# 23

# Color System

## FUNDAMENTALS

Color is a 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 black and white 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.[1]

### 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 200,000 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 pickup tube scans a sensitive surface containing an "electrical image" of the scene of action. The electron beam successively scans the image at great velocity, beginning at the upper left corner and continuing from left to right in a series of paral-

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[1] 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.

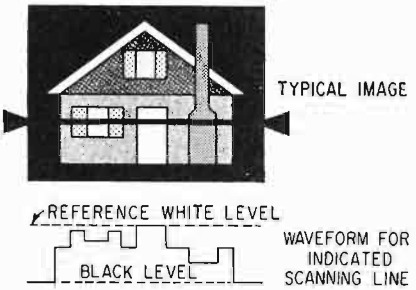

**Fig. 1. Typical image and camera output waveform produced by light and dark areas during one scan along line indicated by arrows.**

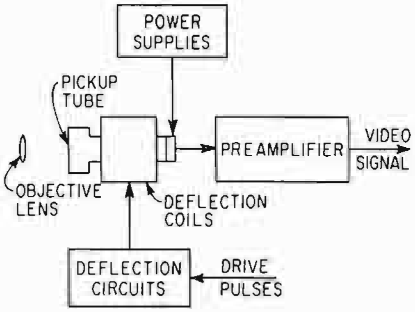

**Fig. 2. Block diagram of monochrome-camera circuits.**

lel lines to scan the image completely. Movement of the electron beam, which can be 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.

Owing 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 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 X 30 or 60 Hz, and the horizontal scanning frequency is 30 × 525 or 15,750 Hz.

## 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.

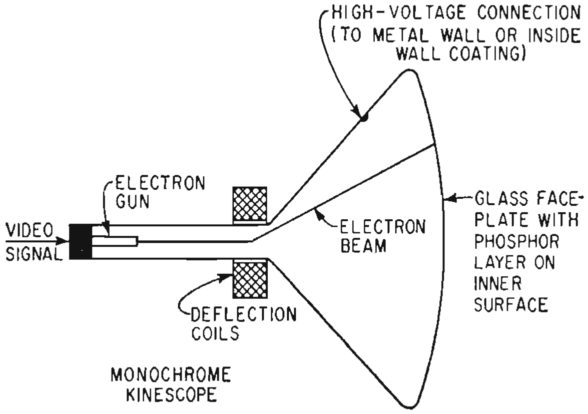

**Fig. 3. Diagram showing principal elements of the monochrome kinescope picture tube.**

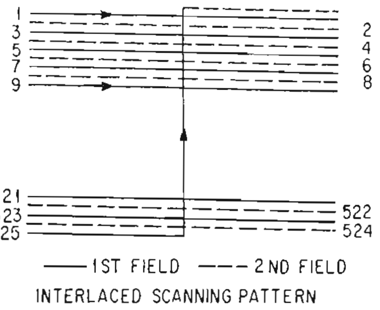

Fig. 4. Diagram showing paths of the electron beam in both the pickup tube and kinescope to produce the interlaced scanning pattern.

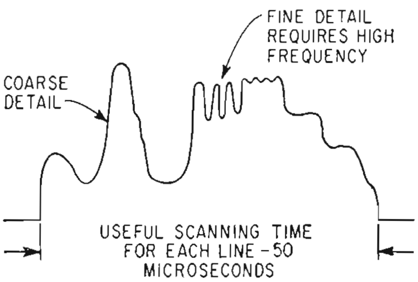

Fig. 5. Diagram illustrating the relationship between picture detail and signal bandwidth.

The standard 6-MHz broadcast channel provides a video bandwidth of approximately 4.1 MHz (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 X 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 percent of the total time, the maximum number of picture elements per frame is reduced in practice to 0.75 X 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 are 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 sec, blank the beam during retrace periods between lines. Vertical blanking pulses, transmitted at the end of each field, or at intervals of 1/60 sec, 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 small fraction of a line.

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 with 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.

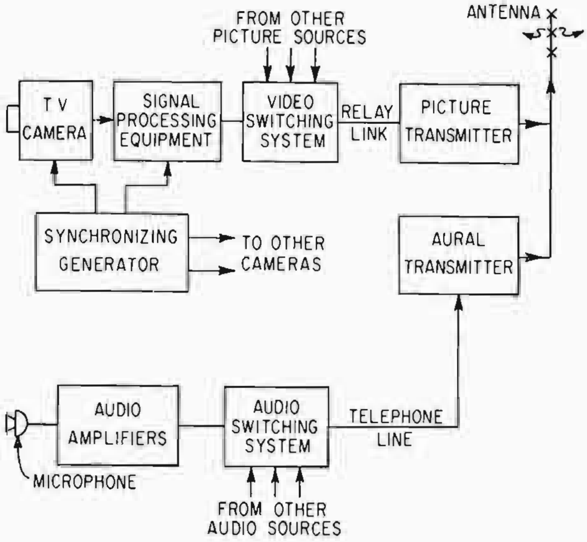

**Fig. 6. Simplified block diagram of the monochrome-television station.**

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 "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 IF 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.

## 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

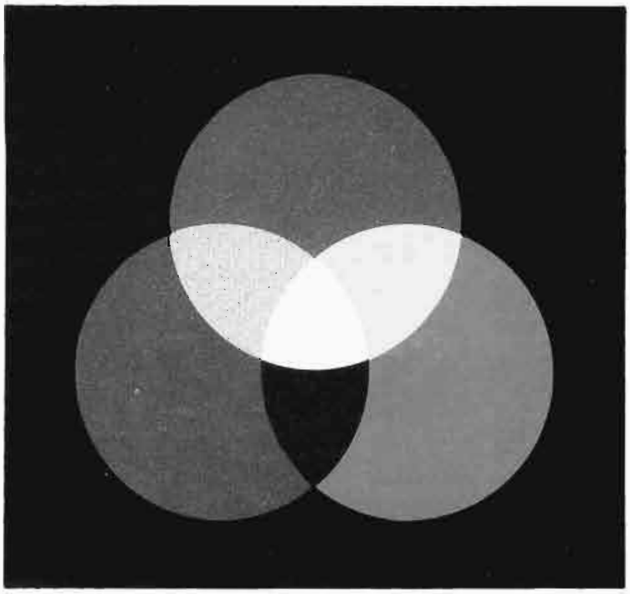

Fig. 9. The primary colors of television are red, green, and blue. Virtually any color can be matched by combining proper amounts of these primaries. White is produced by a combination of all three.

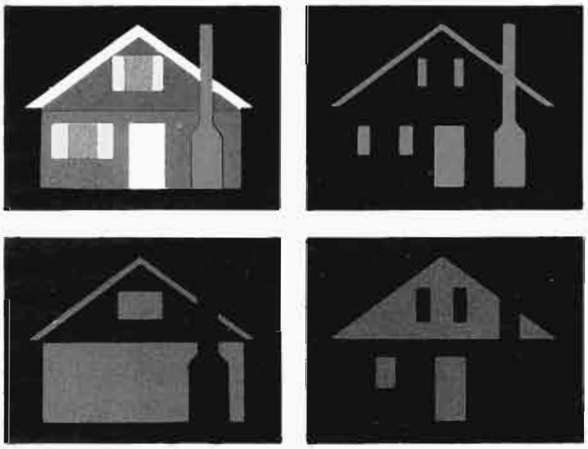

Fig. 10. Illustrating how a typical color image (upper left corner) can be separated by optical means into red, green, and blue counterparts.

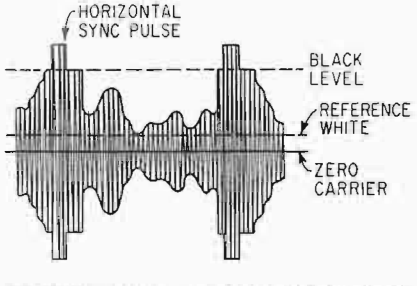

Fig. 7. Waveform and radiated picture signal.

attribute of a color which is 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 (see page between 688-689). 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.

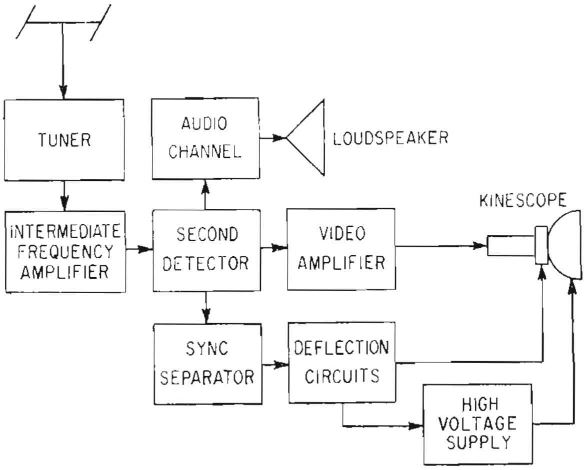

Fig. 8. Block diagram of monochrome-television receiver.

## Generating RGB Signals

Major components of a color-television camera may have the block-diagram form shown in Fig. 11. Whereas the monochrome camera contains only one pickup tube, the color camera usually 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 (color separating) 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. 18) 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 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 tricolor kinescope, the basic components of which are shown in the diagram of Fig. 12. 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 owing 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 1/2 in. 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 on the aper-

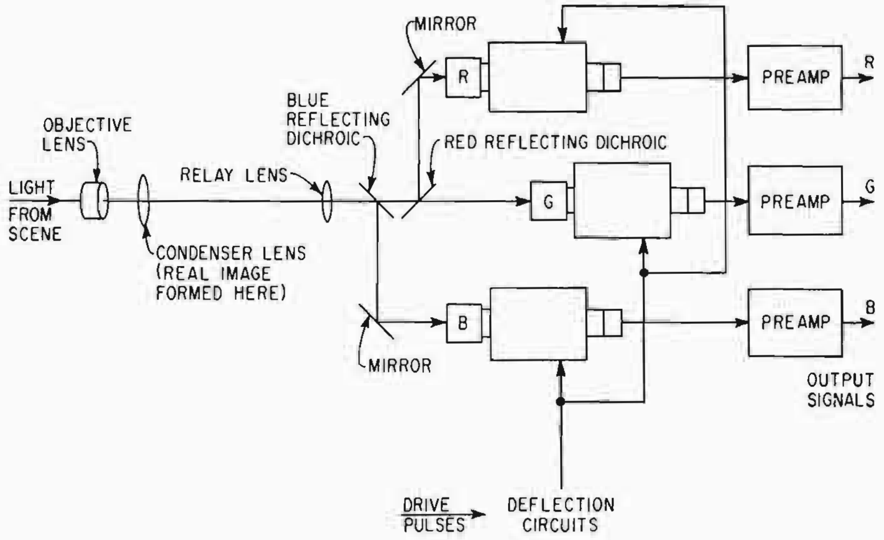

Fig. 11. Simplified block diagram of the optical and electrical components of the color camera.

ture 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 tricolor 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.

## 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 instead of 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, band shaping, 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 6-MHz channel.

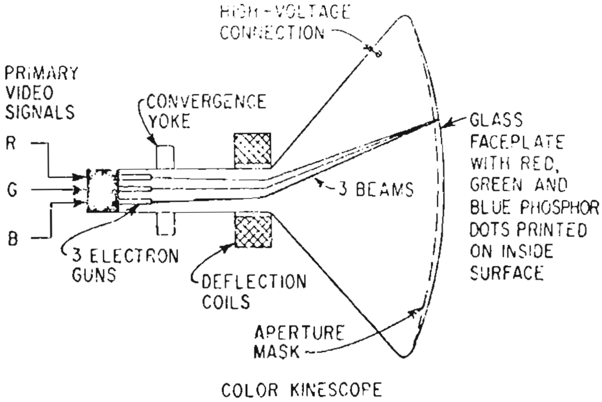

Fig. 12. Diagram showing components of the three-gun kinescope picture tube.

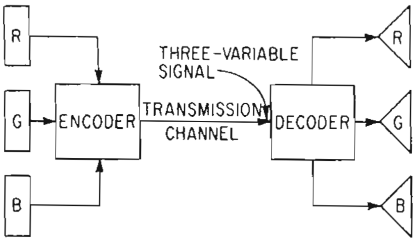

**Fig. 13. Encoding of the RGB signals provides a three-variable signal which can be transmitted over existing monochrome channels.**

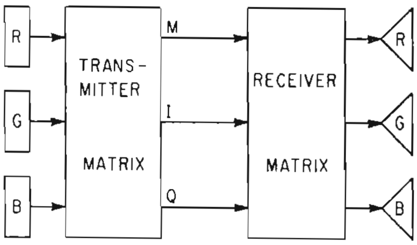

**Fig. 14. A part of the encoding process is the matrixing of R, G, and B signals to provide M, I, Q signals.**

## 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 excellent service to monochrome receivers. The M component is obtained by combining red, green, and blue signals in a simple resistor network (Fig. 15) designed to produce a signal consisting of 30 percent red, 59 percent green, and 11 percent 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 percent red, −28 percent green, and −32 percent blue. Minus values are easily achieved in the matrix circuits by use of phase inverters to reverse the signal polarity (see Figs. 16 and 17). The Q signal is defined as 21 percent red, −52 percent green, and 31 percent 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. 18 and 19, see page of color illustrations between pages 688-689) obtained from the image illustrates

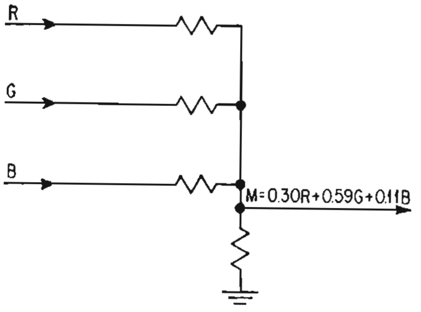

**Fig. 15. Diagram of resistance matrix circuit used to produce the M luminance signal.**

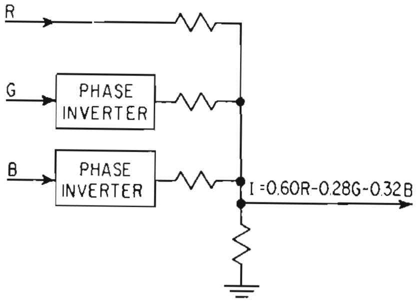

**Fig. 16. Diagram of I matrix showing phase inverters to produce minus green and blue quantities.**

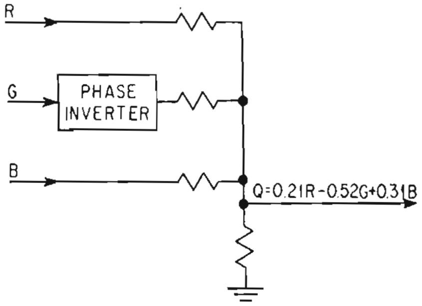

**Fig. 17. Diagram of the Q matrix showing phase inverter to produce required minus green signal.**

the correlation among the types of signals. It will be seen that the M signal remains in the region between black level and reference white. The I and Q signals, on the other hand, swing positive and negative around a zero axis.

