FIG. 3. Simplified diagram of a transistorized switching system providing preview, program and mix/fade output facilities, and accommodating six non-composite inputs and two composite inputs.

Description

Major units of the TS-40 system excepting power supplies are illustrated functionally in the simplified block diagram of Fig. 3. These consist of: Cross-points; Latch Plates; Coupling Circuit Plates; Output Amplifiers; Mixing Amplifier; Distribution Amplifiers; and Sync or Blanking Adders. Power required by the system is obtained from a Transistor Power Supply, dc plate supplies, and a Filament and Bias Supply.

Although the TS-40 employs new circuit elements identified with transistor circuitry, the basic switching philosophy is the same as that used in other RCA video switching systems. Thus, it is practical to supplant or to expand existing switching equipment facilities with the transistorized design. In some installations this may provide the solution to system expansion or possibly the addition of color facilities within the limits of space already available.

Cross-points

The Cross-point illustrated in Fig. 1 is the basic switching element of the RCA TS-40 Switching System. It consists of three transistors and associated circuit components mounted on a phenolic plate. One cross-point provides a single-input, single-output circuit for video; by assembling six cross-points on a specially designed Interconnection Plate, a Cross-point Group providing six inputs and a single output is obtained. This forms the basic plug-in module for the TS-40 system.

A simplified schematic diagram of the basic cross-point is shown in Fig. 4. The circuit is essentially a transistorized flip-flop designed to maintain an internal input impedance, Z, of 825 ohms. The composite termination for video, provided by the crosspoints and padding resistors, is adjusted to 75 ohms. When the cross-point is actuated, flip-flop circuits S and S_1 assume the positions shown; thus, video current flows in the output bus, and the tally relays are energized.

Cross-point groups can be combined in several ways to provide the required number of input and output circuits. For example, the use of two modules with their outputs connected together as shown in Fig. 6 provides a 12-input, single output system; alternatively, the two output busses could be used separately to form a 12-input, two output system.

A Cross-point Frame is used to mount the cross-point modules in an equipment rack or console. Modules plug directly into the cross-point frame as illustrated in Fig. 5. Each frame will accommodate 20 modules and thus provide a system with 12 inputs and 10 outputs. A 24-input, 10-output system can be obtained by using two cross-point frames, each containing 20 cross-point groups. All video input connections are made through coaxial connectors on an Input Connector Strip at the rear of the frame, where signals are distributed to the cross-points by copper busses and etched wiring. Cross-points, Interconnection Plates, Input Connector Strips and tally relays are available separately for use where less than six inputs are needed.

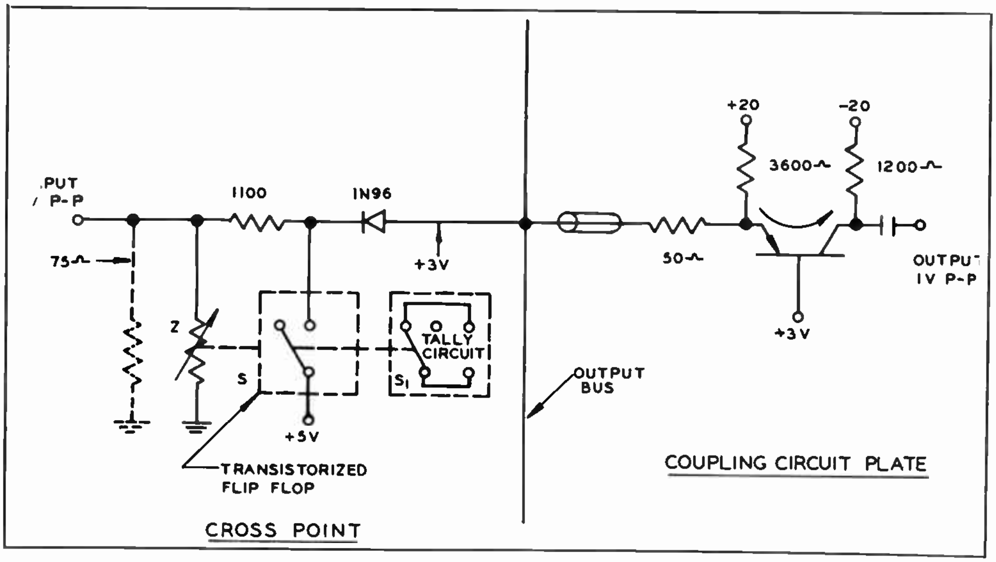


FIG. 4. Simplified schematic diagram of the Cross-point and Coupling Circuit Plate.

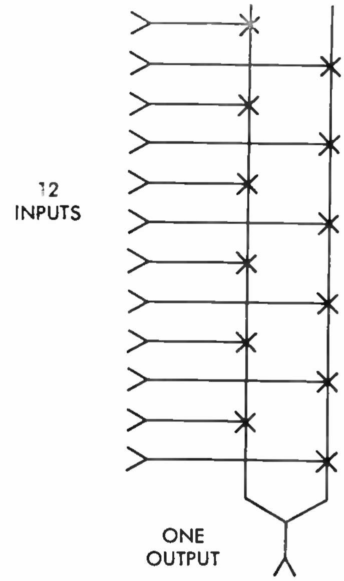


FIG. 6. Connections of two Cross-point Groups to provide a 12-input, one output stystem.

Latch Circuit Plates

Electrical interlock and an extra input for black signal are provided by a Latch Circuit Plate. The interlock (or latch) consists of a transistorized amplifier and clipper which generates a pulse to "turn off" the previous signal each time a different cross-point is activated. One plate is required for each video output bus of the switcher. Any number up to 20 latch circuit plates can be rack mounted using a Latch Frame as shown in

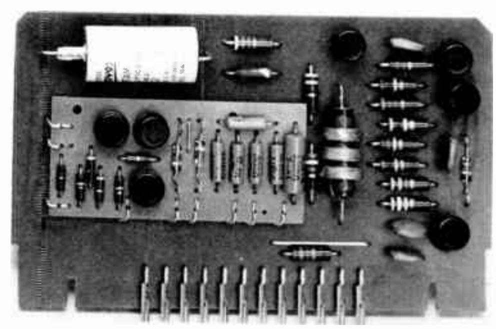


FIG. 7. A Latch Circuit Plate provides electrical interlock and an extra input for black signal.

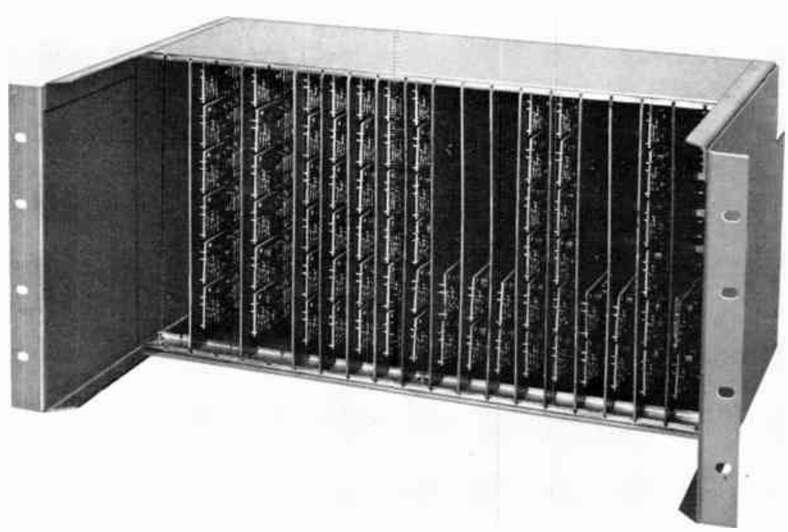


FIG. 5. Cross-point Frame, accommodating 20 Cross-point Groups, is designed for rack mounting.