### Band Shaping

The eye has substantially less acuity in detecting variations in chrominance 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 MHz was found to be satisfactory for the I signal, which corresponds to color transitions in the range extending from orange to blue-green. For color transitions 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 MHz. The M-signal component, which conveys the fine details, must be transmitted with the standard 4-MHz 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-MHz carriers separated in phase by 90°. The resultant waveform is the vector sum of the components. Elements of the transmitting and receiving system are shown in Fig. 20. The two carriers, which are derived from the same oscillator, are suppressed by the balanced modulators. Thus, only the two amplitude-modulated sidebands, 90° 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° phase separation and applying the resultant signals through low-pass filters to the matrix circuits. Typical signal waveforms are illustrated in Fig. 21.

The 3.6-MHz 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-MHz, "bursts" of at least 8-Hz 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-MHz 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

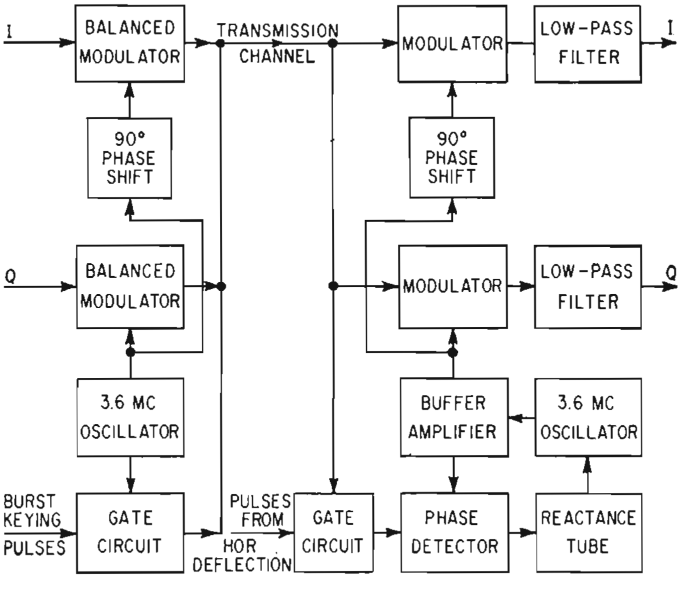

Fig. 20. Simplified block diagram showing elements for transmitting and receiving the I, Q, and burst signals.

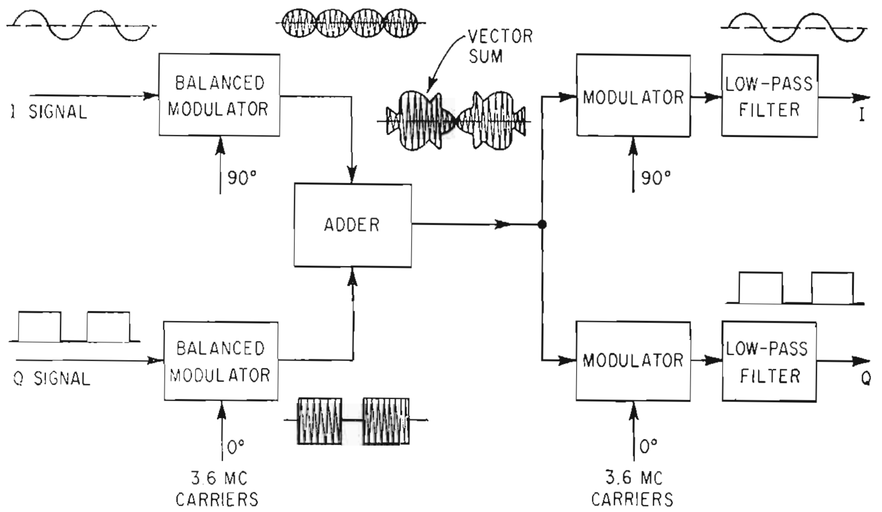

**Fig. 21. Representative waveforms of the separate I, Q signals and the vector sum of the suppressed carrier sidebands at the modulator output. Original I and Q signals are recovered by beterodyning in balanced modulators at receiver.**

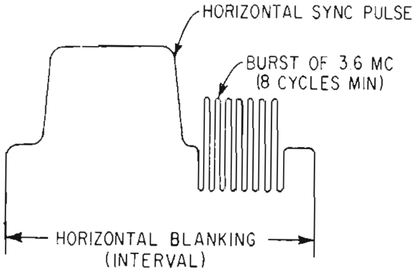

**Fig. 22. Diagram showing position of subcarrier burst during horizontal blanking interval.**

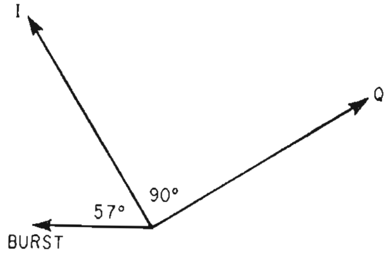

**Fig. 23. Diagram showing phase relationship of I, Q, and burst signals.**

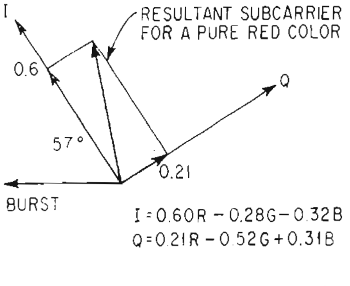

**Fig. 24. Vector diagram showing phase and amplitude of subcarrier for a pure red signal.**

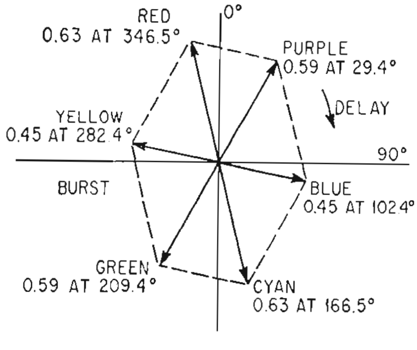

**Fig. 25. Composite vector diagram showing subcarrier phase and amplitude for each of six colors.**

burst are shown in the vector diagram of Fig. 23. The I and Q signals are transmitted in phase quadrature, and the color burst is transmitted with an arbitrary 57° phase lead over the I 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 percent, respectively. When modulated upon their respective carrier, these signals produce the resultant shown in Fig. 24. The phase and amplitude shown are characteristic of pure red of maximum relative luminance. Fig. 25 is a composite vector diagram showing the phase and amplitude characteristics of the three primaries and their complementary colors. 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-MHz carriers, consisting of the I and Q sidebands, fall within the video passband as shown in the diagram of the television channel (Fig. 26), they become subcarriers and can be handled in many respects like unmodulated video signals. By use of *frequency interlace* 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. 27 shows M, I, and Q signals after the latter two have been modulated upon 3.6-MHz subcarriers. Note that both the I- and Q-signal components are at zero during the scanning of the white door, a neutral area. Fig. 28 (see page of color illustrations between page 688 and 689) 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 fact 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.

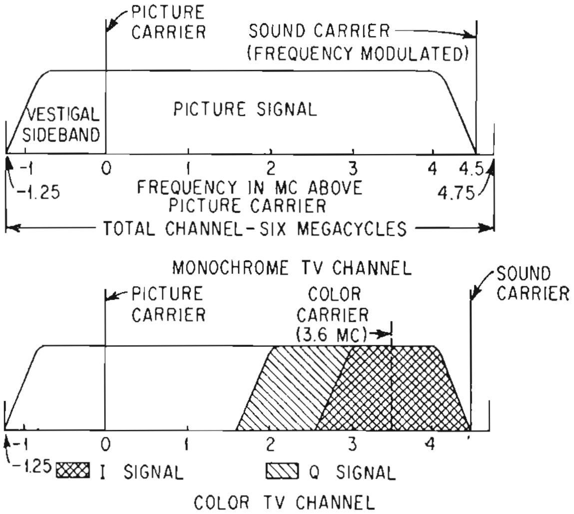

Fig. 26. Diagram of television channel showing portions occupied by color and monochrome signal components.

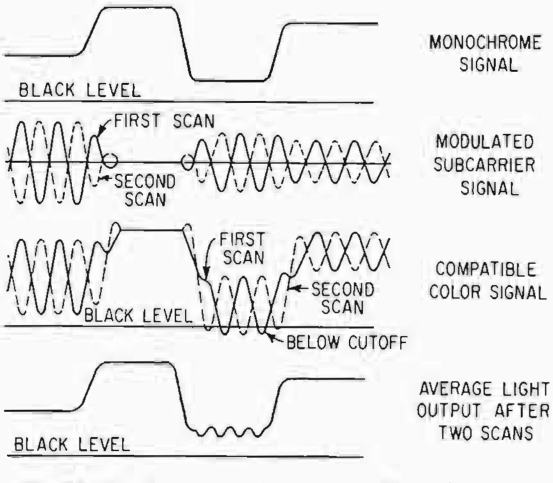

Fig. 29. Waveforms showing superposition of modulated subcarrier on scanning signals, compatible color signal, and effect of subcarrier on average light output.

The frequency-interlace technique is based on two factors—a precise choice of the color subcarrier frequency and the familiar "persistence-of-vision" effect. If the color subcarrier is made 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 tends to be self-canceling, owing to the periodic polarity reversals (see Fig. 29).

## Color-Frequency Standards

The relationships among the various frequencies used in a compatible color system are illustrated in the block diagram of Fig. 29. The

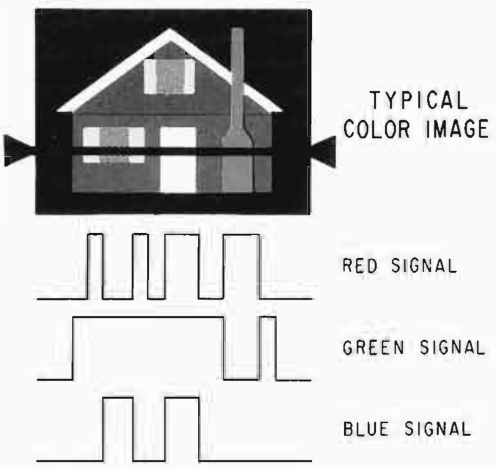

Fig. 18. Typical color image and RGB waveforms.

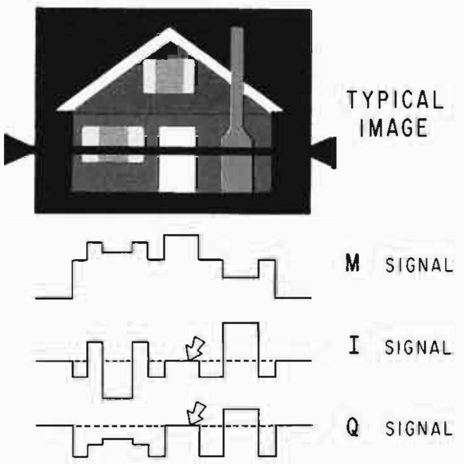

Fig. 19. Typical color image and MIQ wafeforms.

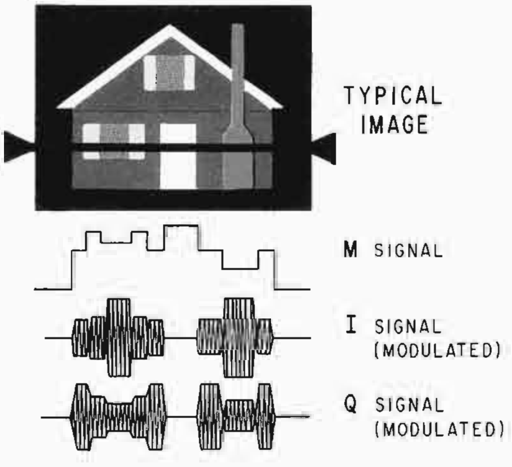

Fig. 27. Typical color image and waveforms of the M signal and modulated I and Q signals.

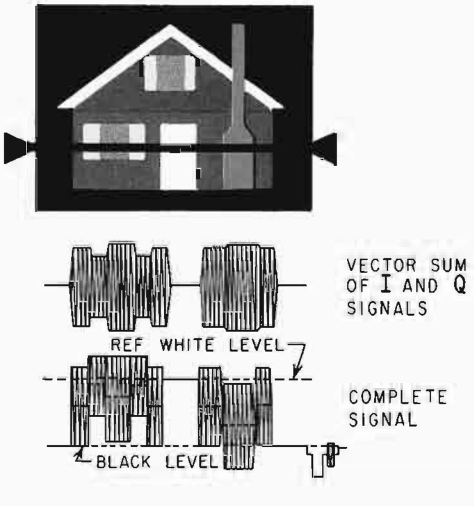

Fig. 28. Typical color image.

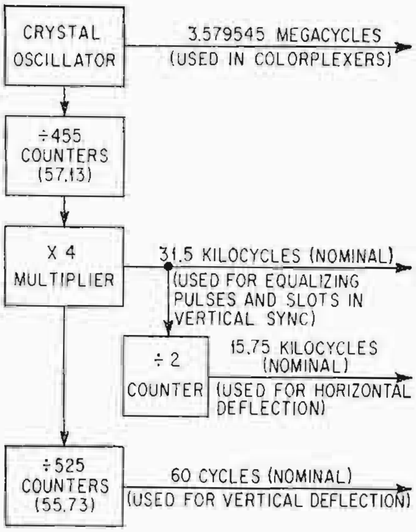

Fig. 30. Block diagram showing relationship between various frequencies used in color-television station.

actual frequency of the color subcarrier, which has been referred to as 3.6 MHz is specified by FCC Standards as 3.579545 MHz or exactly 455 multiplied by 1/2 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 kHz 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-2 counter controlled by the 31.5 kHz signal provides the line-frequency pulses at nominally 15.75 kHz needed to control the horizontal blanking and synchronizing waveforms. Another counter chain provides the 60-Hz pulses needed for control of the vertical blanking and synchronizing circuits.

## 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. 31 and 32).

At the transmitting end, camera output signals corresponding to the red, green, and blue components of the scene being televised are passed through nonlinear amplifiers (the gamma correctors) which compensate for the nonlinearity 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-MHz filter for the luminance channel is shown in dotted lines because in practice this band

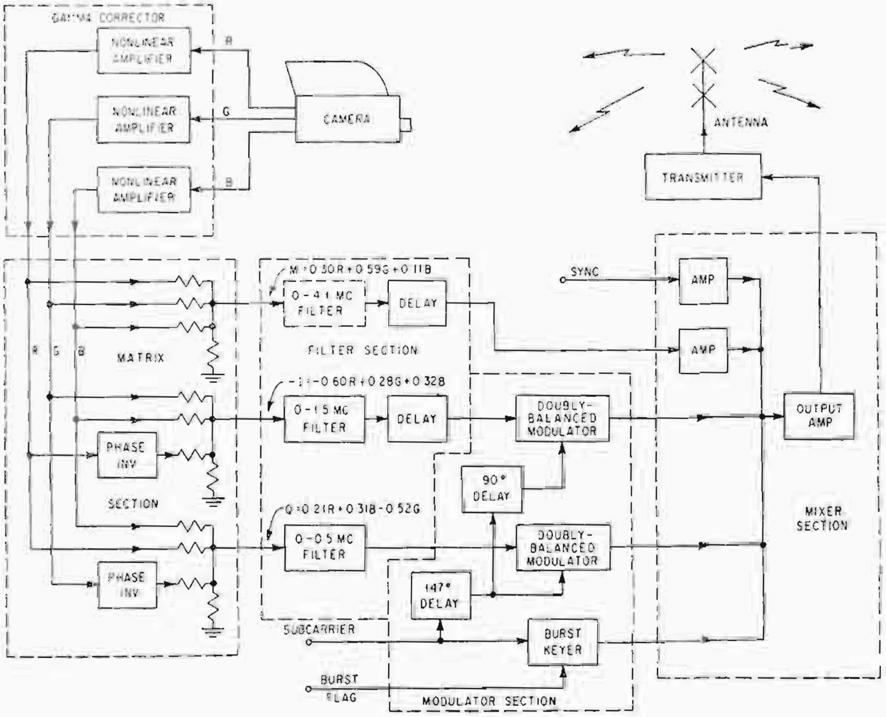

Fig. 31. Block diagram showing major functions of color-transmitting system.