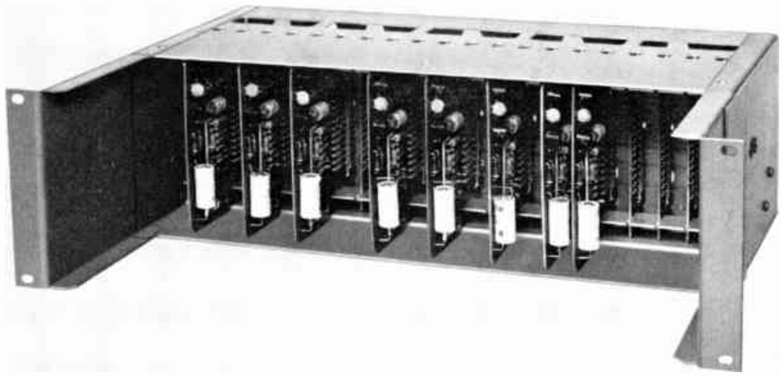


FIG. 8. The Latch Frame provides for rack-mounting 10 Latch Circuit Plates.

Fig. 8. One latch frame containing 20 latch plates can therefore accommodate two independent 12-input, 10-output systems.

Coupling Circuit Plate

The output from each cross-point is at a relatively low level, and therefore a gain-recovery device is required for coupling into the standard-level video distribution system. This gain-recovery is accomplished by the Coupling Circuit Plate shown in Fig. 9. The Coupling Circuit Plate consists of a small phenolic plate containing a transistor and associated components interconnected by etched wiring. Provision is made in both the mixing and output amplifier units for installation of this coupling circuit.

Output/Distribution Amplifier

The Output Amplifier shown in Fig. 10 is a single channel, unity gain video distribution amplifier designed to match the output of the switcher to the video distribution system. The input circuit of this amplifier utilizes the coupling circuit plate previously described. Without this special input circuit installed, the amplifier is identical to the RCA TA-12 Video and Pulse Distribution Amplifier. Both amplifiers are of plug-in construction, and are designed to provide a high degree of isolation between input and output. The inputs of several amplifiers can be bridged to provide multiple outputs. The TA-12, useful for distribution of video, pulse and subcarrier signals, will provide sending-end termination for long or short coaxial lines, and also will match a high impedance signal source to a low impedance line or input.

Mixing Amplifier

The Mixing Amplifier is designed to provide for lap-dissolves, fades and superimpositions of program video. The Mixing Amplifier utilizes a Coupling Circuit Plate for connection to the two mix outputs of the switcher.

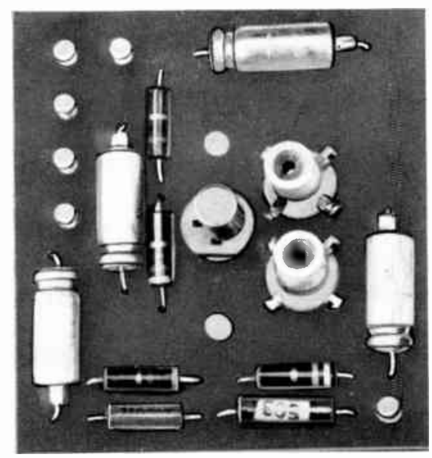
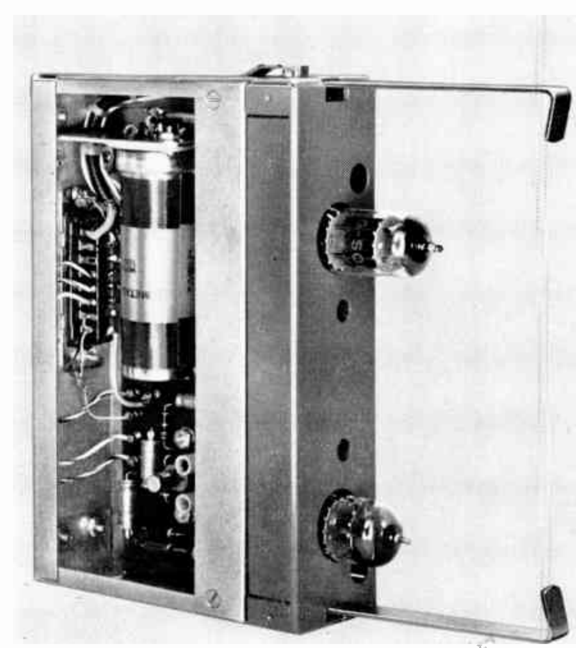


FIG. 9. Coupling Circuit Plate for impedance-matching output of switcher to video system.

FIG. 10. Output Amplifier.



Bias for operation of the amplifier is supplied by the fader potentiometers at the switcher control panel. The amplifier provides two 75-ohm outputs (one non-composite, and the other composite or non-composite) with provision for non-interlocked sync addition to one output.

Sync or Blanking Adders

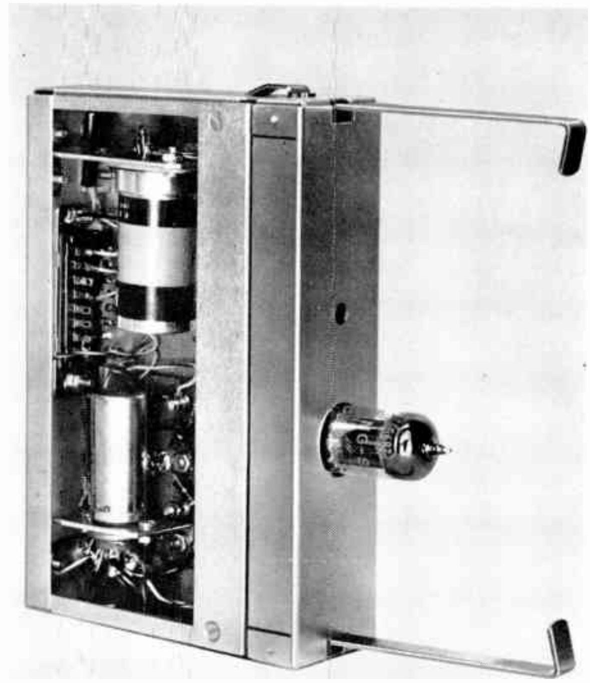
Addition of sync or fixed setup to non-composite signals is accomplished by use of the Sync or Blanking Adder. This equipment incorporates a "sync drop" relay, so that the same output bus can handle both composite and non-composite signals. If both sync and setup are added, two units are used in series as shown in Fig. 11.

Filament and Bias Supply

The Filament and Bias Supply, Fig. 12, is a plug-in unit which furnishes filament and bias voltages for up to ten output and distribution amplifiers. In addition, an external regulated B+ supply is required for these amplifiers.

Transistor Power Supply

The Type WP-40 Transistor Power Supply furnishes voltage to the transistors and tally relays in the TS-40 switching system. The unit, which requires 8¾ inches of rack space, incorporates a trigger generator to reshape the vertical drive pulses (from the sync generator) for proper triggering of the transistor switcher. Switching transitions, which are of the order of a few microseconds duration, are timed to occur during the vertical blanking interval, or between successive television fields. Trigger



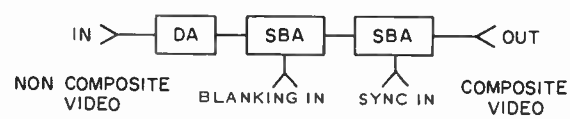


FIG. 11 Sync and Blanking Adder.

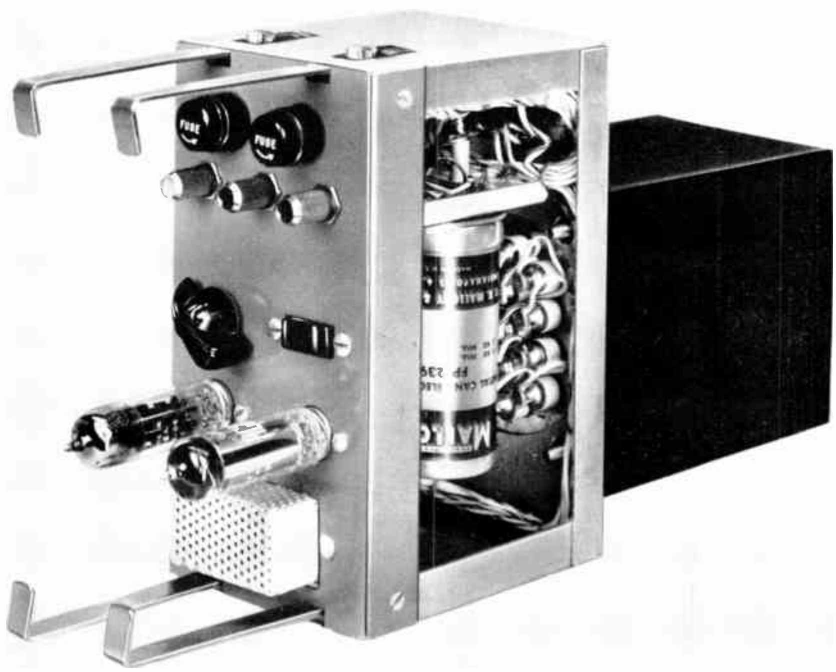


FIG. 12 Filament and Bias Supply.

pulses are fed to a Trigger Circuit Plate mounted beneath the control panel, which distributes the pulses to each row of pushbuttons. When a button is depressed, the trigger pulses are applied to the desired cross-point.

Output amplifiers, mixing amplifiers, filament and bias supplies, and sync or blanking adders are conveniently rack mounted by use of an Amplifier Frame illustrated in Fig. 13. This frame requires seven inches of rack space.

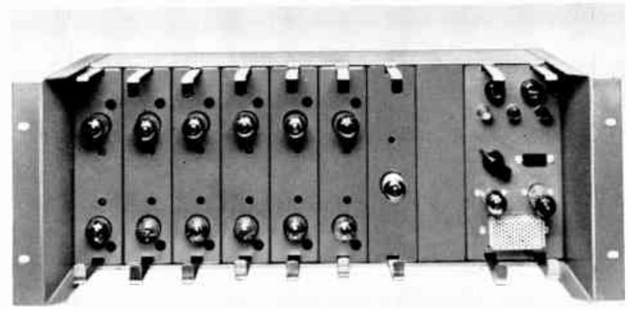


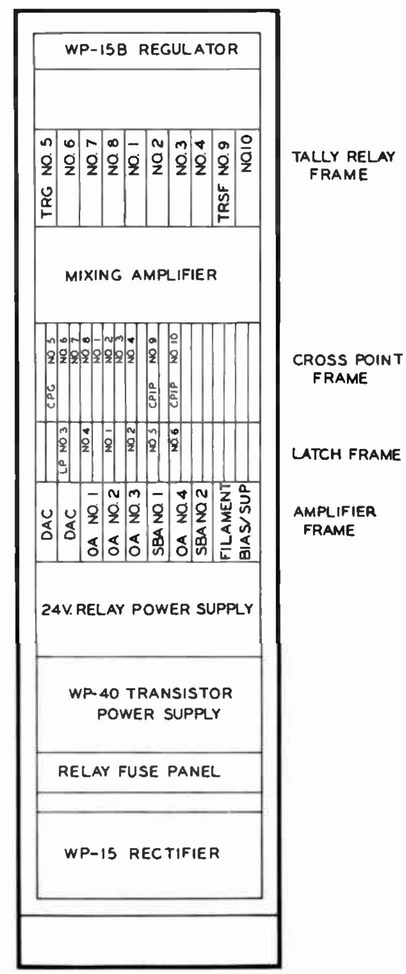
FIG. 13. Amplifier Frame containing six output amplifiers, one sync and blanking adder and a filament and bias supply.

Tally Relays

Each TS-40 cross-point has a tally output signal which is used to activate a tally relay. This relay has the multiple contacts required to operate tally lamps on cameras, monitors, and control panels, and also to operate such auxiliary circuits as sync interlocks and audio ties. A group of six tally relays corresponding to one cross-point group can be assembled as shown in Fig. 15. Ten of these groups can be installed in a Tally Relay Frame which occupies 8¾ inches of rack space. Connections are made at the rear of the frame by taper-pin connectors.

Switching Panels

Switching Controls Panels for the TS-40 Transistorized Switching System are custom-built to specific requirements. These panels include features such as self-illuminated pushbuttons, momentary contact or mechanical latch as desired, standard fader assemblies, and adaptability to desk-top or console mounting. Panel layouts for two representative switching systems are shown in Figs. 14 and 16.