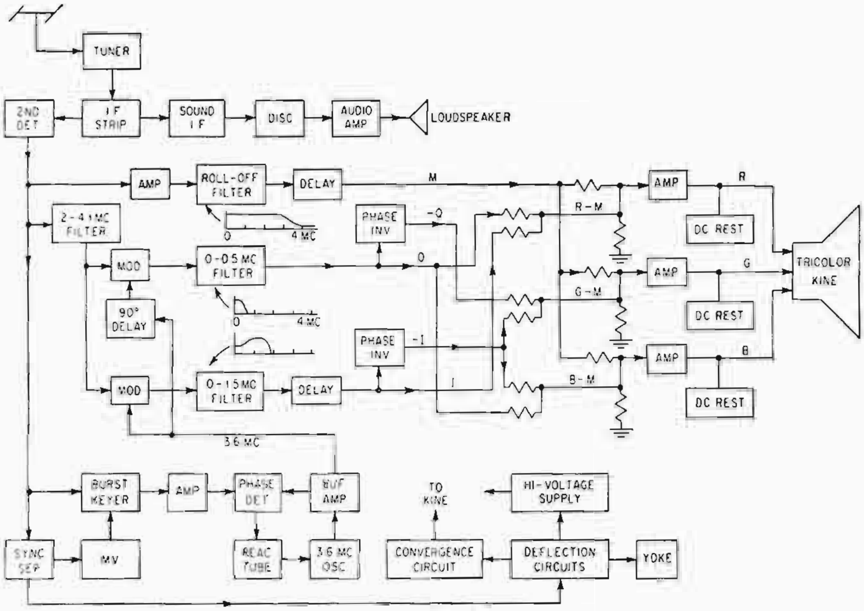

Fig. 32. Block diagram showing major functions of color-receiving systems.

shaping is usually achieved by the attenuation characteristics of the transmiter and the filter is not required.

The bandwidths of 1.5 and 0.5 MHz known 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 can 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 mixer section is a complete color-television signal containing both picture and synchronizing information. This signal can 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 stricter.)

## The Color-Receiving System

In a compatible color receiver, the antenna, RF tuner, IF 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 bandpass filter separates the high-frequency components of the signal (roughly 2.0 to 4.1 MHz) 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 MHz 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 can be obtained either from a "flyback" supply associated with the horizontal deflection circuit or from an independent RF 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 turned circuit of the oscillator. 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 passed through filters of nominally 1.5- and 0.5-MHz bandwidth, respectively, just as at the transmitting end. A step-type characteristic is theoretically required for the I filter, as indicated in Fig. 26, to compensate for the loss of one sideband for all frequency components above about 0.5 MHz. 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, and B signals. The R, G, and B signals at the receiver are not identical with 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 can 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 of Fig. 32 is intended only to illustrate the principles used in color receivers and does not represent any specific model now on the market. Design engineers of color receivers 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 of those principles.

## COLOR FIDELITY

"Color fidelity," as used herein, 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.

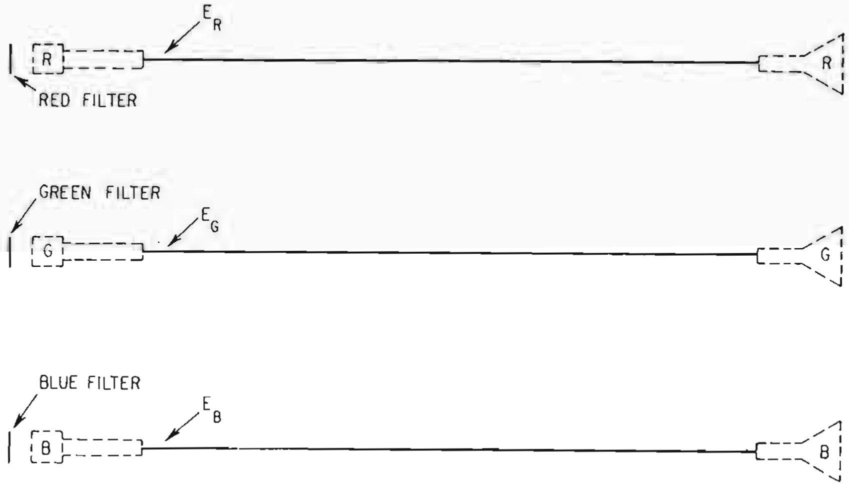

Fig. 33. Diagram of a theoretical color system showing linear RGB pickup tubes and kinescopes interconnected by wire.

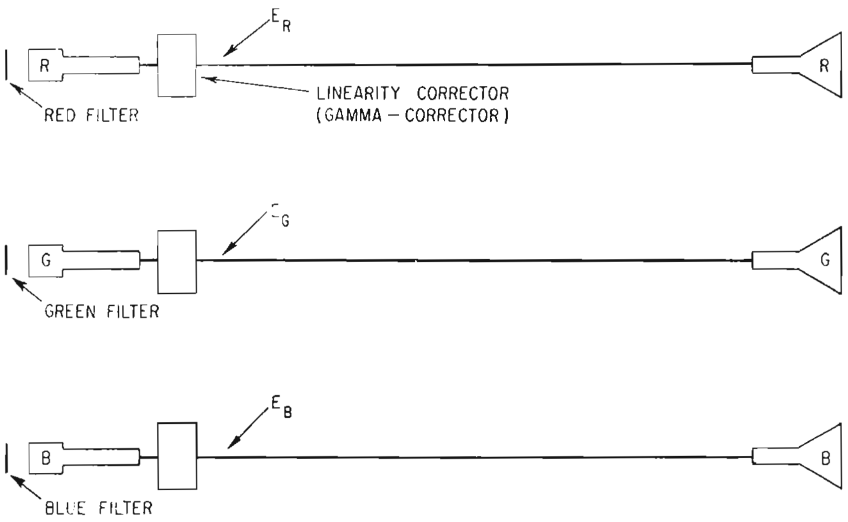

Fig. 34. The basic color system shown with necessary linearity correctors to compensate for color errors introduced by the nonlinear transducers.

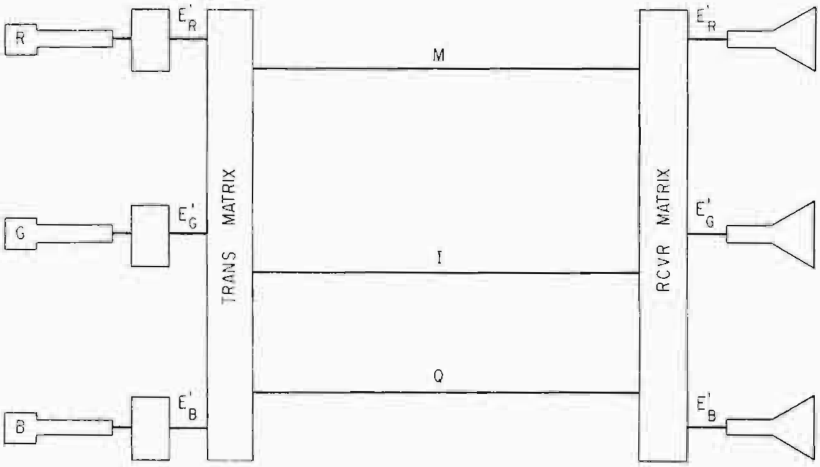

Fig. 35. Diagram showing transmitter and receiver matrix functions in the color system.

Color fidelity, therefore, is a term used to indicate a color reproduction which pleases the viewer aesthetically and persuades him that he is viewing a faithful reproduction of the original colors in the scene being televised.[2]

The following 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.

## 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. 33 through 37.

Fig. 33 is a theoretical color system in that it assumes linear camera tubes and a linear kinescope interconnected by a distortionless wire system. The only distortion that can result from this system is a flaw in colorimetry.

Fig. 34 introduces linearity correctors to compensate for color errors produced by nonlinearities in the transducers.

Figs. 35, 36, and 37 successively introduce the complexities of matrixing, band limiting, delay compensation, and the transmission system (shown dotted in Fig. 37). 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. 33 and 34 are described under Possible Distortions in Transducers, and those in Figs. 35, 36, and 37 under Possible Distortions in Encoding and Decoding Processes. The system shown in Fig. 37 is discussed under Distortions in the Transmission System.

## Characteristics of the Eye

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

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[2] A detailed discussion of colorimetry and perception, and how these factors affect the viewer, is presented in "Color Television Engineering" by John W. Wentworth, McGraw-Hill Book Company, Inc., New York, 1955.

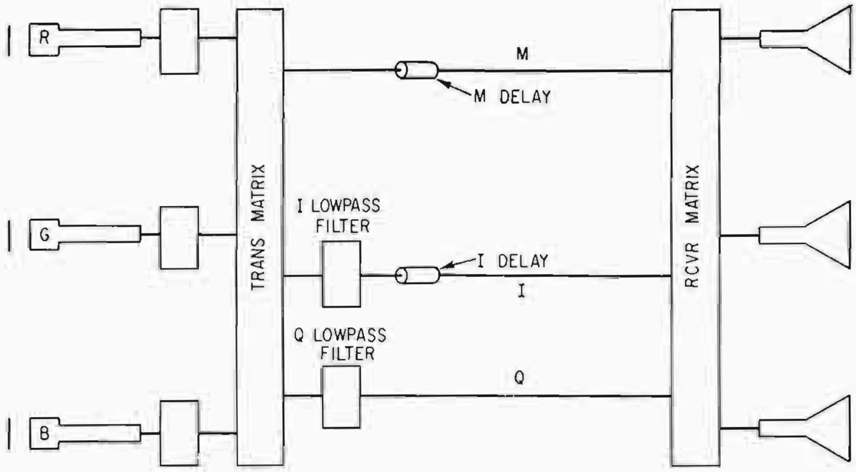

Fig. 36. Basic color system with band limiting and delay compensation.

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 midday sun while the reproduced picture is being viewed in a semidarkened room, with what little light is in the room also being derived from the midday 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 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 can cor-

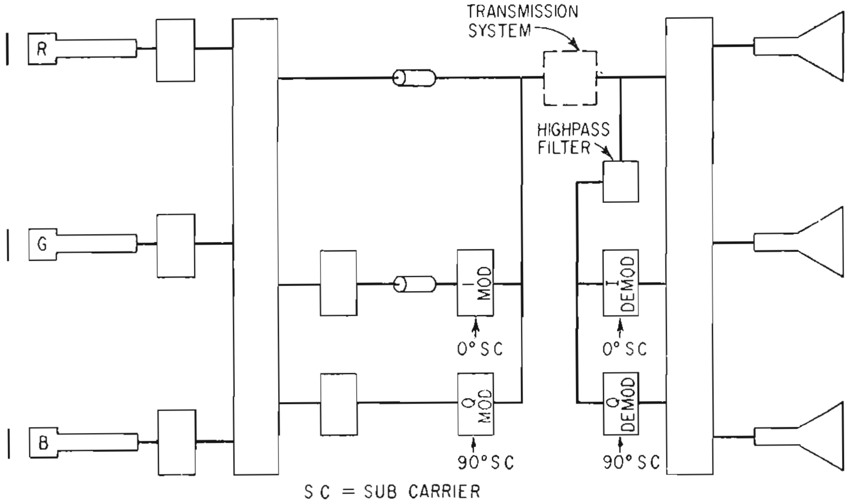

Fig. 37. Basic color system showing all major elements, including the transmission system.

rect 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, for example, the EIA Gray-Scale Chart or a piece of Neutracor white 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.

It has already been mentioned that the eye adapts readily to the illumination that surround conditions of an overcast day. This representative standard illumination has been adopted internationally as a base for the specification of the color of objects when they are viewed outdoors. This standard (Illuminant C) has been chosen to be the "standard-viewing-white" of the receiver. A slightly different illuminant has been proposed as (Illuminant D) more accurately representative of outdoor illumination and may replace Illuminant C in the near future.

The change in reference white between studio and home will 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 on his television screen, under the fluorescent lighting of his supermarket, or under the incandescent lighting of his home and, furthermore, will note little 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.

## 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 in their proper proportions.

## Possible Errors in Transducers

The block diagram of Fig. 33 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, in order to simplify the discussion of the colorimetry of the system.

The general plan in a system such as that of Fig. 33 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 response curve of the filter, plotted against wavelength, and the shape of the light-output curve of the phosphor, 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 color characteristics of the phosphor are generally less easily changed than are filter characteristics; for this reason characteristics of phosphors are taken as the starting point, and characteristics of the filters are determined from them. A laboratory setup which could be used to determine these characteristics is shown in Fig. 38. 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 kine-

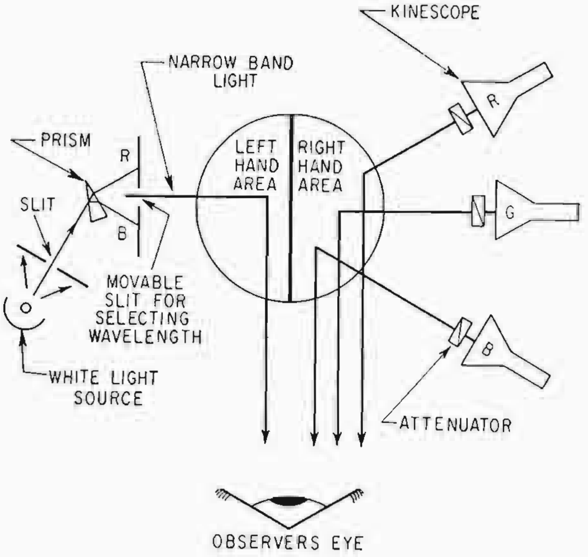

**Fig. 38. Diagram showing laboratory setup arranged to compare narrow-band light source and R, G, and B light produced by kinescopes to determine proper camera-filter color characteristics.**

scope, 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 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. 38.

(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 "nonstandard" 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 can 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.