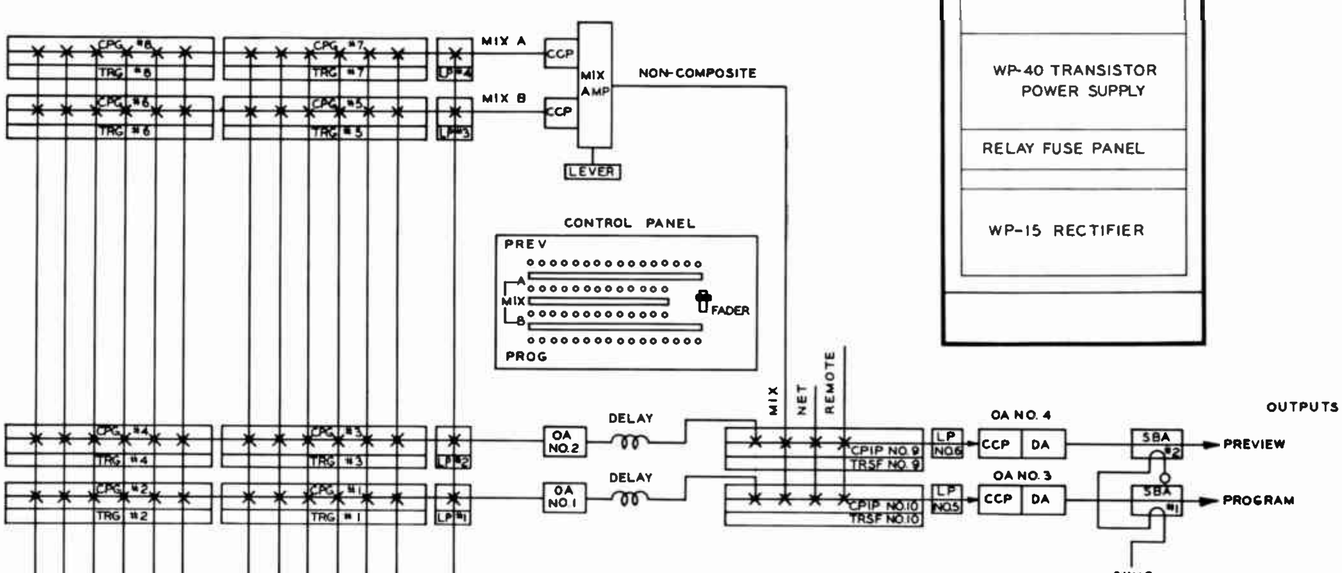


FIG. 14. Block diagram of a TS-40 switching system with facilities for 12 non-composite and two composite (network and remote) inputs, mix/fade, preview and program outputs.

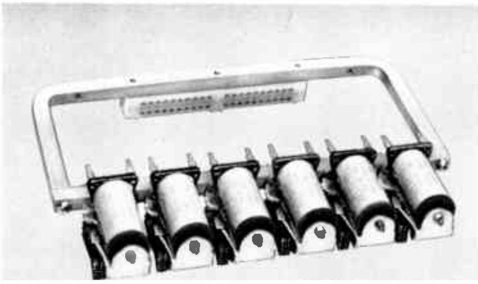
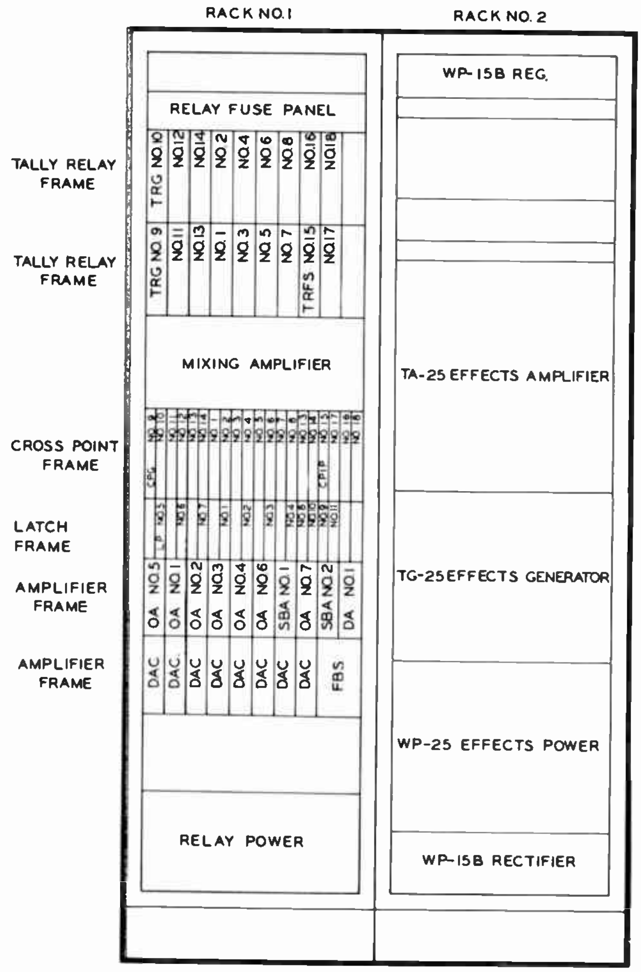


FIG. 15. Plug-in Tally Relay Group consists of six tally relays, one for each of the six cross-points in a Cross-point Group. A Tally Frame mounts 10 tally relay groups.



System Layouts

Typical transistorized video switching systems are diagrammed in Figs. 14 and 16. The system in Fig. 14 handles 12 non-composite and two composite (network and remote) inputs and provides program and preview outputs. Fades and lip-dissolves are provided by two mix busses which feed the mixing amplifier.

The system shown in Fig. 16 is substantially the same as that of Fig. 14 except that "effects" switching has been added. This facility is provided by three additional switching busses which feed a TA-25 Effects Amplifier. It will be noted that for mixing or lap-dissolving with a special effects signal, the non-composite output is bridged and then fed through a delay line equal to the delay of the effects amplifier.

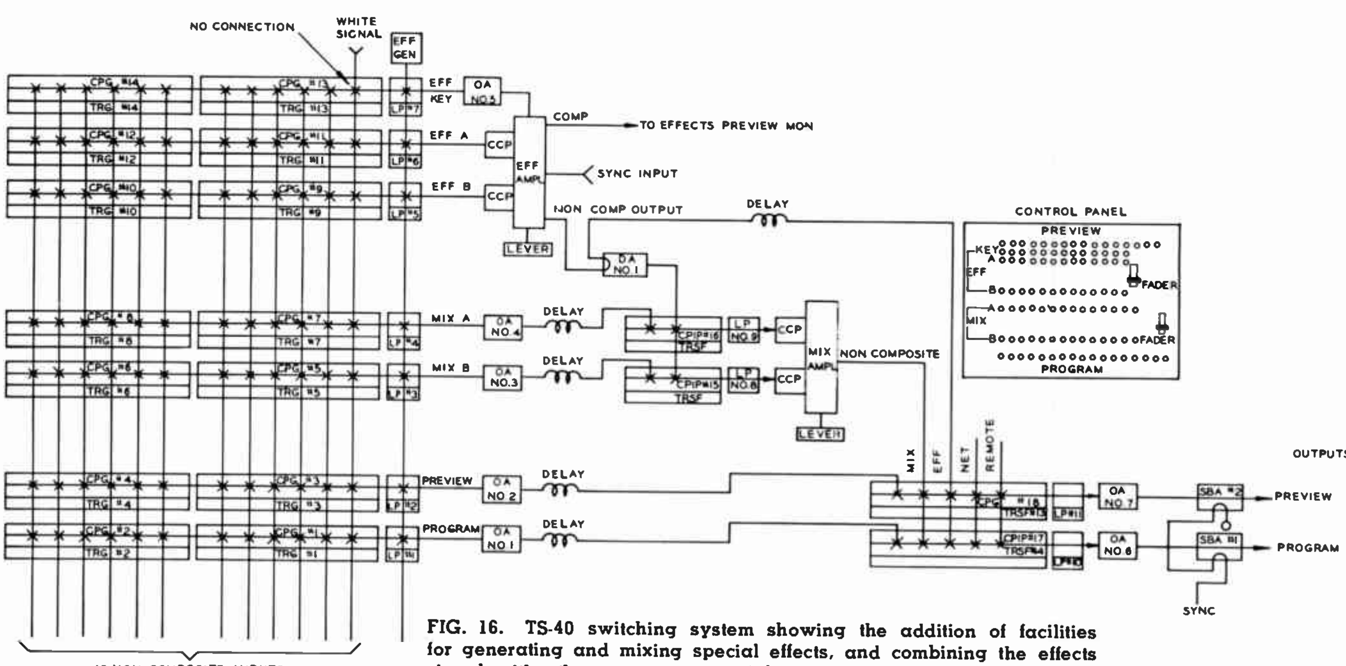


FIG. 16. TS-40 switching system showing the addition of facilities for generating and mixing special effects, and combining the effects signal with other program material.