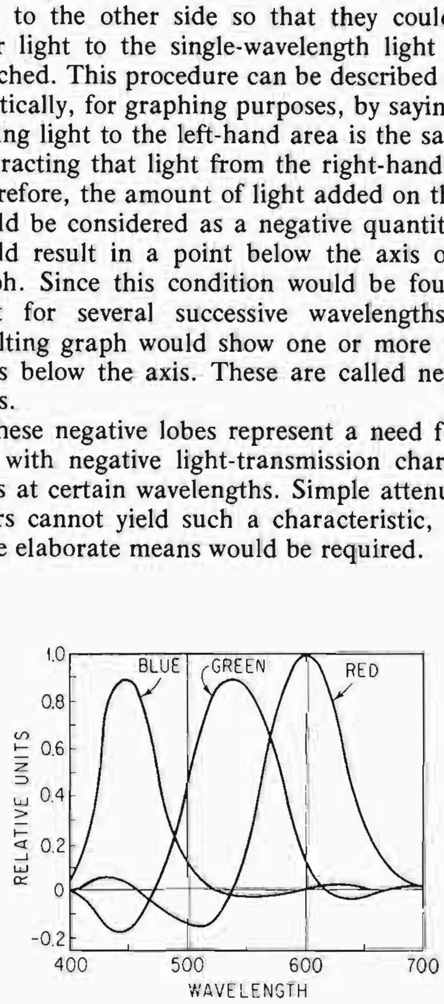

**Fig. 39. Curves showing relative quantities in camera output required to produce correct kinescope colors over the visible spectrum.**

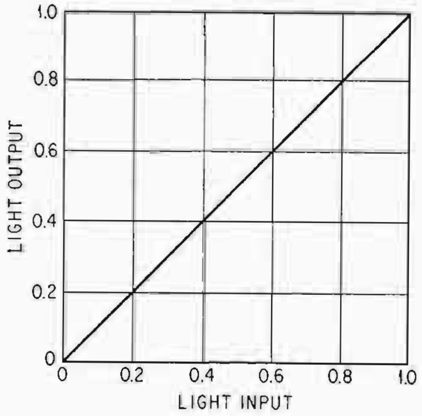

**Fig. 40. Curve showing light-transfer characteristics of a perfectly transparent piece of window glass.**

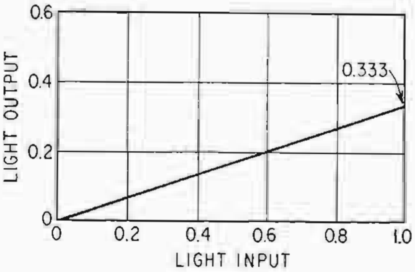

**Fig. 41. Curve showing transfer characteristic of a neutral density filter with 3-to-1 light attenuation.**

It is theoretically possible to achieve these negative lobes with added camera complexity but 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. Masking techniques which employ electrical matrixing have been introduced which can modify the spectrum characteristics of a color camera. These techniques can be used to help compensate for deficiencies in the color fidelity such as the lack of negative lobes.

## 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 with the light input (from the scene). This fact is shown graphically in Fig. 40. This plot could be called the "transfer characteristic" of a piece of glass, since it describes the way that light is transferred through the system.

If the window glass is replaced by a neutral-density filter which attenuates light 3 to 1, the transfer characteristic will then be given by Fig. 40. The difference between Figs. 40 and 41 can be described by these simple relationships:

For the glass:

$$\text{Light output} = \text{light input}$$

For the neutral-density filter:

$$\text{Light output} = k \times \text{light input}$$

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 nonlinear 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 threefold increase in input will result in a ninefold increase in output; etc. The transfer characteristic for this type of system is shown in Fig. 42. Note that the characteristic is definitely nonlinear; that is, it is not a straight line as were Figs. 39 and 40.

In television and photography, nonlinearity is more common than linearity. For example, an ordinary kinescope is a nonlinear device, having a transfer characteristic which can be approximated by the expression

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

Camera tubes can be linear or nonlinear devices. For example, the characteristic of a vidicon is approximately

$$\text{Current input} = k\,(\text{light input})^{0.65}$$

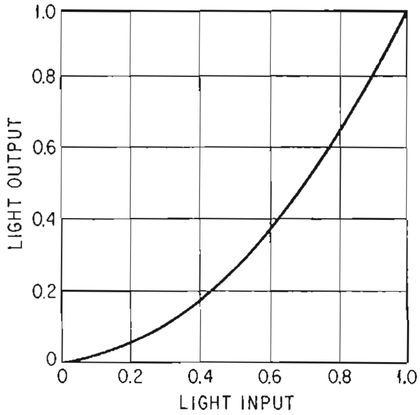

**Fig. 42. Curve showing a nonlinear transfer characteristic.**

The general expression for nonlinear transfer characteristic can be given approximately as

$$\text{Output} = \delta\ (\text{input})\,\gamma$$

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 *XY* 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. 40 and 41). 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 nonlinear. Moreover, the slope of the line describes the attenuation (or gain) of the device. If the slope is unity (which occurs 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. 41).

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 $L_0 = (L_{in})^{2.2}$. 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

$$\log L_0 = \log (L_{in})^{2.2}$$

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

$$\log L_o = 2.2 \log L_{in}$$

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 latter 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.

Figs. 43a and 43b compare the two types of plotting for three types of transfer characteristics.

## The Effect of a Nonlinear Transfer Characteristic on Color Signals

### *Effect of Identical Nonlinearities in Each Channel*

In monochrome television, some degree of nonlinearity can 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 ampli-

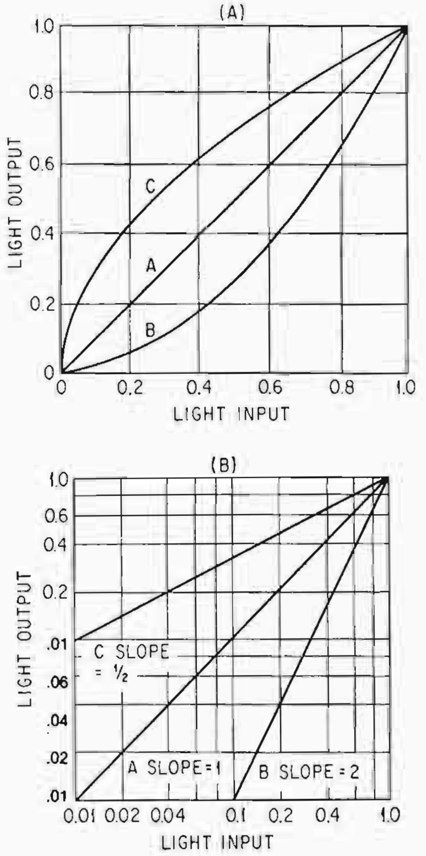

**Fig. 43. Graphs showing the curves obtained by plotting A, B, and C types of transfer characteristics on linear coordinated (A) and on log-log coordinates (B).**

fier 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 $(1.0)^{0.5}G + (0.5)^{0.5}R = 1.0G + 0.707R$ = a greenish yellow which is just a shade off pure yellow.

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

### *Effect of Differing Exponents in Each Channel*

The preceding discussion assumed that all three channels (in Fig. 33) 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 one another. 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 than the requirement for unity exponent.

Figs. 44a, 44b, 44c, and 44d 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. 44a and 44b the green exponent is taken as less than 1, and in Figs. 44c and 44d, as greater than 1. In Fig. 44a, 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. 43b), 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. 44c and 44d). With gains adjusted to reproduce peak white properly (Fig. 44c), lowlights would be purplish; with gains readjusted to provide proper reproduction for one of the lower steps (Fig. 44d), highlights would be green and 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.

This condition is reflected in the transfer characteristic of the system. If, for example, the stray light were 5 percent of the peak highlight brightness of the picture, a linear plot of light output versus light input would have the entire transfer characteristic shifted upward by 5 percent. However, the most interesting change is found in the log-log plot, where, as seen in Fig. 45, the stray light causes a change in the slope in the lowlight regions. Since the slope is equal to the exponent, this change shows that stray

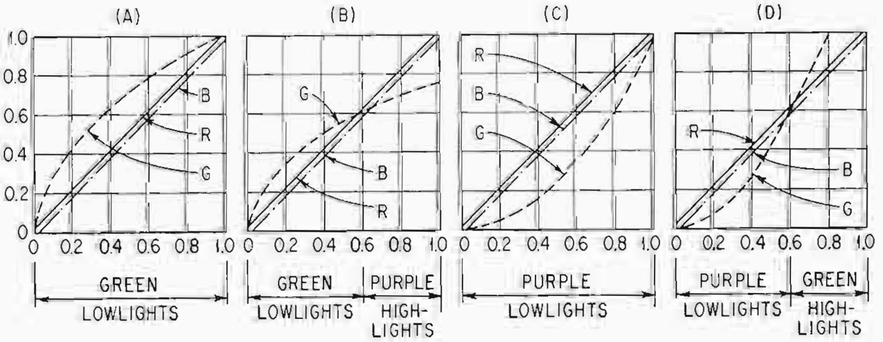

Fig. 44. Linear plots showing graphically the effect of unequal exponents in the R, G, and B channels. In all four graphs the R and B exponents are taken as unity. In (A) and (B) the green exponent is taken as less than 1, and in (C) and (D), as greater than 1.

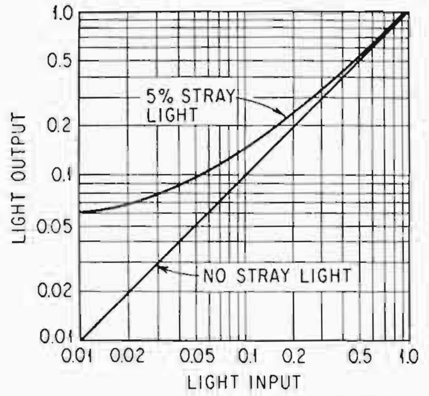

**Fig. 45. Log-log plot of system with stray light, illustrating change of slope in the low-light regions.**

light causes an effective exponent error in the lowlight regions of the picture and hence will cause color-fidelity errors which will be most marked in the lowlight 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. 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 light output of the system from becoming zero when the light input is zero will cause errors similar to those caused by stray light.

### *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. 34, a nonlinear amplifier, or gamma corrector, is shown inserted in each of the three paths.

## Possible Encoding and 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-MHz channels. A fortunate characteristic of the human eye—the inability to see colored fine detail—allows us to modify this requirement to one 4-MHz 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-MHz channel, and the I and Q channels, which contain the color information, are confined to narrower channels. This rearrangement of red, green, and blue to form M, I, and Q is called matrixing and was described in the previous part. A system which uses a matrix is block-diagramed in Fig. 35. The illustration also shows that to recover the original red, green, and blue signals at the receiving end, a "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. 36 shows a system employing such band shaping. The band-shaping 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 can be allowed for both I and Q signals, without incurring visible cross talk, if two techniques, known as frequency interlace and two-phase modulation are employed. A system using these techniques, which were described in the section on Electronic Aspects of Compatible Color Television, is block-diagramed in Fig. 37.

## 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:

$$\begin{aligned} M &= 0.30R + 0.59G + 0.11B \\ I &= 0.60R - 0.28G - 0.32B \\ Q &= 0.21R - 0.52G + 0.31B \end{aligned}$$

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 analogue computers which continuously compute the desired output from the given input. The coefficients 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 coefficients. In general, the resulting picture error resembles cross talk 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 probably 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 misdirected 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 cross talk 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 nonadjustable 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 cross talk 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 percent reduction in the peak red output available and would also result in unwanted red light output in green or blue areas at about 3-1/2 percent of the green or blue level.

## Gain Stability of M, I, and Q Transmission Paths

In the system of Fig. 35, 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 among 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. It previously 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. 35, 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 block-diagramed in Fig. 37.

## 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. 46.

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.

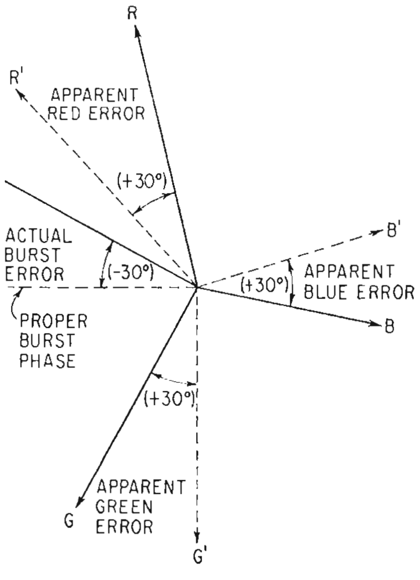

**Fig. 46. Vector diagram showing how error in subcarrier phase becomes an opposite error in all other phases.**

### *Burst Amplitude Error*

In theory, the receiver circuits which extract timing information from the burst are insensitive to variations in burst amplitude as 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, and 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 amplitude 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.

### *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 cross talk of Q and I. The final result will be the same as cross talk 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, cross talk of I into Q or Q into I, with the net picture result resembling cross talk 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. 47, 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 canceled by the carrier-unbalance vector and become white. Such white-to-color and color-to-white errors are very objectionable.

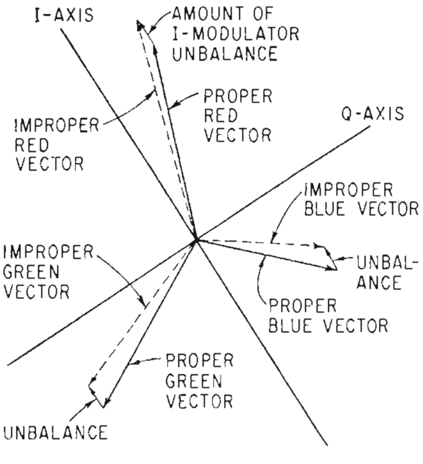

**Fig. 47. Vector diagram of subcarrier phase and amplitude with positive vectors added to represent carrier unbalance in the I modulator.**

### *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 MHz ± 10 Hz. 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 lockup 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 $\pm 90°$ 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; when the signal is transmitted 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 nonlinearities 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.[3] Typical plots are shown in Figs. 48 and 49, respectively. These two characteristics known, it is possible to predict accurately what effect the transmission system will have on a given signal.

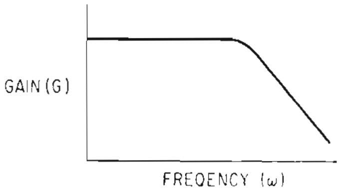

Fig. 48. Typical curve showing gain of a system plotted against frequency to determine its gain characteristic.

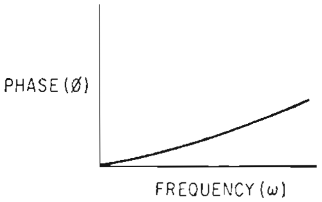

Fig. 49. Curve showing phase characteristic of a system plotted versus frequency.

### Gain Characteristic

Fig. 48 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-MHz bandwidth is required for the monochrome standards, the requirement can 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 cutoff frequency). As pointed out in preceding sections, the entire chrominance information of the color system is located in the upper 1.5 MHz of the prescribed 4.0-MHz 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 MHz is one-half the low-frequency gain. Since the saturation depends chiefly on the amplitude of the 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

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[3] 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 of filter. Almost all common interstage coupling networks are of the minimum-phase type.

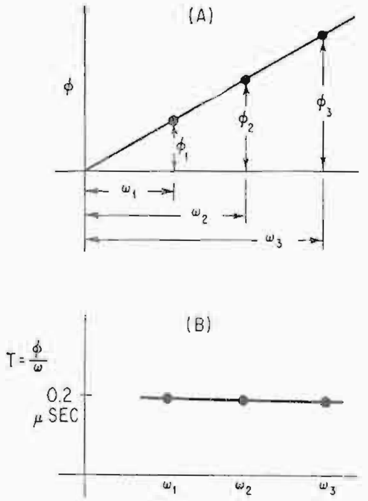

Fig. 50. Curves illustrating a system with linear phase characteristics, which will give the same time delay for signals of all frequencies.