DATA ON WEIGHT, POWER AND RACK SPACE

The following tables have been compiled to enable the television engineer to determine weight, power and rack space requirements for the studio equipment of a color television installation.

Included in the tabulations are the dc voltage and current requirements of each equipment, except that where an integral power supply is used, only the maximum ac power consumption appears. In every case, the ac source required is 115 volts, 60 cycles, single phase. Also given are the sizes of standard panels, and the available mounting space in equipment racks and console type housings, both in inches and in terms of panel units.

PULSE EQUIPMENT

Equipment	Type	MI	Rack Space in Inches	Weight in lbs.	DC MA @ 280 V.	DC MA (Others)	AC Watts	Total Heat (In Watts)
Sync Generator	TG-2A	26102-A	21	50	—	—	275	275
Field Sync Generator	TG-12A	26112-A	—	60	—	—	275	275
Sync Generator Switch	—	26289	5¼	10	—	—	—	—
Color Frequency Standard	—	40201-A	7	12½	60	—	44	61
Burst Flag Generator	—	40202-A	8¾	13½	130	—	25	62
Pulse Amplifier	TA-4A	26158	3½	12½	120	—	55	89
Pulse Delay Line (Quantity 4)	—	26886	3½	2½ ea.	—	—	—	—

CAMERAS

Equipment	Type	MI	Rack Space in Inches	Weight in lbs.	DC MA @ 280 V.	DC MA (Others)	AC Watts	Total Heat (In Watts)
Image Orthicon Camera	TK-11/31	26011	—	78	300	—	90	174
Viewfinder	TK-11/31	26016	—	35	200	80 @ 380 V.	60	150
Vidicon Live Camera	TK-15	26023	—	79	420	½ @ 460 V.	122	240
Color Camera	TK-41	40500-A	—	250	575	210 @ 360 V.	132	375
Viewfinder	TK-41	40501	—	45	125	65 @ 360 V.	58	117
3 Vidicon Camera	TK-45	40545	—	120	575	—	75	235
Monoscope Camera	TK-1C	26030-B	17½	55	300	—	100	184
Vidicon Camera	TK-21	26021-A	—	7	100	—	25	53
3 Vidicon Camera	TK-26	40516	—	20	280	—	70	149

CAMERA CONTROL EQUIPMENT

Equipment	Type	MI	Rack Space in Inches	Weight in lbs.	DC MA @ 280 V.	DC MA (Others)	AC Watts	Total Heat (In Watts)
Studio Camera Control	TK-11	26056-A	—	27	300	—	95	179
Field Camera Control	TK-31	26066	—	67	700	10 @ 150 V.	125	323
1V Camera Control	TK-15	26063	14	23½	215	—	86	150
3 I. O. Camera Control	TK-41	40523	7	18	—	—	—	—
3V Camera Auxiliary	TK-45	40548	3½	19	200	—	10	66
3V Utility Amplifier	TK-45	40554	12¼	35	250	—	75	146

CAMERA CONTROL EQUIPMENT (Continued)

Equipment	Type	MI	Rack Space in Inches	Weight in lbs.	DC MA @ 280 V.	DC MA (Others)	AC Watts	Total Heat (In Watts)
3V Camera Control	TK-45	40549	7	25	—	—	—	—
Vidican Control Chassis	TK-21	26061-A	19¼	30	226	—	92	156
Vidican Deflection Chassis	TK-21	26081-A	12¼	23½	194	—	50	104
Vidican Control Panel	TK-21	26218	5¼	—	—	—	—	—
3V Camera Auxiliary	TK-26	40517	34	80	550	—	75	229
3V Camera Control	TK-26	40522-A	7	12	—	—	—	—

AMPLIFIERS

Equipment	Type	MI	Rack Space in Inches	Weight in lbs.	DC MA @ 280 V.	DC MA (Others)	AC Watts	Total Heat (In Watts)
Distribution Amplifier (8)	TA-12	40326	7	40	256	—	125	197
Distribution Amplifier	TA-3B	26157-B	3½	12½	150	—	55	97
Distribution Amplifier	TA-4A	26158	3½	12½	120	—	55	89
Lap-Dissolve Amplifier	—	40421-B	10½	21	260	—	115	188
AGC Amplifier	TA-21	26296	8¾	15	200	—	50	106
Stabilizing Amplifier	TA-7B	40205	10½	20	350	—	75	173
Stabilizing Amplifier	TA-9A	40222	14	30	400	—	120	232
Processing Amplifier	—	40520	10½	50½	360	—	180	200
Colorplexer	TX-1C	40209-B	21	34	280	—	90	169
Aperature Compensator	—	40414	1¾	3	33	—	10	15
Automatic Carrier Balance	—	40416	3½	10	20	—	15	20
Masking Amplifier	—	40525	8¾	26	500	—	100	240
Shading Amplifier	—	40849	10½	19	150	—	59	101

SPECIAL EFFECTS EQUIPMENT

Equipment	Type	MI	Rack Space in Inches	Weight in lbs.	DC MA @ 280 V.	DC MA (Others)	AC Watts	Total Heat (In Watts)
Special Effects Amplifier	TA-25	40335	21	—	350	500 @ ±150 V.	—	—
Special Effects Generator	TG-25	40337	15¾	—	—	—	—	—
Special Effects Power Supply	WP-25	40339	10½	—	—	—	—	—

POWER SUPPLIES

Equipment	Type	MI	Rack Space in Inches	Weight in lbs.	DC MA @ 280 V.	DC MA (Others)	AC Watts	Total Heat (In Watts)
Regulated Power Supply (Rectifier)	WP-15-B	26087-B	7	59	—	—	850	430
Regulated Power Supply (Regulator)	WP-15-B	26088-B	3½	12	1500	—		
Regulated Power Supply	580-D	21523-C	10½	58	400	—	370	258
Field Power Supply	TY-31A	26091	—	58	1250	180 @ 380 V.	1350	940
Focus Current Regulator	—	26090-A	7	9	—	100	15	55
Focus Current Regulator (Color)	—	40524	5¼	22	12	—	85	90
Centering Current Regulator	—	40839	5¼	22	—	—	40	40
Relay Power Supply (24 V DC) (Quantity 2)	—	11316	8¾	—	—	3000 @ 24 V.	125	43
Circuit Breaker Chassis	—	26240	7	10 Approx.	—	—	—	—