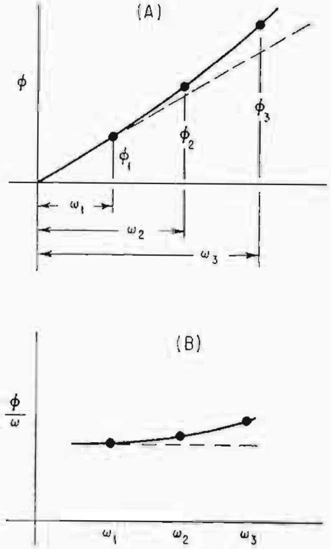

Fig. 51. Curves showing the effect of nonlinear phase characteristic on the time-delay characteristic.

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. 50a. 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. 50 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 $\phi_1/\omega_1 = 0.2\,\mu$sec, then $\phi_2/\omega_2$ also equals $0.2\,\mu$ sec and $\phi_3/\omega_3$, too, is $0.2\,\mu$ sec. Plotting these three values and drawing a straight line through them as in Fig. 50a will show that the time delay for all frequencies is $0.2\,\mu$sec.

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 nonlinear (as in Fig. 51a), the time delays for all parts of the signal are no longer equal (see Fig. 51b). For example, if a complex waveform is made up of a 1-MHz sine wave and its third harmonic, these two components will suffer unequal delays in passing through a system having the characteristics of Fig. 50. The resultant distortion can be seen by comparing Figs. 52a, 52b, and 52c.

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 $\phi_1/\omega_1$, $\phi_2/\omega_2$, and $\phi_3/\omega_3$ 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. 53b), 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. 53a and 53b. To calculate the delay of the carrier-borne signals *after* they have been demodulated, measurements of $\phi$ and $\omega$ must be referenced, not from zero frequency, but from *carrier* frequency.

In Fig. 54a, an 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.

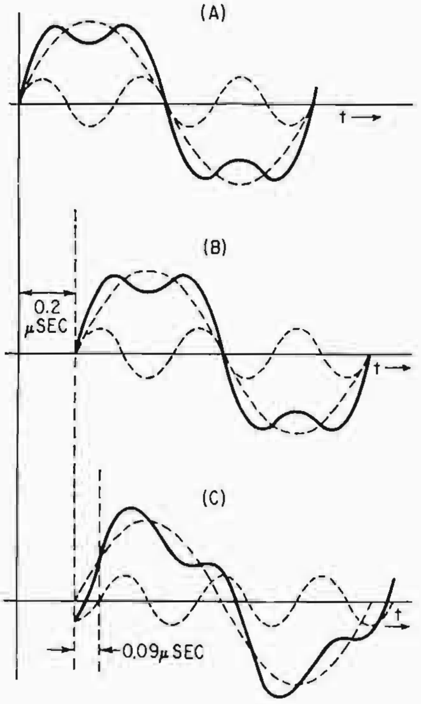

Fig. 52. Curves showing that a complex wave (A) is not distorted by time delay (B) when both components (shown dotted) are delayed by the same amount. Unequal delays (C), however, cause distortion.

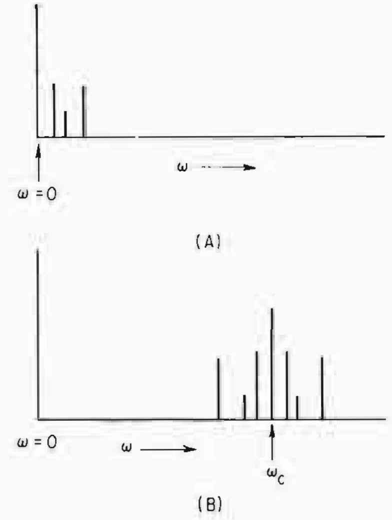

Fig. 53. Sketch showing how a group of frequencies near $\mu = 0$ [sec. (A)] can be translated by modulation onto a carrier to a group of sidebands near $\mu_c - \alpha$ carrier frequency (B).

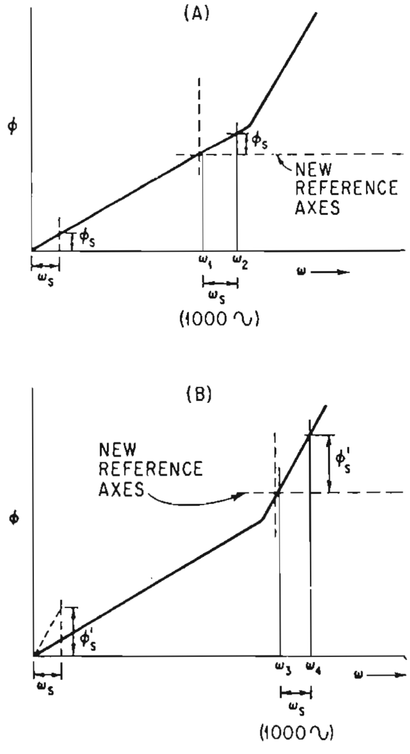

Fig. 54. Idealized straight-line phase characteristics showing how a carrierborne 1,000 Hz signal can be delayed excessively when the carrier and sideband fall on a steeper portion of the phase characteristic.

First, pass two frequencies $\omega_1$ and $\omega_2$ through this system. Let $\omega_1$ be a carrier and $\omega_2$ a sideband which might be, for example, 1,000 Hz higher. If $\omega_1$ and $\omega_2$ fall on the characteristic as shown in Fig. 54a, the delay which the 1,000 Hz will show after demodulation can be found putting new reference axes (shown dotted) with $\omega_1$, the carrier, at zero on these new axes. Now, when $\omega_s$ and $\phi_s$ are measured as shown, the time delay after demodulation is $\phi_s/\omega_s$. In this case, the delay of the 1,000 Hz after demodulation is the same as it would have been had it been passed through the system directly.

Second, pass two other frequencies $\omega_3$ and $\omega_4$ through this system as redrawn in Fig. 54b. This time drawing in the new axes at $\omega_3$, it can be seen that although $\omega_s$ is still 1,000 Hz, $\phi_s$ is larger than $\phi_s$. Therefore, it can be concluded that the time delay $\phi_s/\omega_s$ for this second case is greater than for the first case. The 1,000 Hz, when demodulated, will show a considerable error in timing.

Stressing the phrase "delay in a demodulated wave" 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. 54a introduces a delay of 0.2 μsec to the 1,000-Hz wave (measured after demodulation), then the *envelope delay* of the system is 0.2 μsec. However, it was shown that a 1,000-Hz signal passed directly through the system (without first being modulated into a carrier) would also suffer a delay of 0.2 μsec. As long as the envelope delay $\phi_s/\omega_s$ is the same as the time delay $\phi_1/\omega_1$, the envelope delay introduces no timing errors. But in the second system (Fig. 54b) the demodulated 1,000-Hz wave suffered a *larger* delay, say 0.29 μsec. A 1,000-Hz signal passed directly through this system, however, would still be delayed only 0.2 μsec. Therefore, the second system has an *envelope delay* of 0.29 μsec and an *envelope-delay distortion* of 0.09 μsec.

It is probably wise to point out that the time delay $\phi_3/\omega_3$ in Fig. 54b is considerably less than the 0.29 μsec estimated for the value of envelope delay. Although $\phi_3/\omega_3$ would be greater than 0.2 μsec (say, for example, that $\phi_3/\omega_3$ is 0.22 μsec), the value would be optimistic about the amount of timing error that would be shown by the demodulated 1,000-Hz signal. The need for a knowledge of the envelope delay $\phi_s/\omega_s$ 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 and the delay of the luminance signal is determined principally by the ordinary time delay $\phi/\omega$. 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. 54b, the luminance signal is delayed by 0.2 μsec but the chrominance signal is delayed by 0.29 μsec. The error in registration then amounts to 0.09 μsec, or about 0.2 percent of the horizontal dimension of the picture, which is about 0.3 in. on a 21-in. (diagonal) picture.

Although the subject of compatibility is outside the scope of this part, is 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. 54a and 54b) 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 $\phi$ versus $\omega$ plot as i Fig. 55. Finding the envelope delay of this curved-line plot will clarify what is meant by envelope delay.

Referring back to the plots of Figs. 53a and 53b, 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 $\omega_3$-$\omega_4$ pair (Fig. 54b), was a result of their lying on the steeper slope. The envelope delay of *any* system is equal to the slope of the phase versus frequency characteristic. If this characteristic is a curved line (as for the *RC* network, Fig. 55), then the slope is different at every frequency 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. 56. 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.

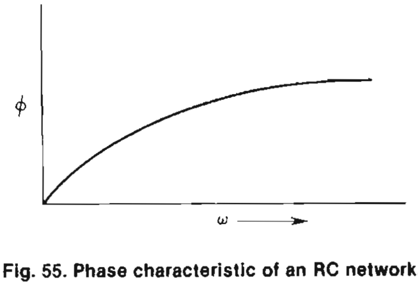

Fig. 55. Phase characteristic of an RC network.

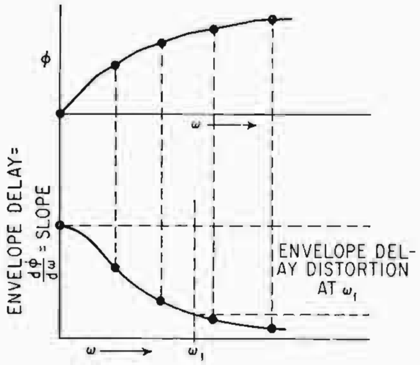

**Fig. 56. Graphs showing how a series of straight-line segments can be used to approximate the smooth curve of Fig. 55 (top) and how the slopes of these segments may be plotted to approximate the envelope delay characteristics (bottom).**

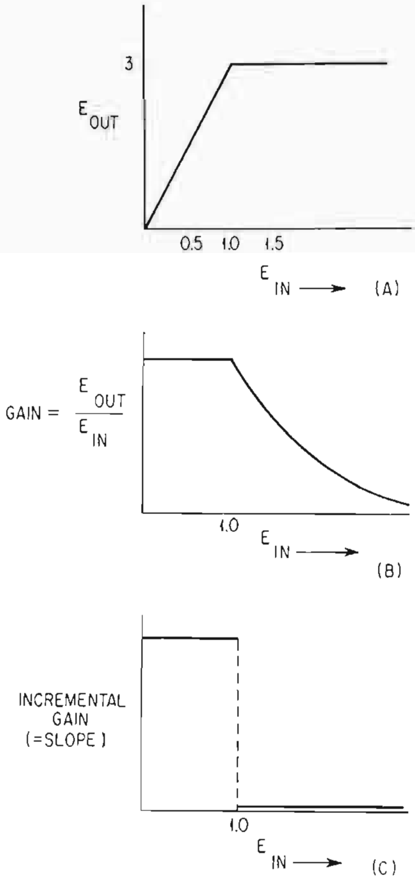

**Fig. 57. Idealized straight-line plots showing (A) output voltage of an amplifier versus input voltage (B) gain of the amplifier versus input voltage and (C) incremental gain of the amplifier versus input voltage. Curve (C) is the slope of curve (A).**

## Nonlinearities of a Practical Transmission System

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

The major sources of nonlinearity in a transmission system are its amplifying devices.[4] These devices—tubes 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. 57a.

Such a nonlinearity 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. 57a 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

$$\text{Gain} = \frac{E_0}{E_{in}} = \frac{3\ \text{volts}}{1\ \text{volt}} = 3$$

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

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

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

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[4] FM systems can have nonlinearity as a result of *passive* networks, but this case is not considered here.

clipping involved.) The gain, defined as $E_0/E_{in}$, is plotted against $E_{in}$ in Fig. 57b. It can be seen in this figure that the gain is constant only as long as the *slope* of Fig. 57a 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. 57a. For the particular plot of Fig. 57a, 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. 57c.

The importance of incremental gain in color television can be assessed by applying the input signal shown in Fig. 57 to the distorting system of Fig. 57a. 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 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. 59. 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-1-volt value. The color signal of Fig. 59 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.

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. 59 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.

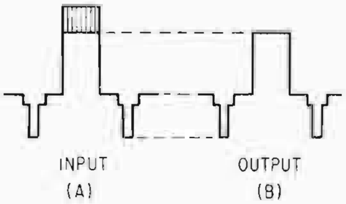

**Fig. 58. Extreme case of distortion resulting from passing signal at left (A) through the amplifier represented by Fig. 57. The output (B) has no color information remaining.**

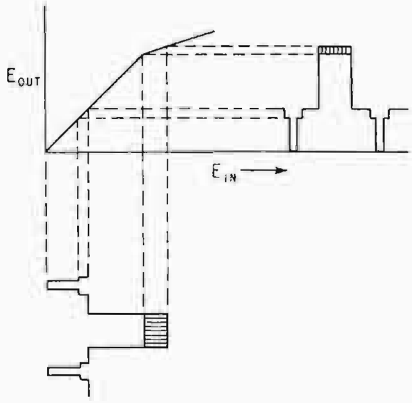

**Fig. 59. Diagram showing effect of incremental gain distortion in reducing amplitude of color portion of signal.**

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. 60a 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. 60b. If the compression is as in the figure, the *incremental gain distortion* (IGD) is indicated by the distorted amplitude of the last step. Numerically, it can be stated as a percentage:

$$\mathrm{IGD} = 1 - \frac{S_{\text{distorted}}}{S_{\text{undistorted}}} \times 100\%$$

where $S$ is a step amplitude.

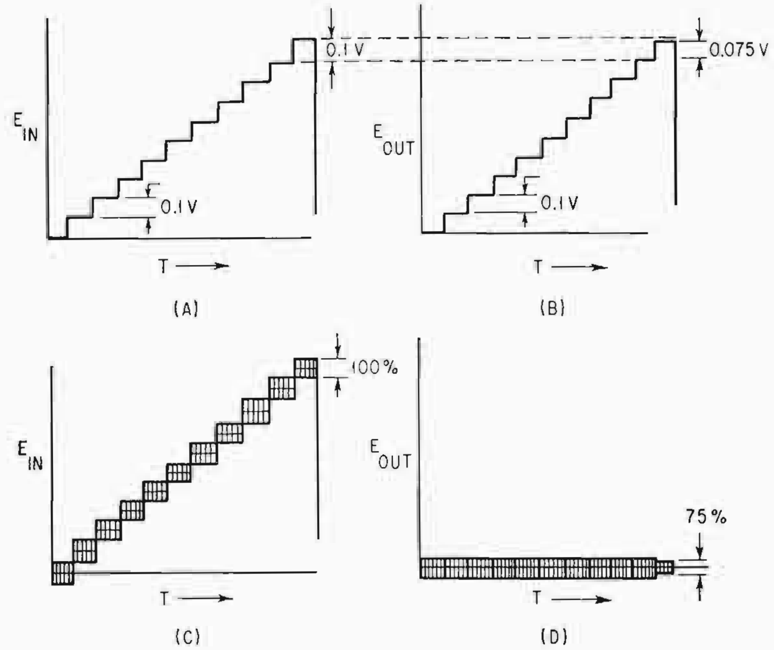

**Fig. 60. Diagrams showing two methods of measuring incremental gain distortion, namely, in (A) and (B) by its contribution to luminance distortion and in (C) and (D) chrominance distortion.**

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 percent.

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. 60c, 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. 60d). In this case, the high-frequency sine wave associated with the top step is shown as having 75 percent 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 percent.