SWITCHING SYSTEMS

Equipment	Type	MI	Rack Space in Inches	Weight in lbs.	DC MA @ 280 V.	DC MA (Others)	AC Watts	Total Heat (In Watts)
Video Switcher	TS-2	26277	—	3	—	—	5	5
Video Switcher	TC-4A	26228	—	138	32	—	37	46
Monitor Switcher	Part of TC-4A	26227	—	—	25	—	5	10
Video Switcher	TS-5A	26229	—	18	125	—	30	65
Video Switcher	TS-11A	26226	—	—	300	65 @ 280 V. for Tally	120	225
Field Switcher	TS-30D	26950	—	71½	—	—	800	800
Relay Switcher	TS-21		Including					
Auxiliary Relay Chassis	—	26230	21	—	—	—	—	—
Basic Relay Chassis	—	26231	26¼*	—	120	—	35	52
Video Jack Panel (15 Outs, 15 Ins)	—	26219	3½	10 Approx.	—	—	—	—
Rack Panel Adapter (for TS-2)	—	26254	3½	2	—	—	—	—
Cross Point Frame	TS-40	40301	8¾					
Latch Frame	TS-40	40306	3½					
Power Supply	WP-40	40312	8¾					
Tally Relay Frame	TS-40	40315	8¾					
Relay Fuse Panel	TS-40	40321	3½					

* Allow 1¾" additional wiring space above basic chassis MI-26231-A

MONITORS

Utility Monitor 14"	TM-4C	26113	—	65	—	—	125	125
Utility Monitor 14"	TM-4R	26114	10½	65	—	—	125	125
Master Monitor	TM-6C	26136-B	19¼	55	450	450 @ 4 V.	90	220
Utility Monitor 17"	TM-7AR	26142	17½	87 In Rack	—	—	180	180
Utility Monitor 17"	TM-7AC	26141	—	90 In Cab.	—	—	180	180
Utility Monitor and Cabinet 21"	TM-8AC	26143	—	122	—	—	180	180
Color Monitor	TM-21-B	40226	—	210 In Cab.	—	—	780	780
Monitran	TM-30	26499	8¾	45	—	—	80	80
Monitran	TM-40A	40218	8¾	30	—	—	122	122
Monitran	TM-41A	40219	8¾	30	—	—	122	122

MICROWAVE

Receiver Head	Part of TVM-1A	26400	—	53	—	—	—	—
Receiver Control	Part of TVM-1A	26411	14	52	—	—	—	—
Receiver Power Supply	Part of TVM-1A	26413	14	58	—	—	—	530
Transmitter Head	Part of TVM-1A	26450	—	60	—	—	—	—
Transmitter Control	Part of TVM-1A	26460	14	66	—	—	—	465
Transmitter AFC	Part of TVM-1A	26643	—	2½	—	—	—	—
Transmitter Monitor	Part of TVM-1A	26644	—	3	—	—	—	—
Transmitter Mon/AFC Cav.	Part of TVM-1A	26645	—	1½	—	—	—	—
Sound Diplexer Mod. TSD-2B	Part of TVM-1A	26443	3½	8½	—	—	57	—
Sound Diplexer Demod. TSD-2B	Part of TVM-1A	26444	3½	9½	—	—	56	—

TEST EQUIPMENT

Equipment	Type	MI	Rack Space in Inches	Weight in lbs.	DC MA @ 280 V.	DC MA (Others)	AC Watts	Total Heat (In Watts)
Transmission Measuring Set.	BI-11A	11350	7	19	—	—	—	—
Calibration Pulse Generator	WA-9A	26070	5¼	14	—	—	50	50
Grating Generator	WA-38	30003	8¾	42	—	—	180	180
Video Sweep Generator	WA-21B	30021	8¾	80	—	—	180	180
Audio Push Button Oscillator	WA-28A	30028-A	7	32½	—	—	45	45
Distortion & Noise Meter	WM-71A	30071-A	7	37½	—	—	65	65
Color Bar Generator	WA-10	34001-D	14	30	—	—	135	135
Color Signal Analyser	WA-6A	34016-A	17½	80	—	—	140	140
Linearity Checker	WA-7B	34017-A	8¾	40	—	—	210	210
Color Stripe Generator	WA-8A	40214	8¾	20	—	—	125	125
Visual Side Band Demodulator	BW-4A	ES34006	14	32	—	—	250	250
Visual Side Band Demodulator	BWU-4A	ES34007	14	32	—	—	250	250
Side Band Response Analyser	BWU-5A	ES34009	14	69	—	—	240	240
Side Band Response Analyser	BW-5A	ES34010	10½	58	—	—	200	200
Transmission Monitor	—	G.R.	14	30	—	—	135	135
TV Oscilloscope	TO-1	26800	8¾	35	—	—	295	295
Burst Controlled Oscillator	WA-4A	34023	8¾	39	—	—	165	165

AVAILABLE PANEL MOUNTING SPACE

Equipment	MI	Space in Panel Units	Space in Inches
BR-84 Rack	30951-84	44	77
Console Housing	26787	12	21

STANDARD PANEL AND CHASSIS SIZES

Blank Panel	Blank Chassis	Units	Inches
MI-4590-A	MI-26525-1	1	1¾
MI-4591-B	MI-26525-2	2	3½
MI-4592-B	MI-26525-3	3	5¼
MI-4953-A	MI-26525-4	4	7
MI-4594-B	MI-26525-5	5	8¾
MI-4595-B	MI-26525-6	6	10½
MI-4596-A	MI-26525-7	7	12¼
MI-4597-A	MI-26525-8	8	14

LUMINOSITY FUNCTION, STANDARDS FOR SYNCHRONIZATION OF COLOR

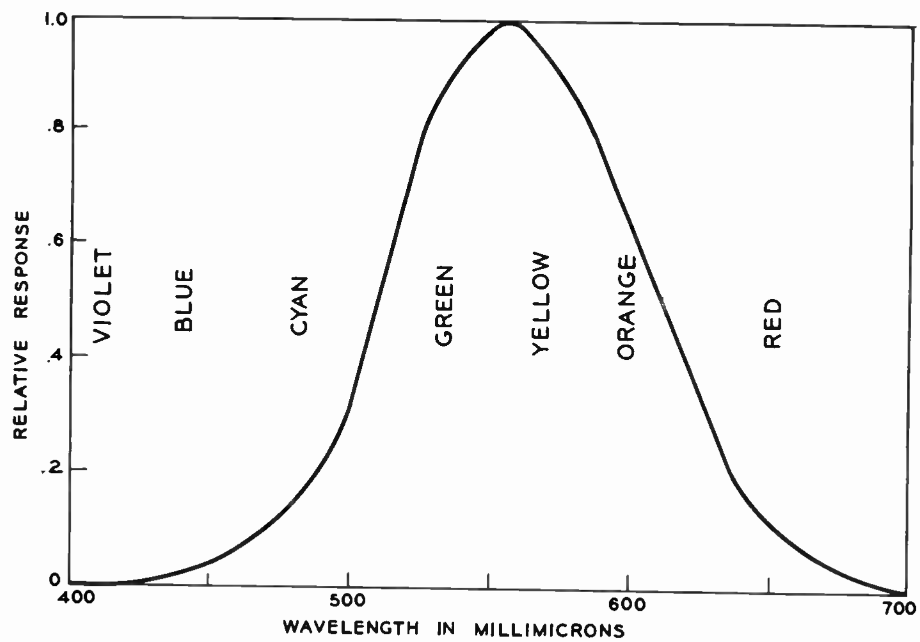


Chart of the visible spectrum, showing the major hue regions.

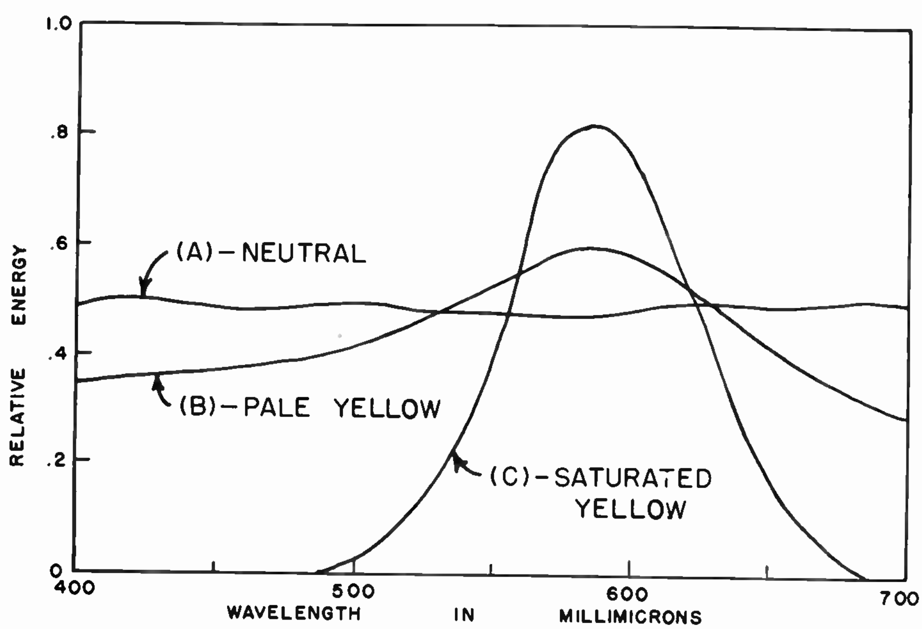


Chart of the visible spectrum, showing how hue and saturation are controlled by spectral distribution.

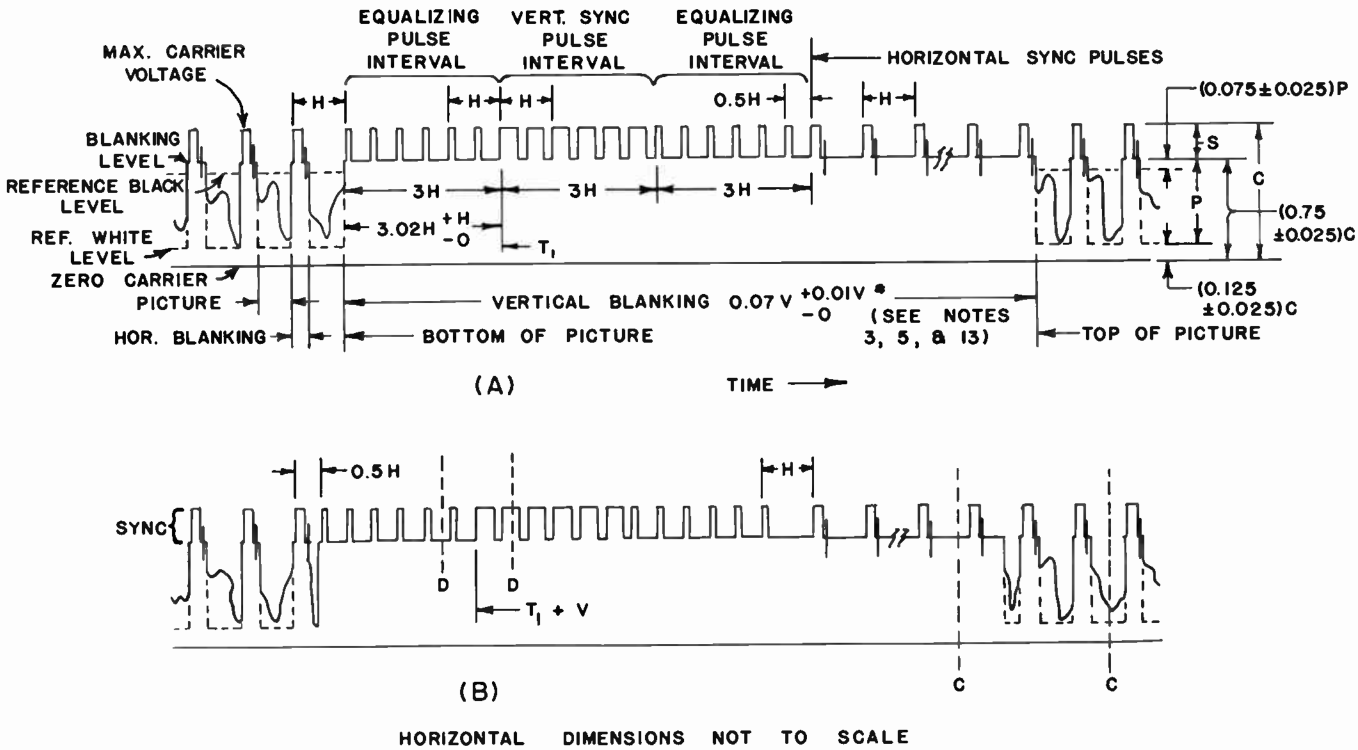


FIG. 1. Television synchronizing waveform for color transmission.

NOTES FOR FIGURE 1

1. H = time from start of one line to start of next line.
2. V = time from start of one field to start of next field.
3. Leading and trailing edges of vertical blanking should be complete in less than 0.1H.
4. Leading and trailing 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 tolerances given 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 burst follows each horizontal pulse, but is omitted following the equalizing pulses and during the broad vertical pulses.
8. Color bursts to be omitted during monochrome transmission.
9. The burst frequency shall be 3.579545 mc. The tolerance on the frequency shall be ± 10 cycles with a maximum rate of change of frequency not to exceed 1/10 cycle per second per second.
10. The horizontal scanning frequency shall be 2/455 times the burst frequency.
11. The dimensions specified for the burst determine the times of stopping and starting the burst, but not its phase. The color burst consists of amplitude modulation of a continuous sine wave.
12. Dimension "P" represents the peak excursion of the luminance signal from blanking level, but does not include the chrominance signal. Dimension "S" is the sync amplitude above blanking level. Dimension "C" is the peak carrier amplitude.
13. For monochrome transmission only, the duration of the horizontal sync pulse between 10 percent points is specified as 0.08H ± 0.01, the period from the leading edge of sync to the 10 percent point on the trailing edge of horizontal blanking is specified as 0.14H Min., and the duration of vertical blanking is specified as 0.05V + 0.03V − 0. All other dimensions remain the same.