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 can be used to provide *both* tests by observing the system output (for this test waveform input) first through a low-pass filter and then through a high-pass 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 with 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."[5] In other words, differential gain is a special form of incremental gain distortion which describes the IGD of a system for the superimposed 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. 58, when the ". . . high-frequency sine wave . . ." of the definition was made equal to color subcarrier. This special case of differen-

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[5] From the definition of differential gain by IRE Subcommittee 23.4.

tial 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 Hz staircase, sine-wave, or sawtooth. The complete specifications for the signal presently used in this measurement will be found elsewhere in this article.

Another reason for emphasizing high-frequency IGD was implied previously by the sentence ". . . the signal . . . would . . . be reproduced . . . with the only apparent error being a luminance distortion . . . which, for the magnitudes shown ehre, would probably pass unnoticed." The magnitude shown was a 25 percent IGD, which is passing unnoticed, indicating 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 IGD was deliberately omitted from the definition of differential gain.

### *Incremental Phase and Differential Phase*

The phase characteristic sketched in Fig. 49 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 MHz. If the system in question were perfectly linear, this 60° phase shift would be produced regardless of how the 2-MHz 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. 61, will introduce a delay *different* from 60°, depending on where the zero axis of the sine wave falls on the transfer characteristic of the system. 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.

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.

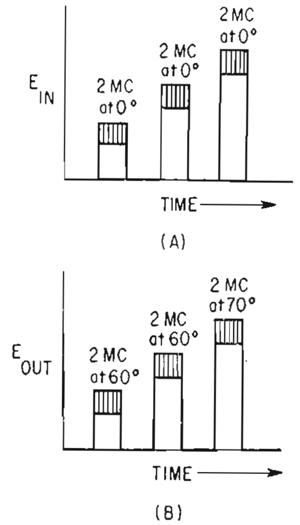

**Fig. 61. Graphs illustrating how a signal (A) may undergo different phase shifts (B) depending upon where the zero axis at the sine wave falls on the system transfer characteristic. This distortion is called differential phase.**

*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. 61 the 2-MHz 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 with *incremental gain distortion* for the superimposed-high-frequency case only. Similarly, *differential phase* is identical with *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 with 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.[6]

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[6] From the definition of differential phase by IRE Subcommittee 23.4.

It is important that the phrases "differential phase *distortion*" and "differential gain *distortion*" be avoided because differential phase *is* distortion as is differential gain, since they are defined as being identical with 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 percent and a differential phase of 0.5°."

*Effect of Differential Phase on a Color Picture*

The phase of subcarrier in a composite signal carries 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 zero axis of the subcarrier. 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.

## 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 parameter 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 generally small in comparison with other sources of error.

### System Exponent

At the present state of the art, adjusting a system to precompensate 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 precompensate 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 percent of the peak signal amplitude. The exponents of the three channels can be made to match within 1 percent 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 .5 percent 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 1 percent 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 .5 percent 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 Hz 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 Hz.

### Transmission Characteristics

A single amplifier should have a gain characteristic with less than ±1/2-dB variation out to 8 MHz. Its envelope-delay error should be of the order of 0.001 μsec at 3.58 MHz, relative to 200 kHz. Differential gain of .5 percent and differential phase of 0.25° represent good performance.

### Tolerable Color Errors

Sensitivity of the eye 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 or color errors. However, if the comparison is made only by recollection or long term 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 not 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.

Fortunately, side-by-side comparison of colors seldom, if ever, 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. Reproductions of these objects must be accurate enough to satisfy the viewer's recollection or color memory. If the system can satisfy the color memory of the viewer, the color-plausibility requirement will be easily met.

Investigations made to determine the sensitivity of the eye to color errors introduced by a deliberate shift of burst phase show that a shift of 10° or more produces perceptible change of hue. With color bar signals a burst phase shift of 3° can just be detected as a hue shift. With typical scenes a phase shift of 5° can be tolerated.

Tests have shown that the eye is much more tolerant of amplitude shifts in R, G, B components, which correspond to changes in color saturation, than it is of phase shifts or changes in hue.

One must distinguish between long-term adaptive errors in viewing a color television picture and short-term differential color errors. In the first case the eye is quite tolerant of changes or shifts in color balance providing that no direct side-by-side comparisons are involved. Thus a viewer is reasonably well satisfied with color pictures in which white is reproduced within the range of 3200°K to 9500°K. As soon as he views two color TV pictures side-by-side at two different white balance conditions, there will be a much more critical reaction to color fidelity.

For this reason, it is important that color monitors in a broadcasting control room be adjusted to have the same effective white balance, the same color phasing, and the same peak brightness. Since such monitors are usually arranged in a row adjacent to each, great care must be taken so that when the same picture signal is applied to all monitors, there is negligible difference in the color picture displays. Only then can the color monitors be useful in matching and comparing color balance of the various camera signal sources.

It is unusual to have more than one color receiver at a home viewing location at a given time. There the absolute color balance problem has little direct impact.

Control of short-term differential color errors is vitally important to the broadcaster. In any broadcast sequence, a given scene is generally viewed from different angles with several color cameras, at various magnifications, and the available video signals are selected from camera to camera to obtain program continuity. The eye views these color scenes in quick succession and is very critical of even small color differences, particularly with regard to skin tone rendition. Variations of the R, G, B or primary color components of 2 percent can be detected. Although the eye can easily adapt to any of the pictures in a few seconds, the viewer will find the abrupt color shifts very disturbing with switching transitions. Thus great care is taken with colorimetric tolerances in color cameras and with color-balancing procedures to provide color matching among cameras which will be precise.

A similar situation exists in the reproduction of color motion pictures. A feature movie having adequate color quality is usually shown in a sequence lasting 15 minutes or more, with the eye having adequate time to adapt to any discrepancies in color balance and skin tones. Commercials spliced into this feature program produce an instantaneous switch to a new and different skin tone balance without time for eye-adaptation. This transition to commercials and back to the feature can exhibit color mismatch in varying degrees, depending on the colorimetric control which has been exercised.

In fact, if the feature film is somewhat misbalanced, and intentionally "corrected" by appropriate use of R, G, B gains or "paint-pot" controls, the transition to the commercial will be more objectionable since the "correction" can then increase the misbalance, even for a "perfectly-balanced" commercial. Effort is going on in the industry to tighten up tolerances on skin tone rendition so that adequate performance can be obtained by purely routine operating methods.

## Conclusion

This discussion of color errors indicates *possible* degradations in color fidelity and their probable sources. However, in a properly adjusted color TV system the picture quality is excellent. The various techniques now in development to improve picture quality within the framework of the NTSC system have assured a bright future for color TV.

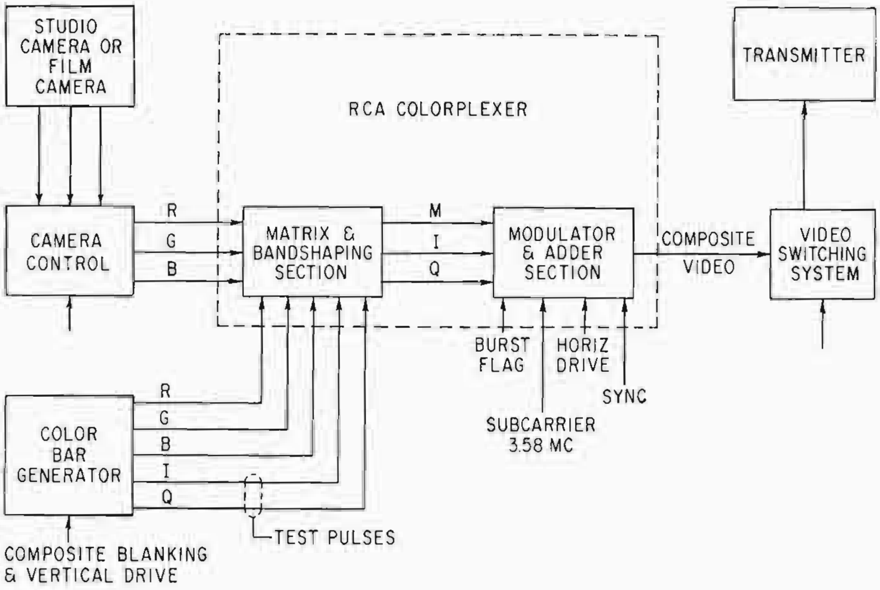


Fig. 62. Basic color-television system showing functions and major components of the colorplexer.

## THE COLORPLEXER

The Colorplexer or encoder in the color television system performs the required encoding of the R, G, B signals from three-tube cameras or the R, G, B and Y (luminance) signals from four-tube cameras into a single color video signal conforming to FCC specifications. It is the heart of the modern color television system and represents a most ingenious application of many elements of communication circuit theory.

Fig. 62 shows a block schematic of a basic color television system indicating the functions and major components of the colorplexer.

A more detailed block diagram of the colorplexer showing the matrixing, bandwidth-limiting and quadrature modulation functions is shown in Figs. 36 and 37.

### Basic Functions

The principal operations and functions performed by the colorplexer are:

1. Matrixing of R, G, B video signals to produce luminance and chrominance signals.
2. Filtering of the chrominance signals to obtain the required bandwidth.
3. Delay compensation to correct for band-limiting time-delay.
4. Modulation of 3.58 MHz carriers by chrominance signals.
5. Insertion of color sync burst.
6. Addition of luminance and chrominance signal to form a complete color signal.
7. Optional addition of sync.

Design and system philosophy determines whether a colorplexer is a separate unit or an integral portion of a modular assembly. Present solidstate equipment design tends toward the modular concept since it is generally easier to maintain, repair, up-date and revise specific modular units or board assemblies without affecting the overall installation.

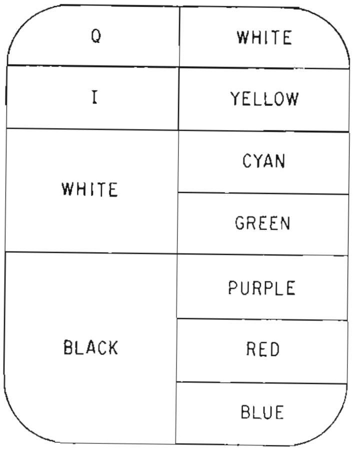
The electrical color bar generator which is generally provided for systems test and colorplexer alignment is available either as a separately contained unit or as a module in a complete operating assembly.

Colorplexers of modern solid-state design are inherently stable and require only routine verification or adjustment. Set-up of a colorplexer involves the use of color-bars which are electrically generated waveforms of high precision. A color bar generator is capable of producing on a color monitor all of the signal bars illustrated in Fig. 63.

Colors at the top of this display pattern are arranged from left to right as white, yellow, cyan, green, magenta, red and blue in their decreasing order of luminance. The lower portion of the pattern contains "I," "100% White," "Q," and black signal areas. The "I and "Q" signals simplify subcarrier phase adjustments in the colorplexer and the 100 percent white bar facilities white-balance adjustments. The specifications of the standard encoder color bar signal are given in EIA standard RS-189.

### Waveforms

Fig. 64 shows the oscilloscope waveforms at a horizontal sweep rate of the color bar signals displayed on the television raster. Note that this is a composite representation of waveforms of



| | |
|---|---|
| Q | WHITE |
| I | YELLOW |
| WHITE | CYAN |
| | GREEN |
| BLACK | PURPLE |
| | RED |
| | BLUE |

**Fig. 63. Diagram showing color monitor display of color and test bars electronically produced by RCA color-bar generator.**

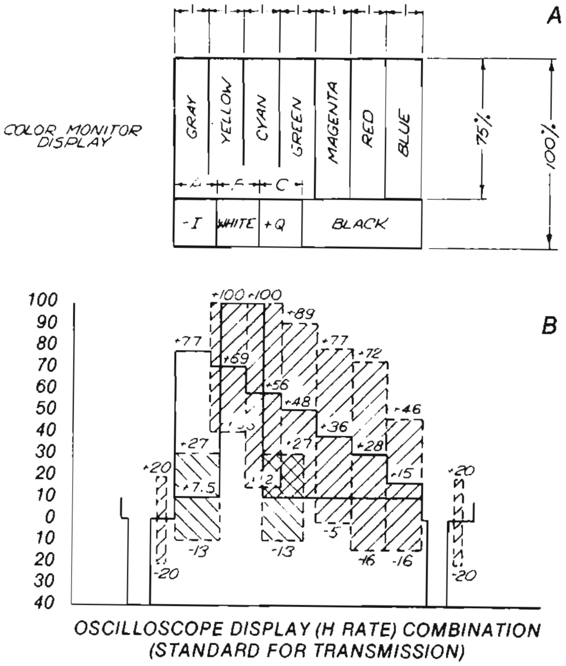


**Fig. 64. (A) Color monitor display and (B) Oscilloscope display (H rate).**

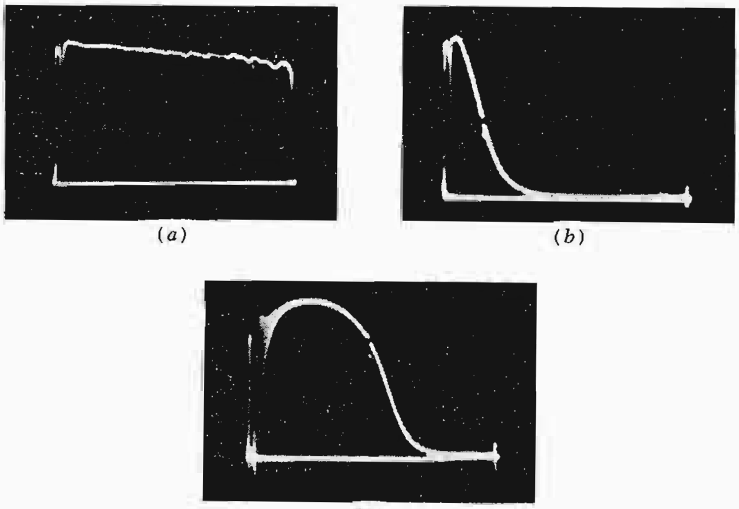
the top and the bottom areas of the raster. The color sync precedes the color bar pulse information.

Fig. 65 shows the various band-pass response characteristics of the luminance channel and of the "I" and "Q" channels of the colorplexer.

A colorplexer is set up and adjusted by using the calibrated color bars just described. The colorplexer luminance gain is adjusted by using the 75 percent white bar as a reference. By switching off the luminance channel the appropriate "I" and "Q" waveforms are available to set the proper peak amplitudes and the 90° phase separation. Either a wide-band oscilloscope or a vectorscope can be used for display in a variety of specialized set-up procedures. The vector relationship of chrominance components is shown in Fig. 66.

## Aperture Compensation

Aperture compensation is used in television systems to correct for the decrease in signal out-


(*a*)

(*b*)

(*c*)

**Fig. 65. Waveforms showing response characteristics of colorplexer monochrome, I and Q channels. (*a*) Response of monochrome channel without aperture correction, marker at 8.0 MHz; (*b*) output of I filter, marker at 2.0 MHz; (*c*) output of Q filter, marker at 500 kHz.**

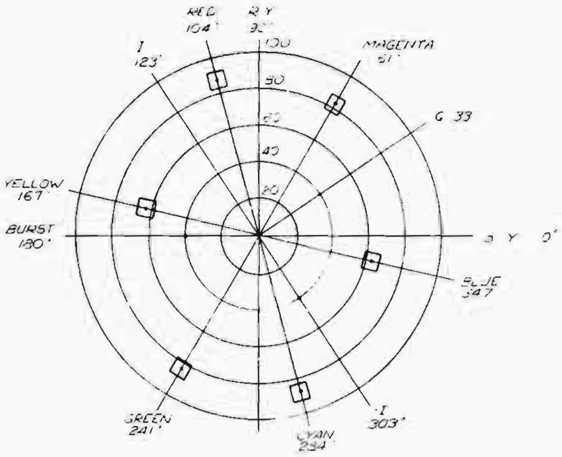


**Fig. 66. Vector relationship among chrominance components.**

put at high frequencies caused by the finite-size limitations of the scanning spot or of equivalent optical lens aperture response. If one considers abrupt or black to white square-wave transitions at 400 TV lines, corresponding to 5 MHz video components, the video signal amplitudes from a Plumbicon or vidicon pick-up tube may be only 30 to 40 percent of the amplitude of low frequency transitions at 40 TV lines or 0.5 MHz. If the signal-to-noise ratio of the output video is good, aperture compensation to give practically 100 percent flat response at 5 MHz can be applied, producing subjectively sharper pictures.

Horizontal aperture correction is done by comparing the amplitude response of a given picture element with that from adjacent elements by the use of differential amplifiers and electrical delay lines. This difference, suitably amplified and of correct polarity is added to the signal being corrected which increases the sharpness of the transition.

Vertical aperture response can also decrease with increased line number and can similarly be improved by comparing the response of picture elements on a given TV line with that of line elements preceding and following it. Differential amplifiers compare the video signals obtained from delay lines of a horizontal period (63.6 $\mu$sec) in duration with the picture elements of the TV line to be corrected.

Differences between these video responses are obtained from differential or comparison amplifiers amplified and suitably added to the main signal, to improve the vertical transition sharpness.

Judicious use of combined horizontal and vertical aperture correction or enhancement produces marked improvement in subjective picture sharpness. Since the luminance channel of a color system provides the sharpness information, it is generally used as the signal for aperture response improvement.

A block diagram of aperture compensation circuits is given in Fig. 67.

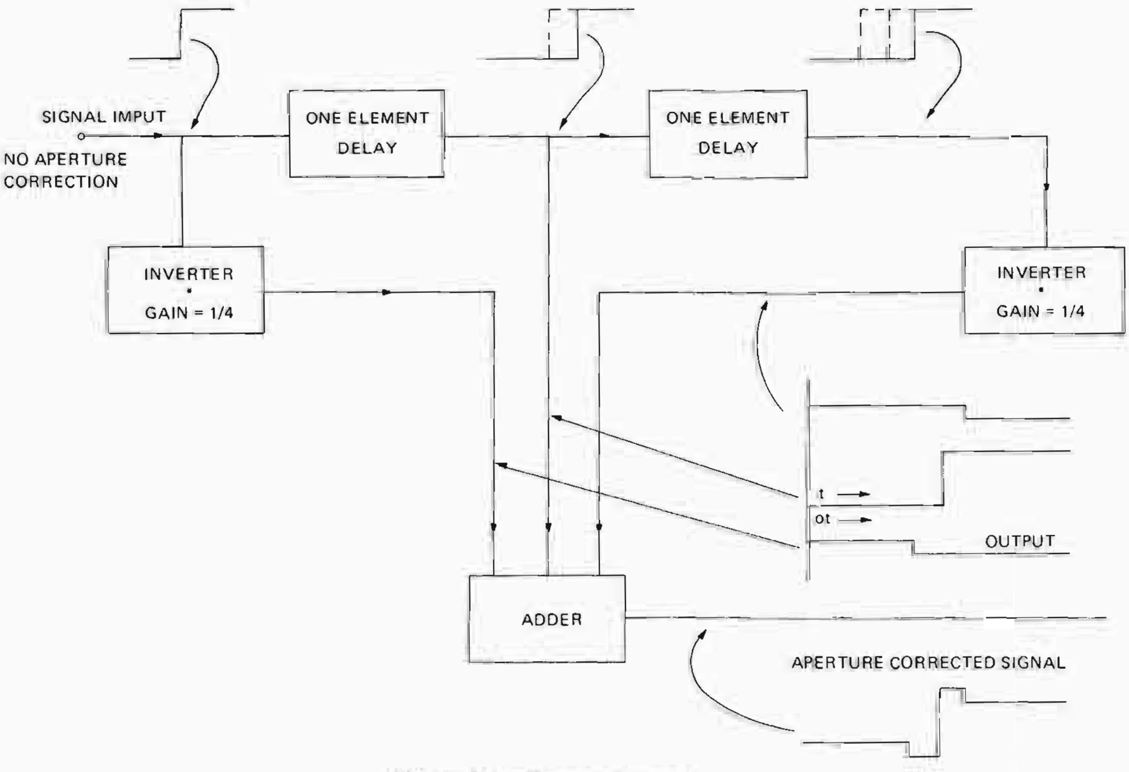


**Fig. 67. Generalized aperture corrector.**

## Factors Affecting Color Camera Performance

The following general principles, which outline procedures for the proper alignment and operation of color cameras, are directed toward three-tube color camera models and are presented to assist the station engineer in understanding the effect that each adjustment can have on the composite color picture. No attempt is made to present a step-by-step alignment procedure which, while basically the same for all cameras, will vary in detail depending on the manufacturer and the type of camera.

## CAMERA ALIGNMENT

It is important to point out that color camera alignment should be made by viewing the proper test charts for a given adjustment or procedure. Such charts are useful for direct indication of the required camera adjustments. The practice of making an indiscriminate adjustment during a scene to "paint" a pleasing picture should be avoided in any operational procedure. Such an adjustment is usually successful for only isolated conditions and may easily produce errors in subsequent scenes. It is also important to note that certain controls in the color cameras when improperly set may give a false indication that other controls are misaligned. Therefore, maximum effort should be given to logical rigorous routine alignment of the controls before program time.

During operation a properly aligned camera should require no more than exposure control using the lens iris as an operating control and an occasional adjustment of pedestal or black level setting.

### The Three-Tube Concept

A three-tube camera consists basically of an optical system which "sees" the scene being televised through a dichroic mirror or prism assembly, suitably separated into its red, green, and blue image components. These three red, green, and blue images are focused on the photosensitive layer of the pickup tube in each color channel. By synchronous scanning of the three pickup tubes one obtains three independent video signals which differ only in their amplitude response to the three color images. Thus, we effectively obtain a red signal from the red tube, a green signal from the green tube and a blue signal from the blue tube. With the optical and electrical adjustments available, these three pictures are superimposed or registered on each other within an accuracy of a picture element. In order to carry out this registry process one has access to individual horizontal and vertical size and centering controls, as well as to mechanical rotation of the individual yokes and to "skew" which provides for orthogonal deflection by means of electrical cross-coupling between horizontal and vertical deflection. Thus, in principle one can obtain three independent R, G, B channels which are effectively superimposed in space at the pickup device and in time by virtue of the synchronous deflection process. One could apply these three signals to the red, green, and blue gun of the color kinescope to produce a replica of the scene being televised. However, certain procedures are necessary to obtain normalized and predictable camera behavior.

### Signal-to-Noise and Sensitivity

One must set the gains of the individual video amplifiers in the R, G, B channels to a specific value. Then a given signal current from the Plumbicon will produce the required output level at the required signal-to-noise ratio. The Plumbicon signal-to-noise ratio depends almost entirely on the figure of merit of the external video amplifier. Nominal values of signal current are of the order of 300 to 400 nanoamps. These are obtained at exposures of approximately f:4 with 150 to 200 fc on an average scene. In contrast to the Image Orthicon camera where the signal-to-noise ratio is determined primarily by the signal-to-noise ratio of the image orthicon tube itself, there is a trade-off possible between sensitivity and signal-to-noise in the Plumbicon camera. Thus one can obtain twice "normal" sensitivity with a 6 dB decrease in signal-to-noise ratio or four times this sensitivity with a 12 dB decrease in signal-to-noise ratio. As long as the signal-to-noise ratio under standard conditions is excellent, in practice about 50 dB before gamma correction, one can tolerate such a degradation to obtain increased sensitivity and still achieve pictures which have adequate signal-to-noise.

### Specular Highlights

The signal current magnitude is chosen so as to achieve a compromise between signal-to-noise ratio and the ability of the tube to discharge highlights. A standard procedure is to adjust for a factor of two reserve in the signal current by proper beam bias adjustments. In set-up, the normal scene lens exposure opening is deliberately increased by one f stop, doubling the light to the Plumbicons and the beam currents in the

R, G, B tubes are then adjusted to just discharge the picture highlights. The exposure is then restored to its "normal" setting. With this camera adjustment procedure any increase in peak brightness due to speculars or highlights in a scene which does not exceed this factor of two will be discharged effectively in the Plumbicon by the "available" beam current reserve which has been provided. If one attempts to use larger signal currents than 400 nanoamperes there may be limitations in the gun which cause loss of normal resolution and an inability to supply the required beam current reserve for satisfactory discharge of highlights.

When a camera is operated under conditions of specular highlights and there is motion in the scene, the presence of undischarged areas in the raster will give rise to false color halo effects, generally red, which are usually described as comet tails. This comet-tail effect on motion is called "puddling" by British broadcasters. The two-to-one highlight beam reserve usually controls the comet-tail effect satisfactorily.

## Gamma Correction

Since the gamma of the Plumbicon tube is essentially unity, gamma correcting amplifiers must be used to produce a pleasing picture display using modern color kinescopes. The effective gamma characteristic of the color kinescope has approximately a 2.2 exponent; thus gamma correction of 1/2.2 or 0.45 is needed to obtain an overall gamma or transfer function of unity.

In order to obtain color "tracking" with changes of lighting or exposure, it is important that the transfer characteristics or gamma of the R, G, B channels be identical. This matching can be achieved by using techniques such as superpositioning of the transfer characteristics waveforms on a display oscilloscope, using a standard input sawtooth, and adjusting the individual gamma circuits for the same power law and the individual black levels or capped lens references for zero. A direct check for transfer characteristic adjustment is to use the neutral EIA logarithmic gray scale chart[7] placed directly in the scene viewed by the camera. When the tube and gamma circuits are correctly adjusted to an overall gamma, which is the same for all three channels, and a 0.45 slope value is maintained, the color picture display of the EIA chart on the kinescope will be observed as neutral or shades of gray with no apparent color misbalance over the entire gray scale range.

## Aperture Correction

The aperture response of Plumbicon tubes of the 30 mm variety generally used for color TV broadcast is approximately 35 to 45 percent at 400 TV lines or 5 MHz as compared to a 100 percent reference response for low line-number transitions. For this reason it has been almost universal practice to aperture-correct or crispen the picture both horizontally and vertically by the use of omnidirectional aperture correction circuits. The response can be made effectively 100 percent of the time within the 5 MHz TV channel without noticeably deteriorating the signal-to-noise ratio. Such aperture correction techniques are described in the section on colorplexer and shown in Fig. 66. Clamping, blanking addition, and clipping of the processed signal, following accepted monochrome picture techniques, are performed on the three channels before they are ready to encode into the NTSC colorplexed form adopted for transmission.

## Color Matching Techniques

In a color television operation the color-matching of the individual color cameras against each other is of prime importance. Ideally there should be *no* discernible color differences in the color TV pictures from all cameras when viewing the same subject. Experience has shown that by exercising tight control on the production tolerances of dichroic colorimetric components in the optical system and on the electronic components, one can achieve accurate color rendition from any cameras used on a given scene.

In practice each camera is aligned under normalized video gain conditions so as to obtain the required signal-to-noise performance and the same effective sensitivity. Then routine adjustment procedures to obtain the same gamma correction or transfer characteristic in the R, G, B are carried out.

The cameras now view an EIA logarithmic neutral gray scale under standard conditions. If the inputs to the colorplexer are standardized and cameras have been well aligned, the gray scales will be reproduced on a color monitor over the complete brightness range as a neutral picture, since the subcarrier amplitude every-

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[7] Electronic Industries Association.

where in the scene should be zero. Such a chart is a very sensitive indicator of small misadjustments and is generally used as a tool for vernier balancing of a color camera.

Any minor discrepancies in color rendition of the cameras used in a studio are corrected by very small changes in either R, B, or G gain provided by "paint pots."

Operationally it has been found that one camera control operator, using a single color monitor, can match four cameras more rapidly and accurately than four operators working independently.

Electronic masking devices such as the RCA Chromacomp and the CBS Color Masking Processor permits color matching cameras to any degree of precision without upsetting white balance.

### Flare in Pickup Tubes

Under certain conditions of scene content, an unwanted lift of black level or pedestal can occur in one or more of the color pickup tubes. The effect is due to light scattering in the photoconductive layer of the tube itself and is strongest in the red channel. Thus, for example, if a scene which is predominantly red is viewed by the camera, the red pedestal will rise by 3 or 4 percent producing a red cast in the picture. This can be corrected by manually resetting the red tube black-level control. Automatic circuits which are duty-cycle sensitive are often used to provide a good approximation to black level with changes in scene content without any operator attention. Flare in green is much less than in red and is quite negligible in the blue channel. Light scattering in optical components and lenses will also cause artificial lift of black level.

In a well-designed and well-aligned camera, color balance and color tracking are obtained automatically over a wide range of scene content and exposure.

A special opaque test pattern developed by BBC uses a "super-black" enclosure hole as a reference for black level setting in addition to the usual logarithmic gray scale for gamma checks. American broadcasters often use a square of clean black velvet as a "super-black" for flare-compensation circuit test and adjustment and as a solid black-level reference.

### Lighting on the Scene

With Plumbicon cameras the incident lighting required for studio-quality signal-to-noise picture performance generally approaches 250 fc for a lens opening of f:4. The contrast of the scene which the color camera must handle is the product of the incident light and the reflectance of the subject matter. Technically, uniform or flat lighting is easiest to handle since this limits the range to the reflectance of the scene components, generally restricted to a highest white of 60 percent reflectance and a lowlight of 2 to 3 percent, giving a range of 20 or 30 to 1 at most. The rendition in monochrome TV is as important as the rendition in color since many of the TV viewers still look at the picture in monochrome. It is therefore important to select scene materials and surfaces so as to obtain good monochrome separation in the gray scale as well as to provide colorful rendition in the final color picture. Flat lighting, as mentioned previously, is easiest to carry out, but becomes monotonous and boring from the standpoint of the producer. Any departures from flat lighting must be executed with caution. It is necessary to "fill-in" holes and deep shadows in lighting the scene to obtain results which are pleasing from the standpoint of signal-to-noise, range, and lag.

Specular or mirror reflections can be controlled by positioning of lighting and cameras or by "dull-spraying" of the surfaces responsible. Dimming is not an acceptable method of controlling scene lighting, since skin tone balance, which is the key to good performance, is very susceptible to changes in illuminant color temperature. Changes in scene lighting are generally provided by changing the total number of fixtures illuminating the set. Where skin tones are not involved, some liberty can be taken in dimming or fading.