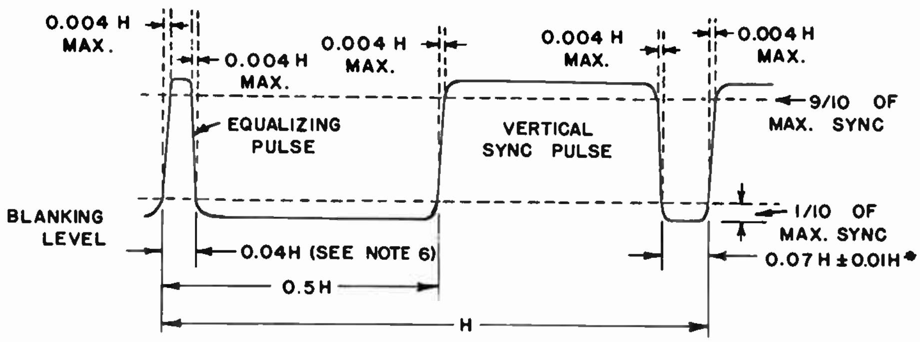


FIG. 1C. Detail between D-D in Figure 1B.

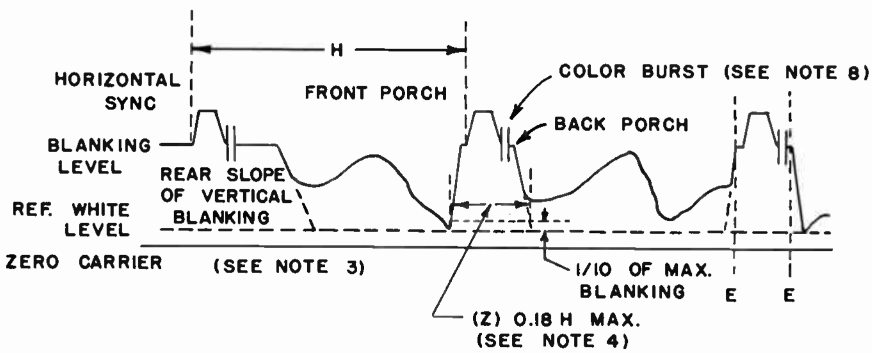


FIG. 1D. Detail between C-C in Figure 1B.

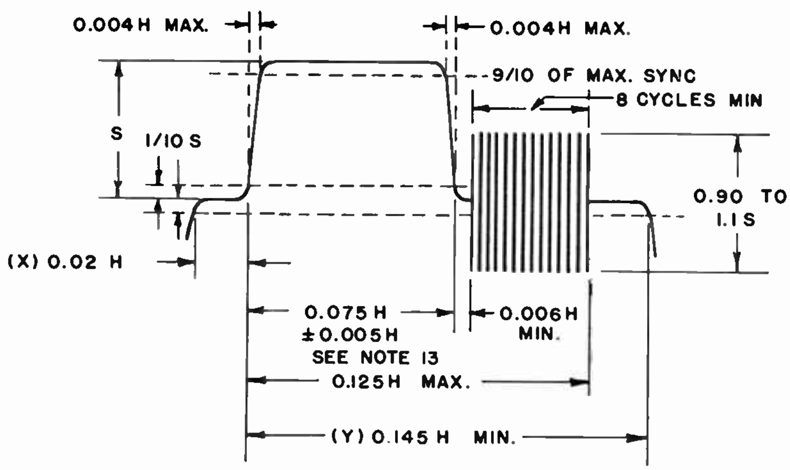
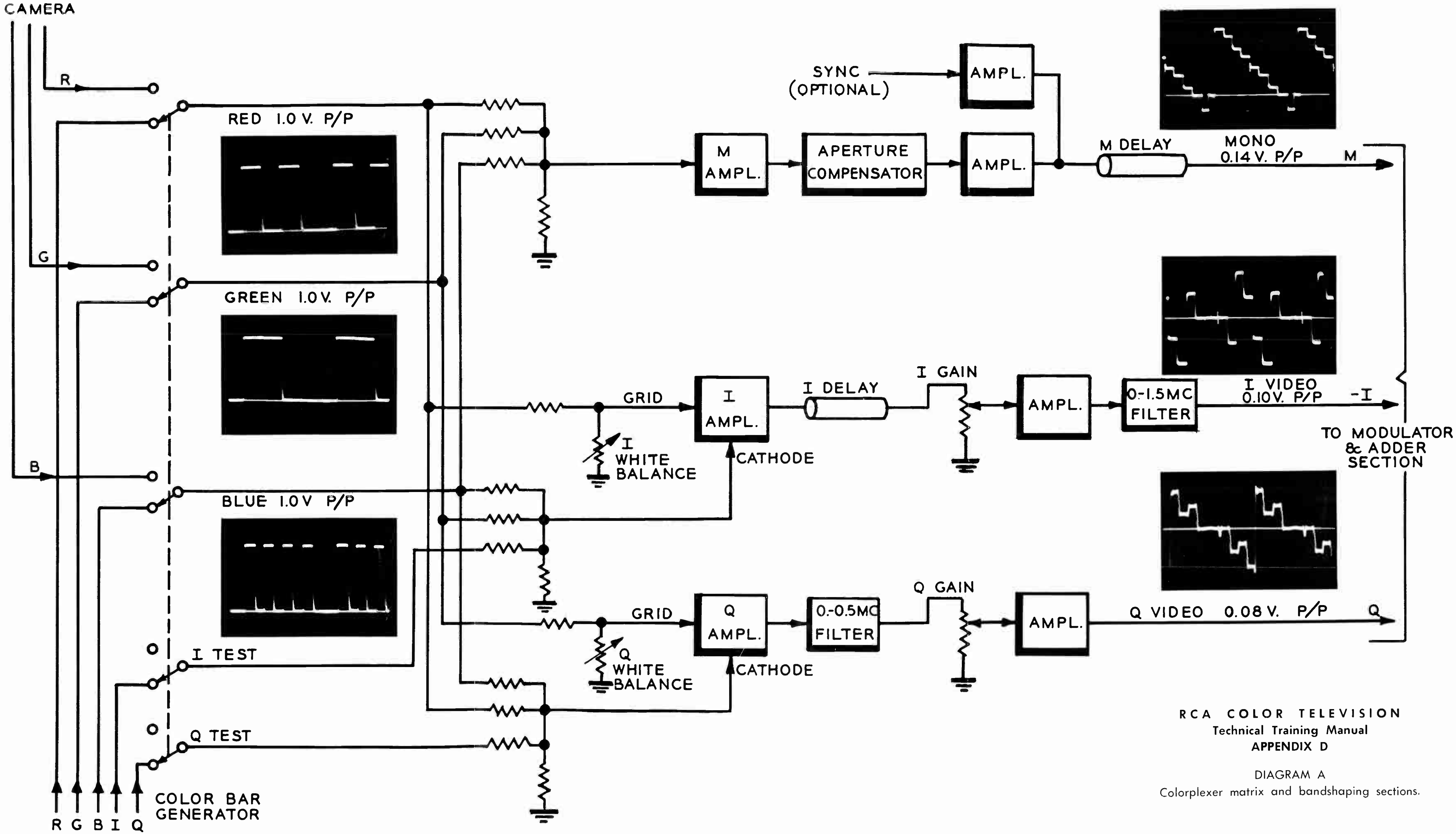


FIG. 1E. Detail between E-E in Figure 1D.



RCA COLOR TELEVISION
Technical Training Manual
APPENDIX D

DIAGRAM A
Colorplexer matrix and bandshaping sections.

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Technical Training Manual
APPENDIX D

DIAGRAM B
Colorplexer modulator and adder sections.