### Outdoor Broadcast Pickup

When color cameras view outdoor scenes, such as football and baseball games and other outdoor events, the subject matter and the illumination on the scene are no longer under the direct control of the broadcaster. Thus, for example, in the sunlight and in the shadows the incident illumination can vary 10 to 1, thereby increasing the effective scene range from 200 to 1 or more for a reflectance gamut of 20 to 1. In this case the broadcaster has an option of exposing for proper rendition of detail in the lowlights and compressing the highlights or adjusting for proper highlight exposure and crushing the dark portions of the scene. Fortunately, with multiple-camera pickups used in sporting events, one can attempt to provide correct exposure for a camera scene with minimal overlap into underexposed or overexposed areas.

### Specular Reflections

An annoying problem frequently met in outdoor pickup is specular reflection from shiny surfaces which can effectively direct an image of a light source or the sun itself into the pickup tube. Under such conditions there will be "tailing," "puddling," or "comet-tail" effects during motion due to the fact that it is impractical in standard cameras to provide sufficient beam current to completely discharge such specular highlights. Usual practice is to provide a minimum of twice the normal peak signal reserve for beam current to take care of such specular highlights. The signals themselves, of course, are clipped electrically in the video circuits so as to avoid overload problems in transmission. New developments now underway show promise of providing relief from "comet-tail" effects by providing a very high current discharge beam during horizontal retrace time.

## Low-Light Pickup

A frequent color camera problem is the case of providing satisfactory results with insufficient or minimal light on the scene. In this case one trades signal-to-noise ratio in the camera for increased sensitivity. For example, with a reduction of 6 dB in signal-to-noise ratio, an effective gain of 2 in sensitivity can be obtained. Even a factor of 4 gain in sensitivity is quite possible with acceptable signal-to-noise performance. However, at low values of scene lighting, lag on motion becomes a limiting factor in obtaining satisfactory performance. Under these conditions "bias lighting" has been used experimentally in color cameras to provide increased sensitivity with reduced differential color lag on motion. A uniform "light level" applied to the red, green, and blue photocathodes of the Plumbicon tubes so as to increase the dark current to about 8 nanoamperes provides a noteworthy improvement in build-up and decay lag performance, under low-light operating conditions.

## Color TV Film Chains

It is universal American practice to use photoconductive pickup tubes in the reproduction of color film. A powerful reason for this choice is that conventional high reliability intermittent pull-down motion picture film projectors for 16 and 35 mm film transport can be used. These are generally modified to convert the 24 frames per second motion picture standard to the 60 exposure fields per second required for nominal color TV standards, using the well-known 3-2 intermittent TV motion sequence. With a 3 to 2 intermittent film pull down, one motion picture frame is scanned by three television fields and the next picture frame is scanned by two television fields. Since each field lasts 1/60 second, the five fields take exactly 5/60 seconds or 1/12 second, which is exactly the same time as required to show two motion picture frames, 2/24 or 1/12 second. Thus we have automatically the 24 frames to 60 field conversion needed for TV.

The use of photoconductive tubes with storage such as the vidicon or the Plumbicon permits nonsynchronous system operation. The projector can be driven from the nominal 60 Hz house power supply even though the color TV field frequency is slightly less than 60 Hz. There is an effective tolerance of 1/4 to 1/2 Hz in the power supply frequency before any disturbing "application bar" effects can be noticed due to the nonsynchronous operation of the projector with respect to the vertical scan rate. Experience has shown that this tolerance is entirely adequate for well-stabilized electrical power systems used in America.

In addition to 16 mm and 35 mm color film, 2 X 2 in. slides are used for program announcements, commercials, and special tests. It is standard practice to provide as many as 3 or even 4 different optical inputs into the same color TV film chain by the use of moving-mirror or fixed-prism multiplexing techniques. Any one of these sources can be selected for color transmission thereby increasing the utilization of the equipment. Practically all modern color film chains use a field lens into which the image is projected. A typical film island is shown in Fig. 68 and a schematic of an optical multiplexer arrangement is shown in Fig. 69.

Network operations rely heavily on 35 mm color films for prime time programs. The local or regional stations use 16 mm color film and it is also used for news programs.

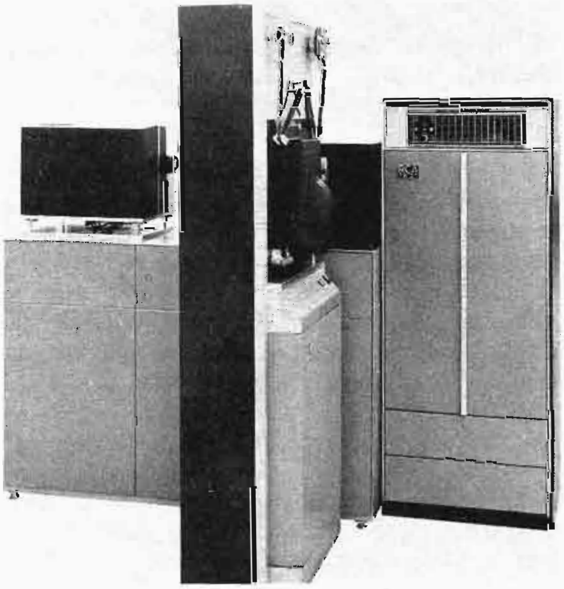

Fig. 68. A typical film island.

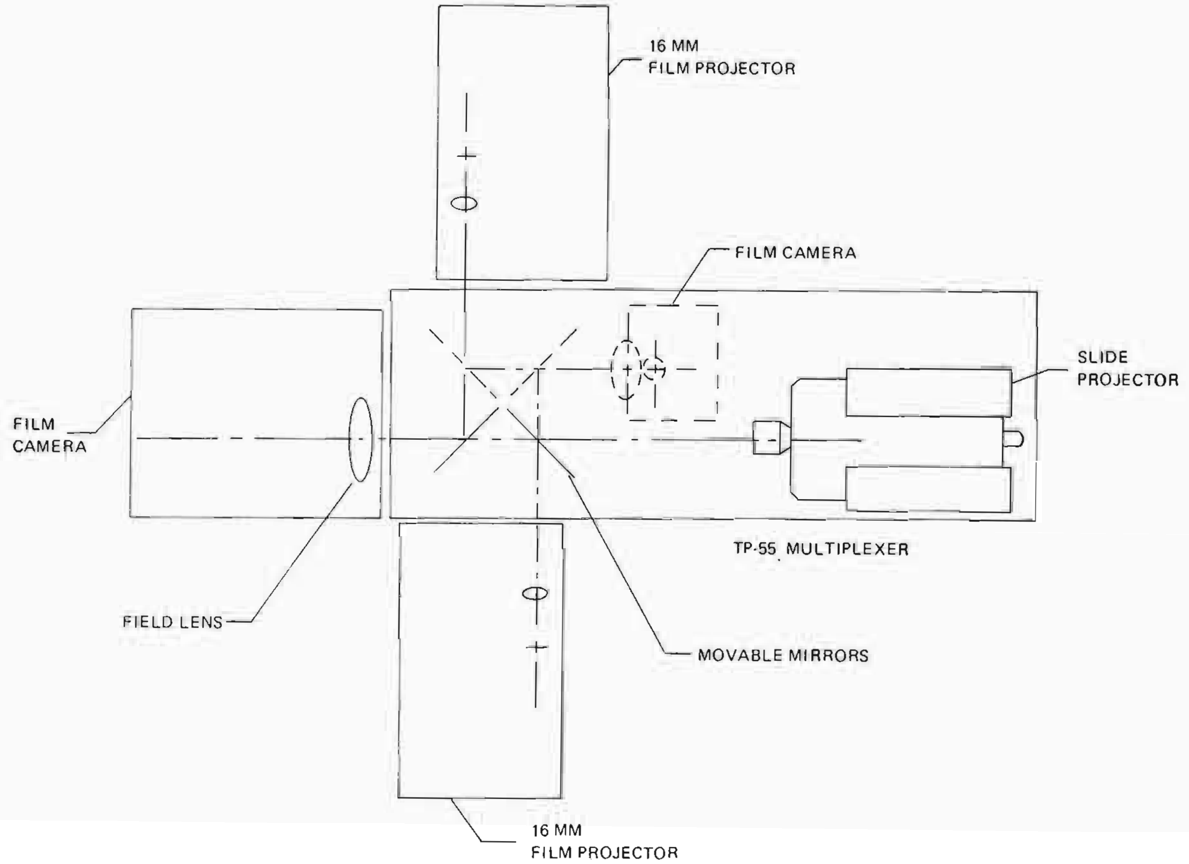

**Fig. 69. Schematic of an optical multiplexer.**

A recent publication titled, "Color Television" contains reprints of important color TV technical papers from the *Journal of SMPTE,* and is an important reference for the background of some of the fundamental developments in color TV theory, equipment design, and practice. It also provides a reference appendix listing current standards and recommended practices for TV and motion pictures, and a comprehensive bibliography of color television papers published in the SMPTE Journal.

## COLOR TEST EQUIPMENT

The color television broadcast station relies heavily on specialized test and monitoring facilities in order to maintain adequate standards of performance and to ensure compliance with FCC regulations. In the early days of monochrome and color TV, the techniques and equipment were cumbersome and difficult to use on a routine basis. With the growth of the TV art the test signals especially developed have become more sophisticated and yield much more useful information on the performance of monochrome and color TV systems than was previously available with a series of isolated-functions measurement techniques.

A stable high-performance color monitor is an essential element of color test equipment. This, together with a vectorscope and a standard color bar generator for set-up and calibration, serves as a means of evaluating performance.

The color monitor, vectorscope, and color bar generator find utilization in rapid routine day-to-day check of the television system adjustments.

Additional test equipment needed for color TV performance evaluation falls into two categories: (1) equipment to evaluate studio performance and (2) equipment to evaluate microwave relay and transmitter performance.

The important electrical characteristics to be measured in either category are:

1. Linearity or differential gain;
2. Frequency response and differential phase performance;
3. Group delay characteristic;
4. Low frequency square-wave response.

Evolutionary developments have followed the requirement that specific test waveforms be made available which are compatible with normal television signal systems and can be introduced easily without disabling or upsetting normal operating conditions. Measurements of such test waveforms after passing through selected portions of the equipment or the complete system under evaluation will give the required differential gain, phase and group delay information.

## Stair-Step Generator

A modulated stair-step generator waveform is shown in Fig. 70. The signal conforms to IEEE standad IEEE 206. It consists of five 20-IRE-unit risers with subcarrier modulation on each transition. The amplitude-linearity or differential gain response of an amplifier can be determined directly from oscilloscope measurements of the output wave display. By the use of a high-pass filter the differential gain characteristic can be displayed more graphically (Fig. 71, input); (Fig. 72, output) showing appreciable distortion. Differential phase measurements can be obtained by comparison of the subcarrier phase at each discrete level with phase of the color burst. Various oscillographic display techniques for precision phase measurements are available.

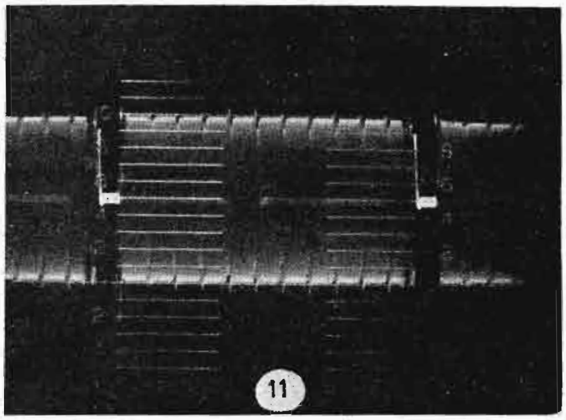

Fig. 71. High pass filter output with modulated stair-step waveform input. (Picture courtesy of Marconi Instruments, Division of English Electric Corp.)

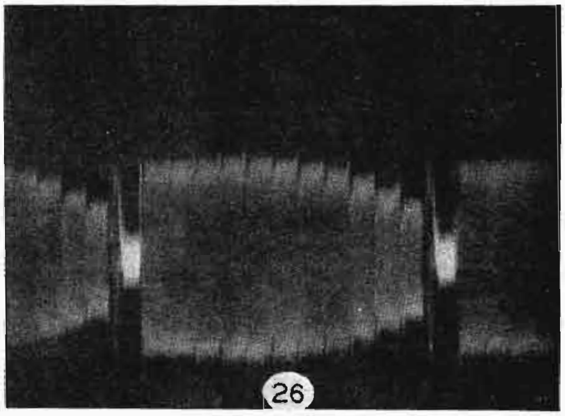

Fig. 72. High pass filter output of modulated stair-step waveform showing large amount of differential gain error in amplifier under test. (Picture courtesy of Marconi Instruments, Division of English Electric Corp.)

## Sine-Squared Pulse and Bar

A second specialized waveform which is rapidly gaining popularity in color TV testing is the sine-squared pulse and bar with chrominance subcarrier modulation as shown in Fig. 73. It evolved from the monochrome sine-squared pulse and bar shown in Fig. 74. Use of this color test signal shows presence of differential gain distortions as in Fig. 75 and delay distortions as shown in Fig. 76. Operationally the elegance of the method is in the direct-display presentation where distortion limits may be checked by reticle overlay techniques.

Another frequently used waveform is the multi-burst signal, Fig. 77, which provides a series of selected frequency, constant-amplitude sine-wave electrical bursts of 0.5 MHz, 1, 2, 3, and 4 MHz at a horizontal line repetition rate. This, as in Fig. 78, is useful for check of amplifier and system frequency response. In principle it does not completely replace the continuous video

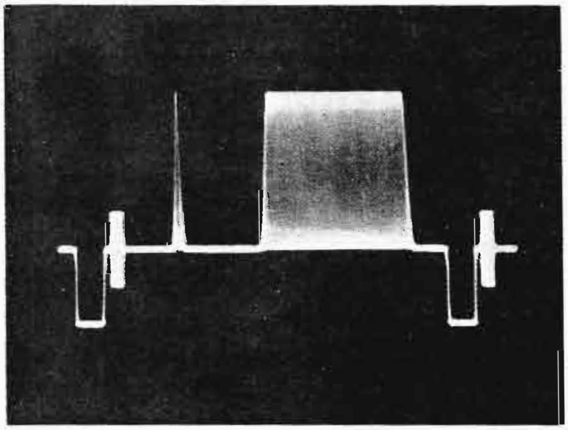

Fig. 73. Combined luminance and chrominance sine-squared pulse and bar. (Picture courtesy of Marconi Instruments, Division of English Electric Corp.)

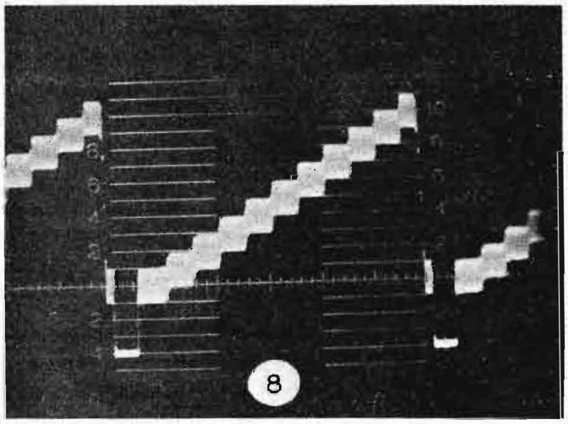

Fig. 70. Modulated stair-step generator waveform. (Picture courtesy of Marconi Instruments, Division of English Electric Corp.)

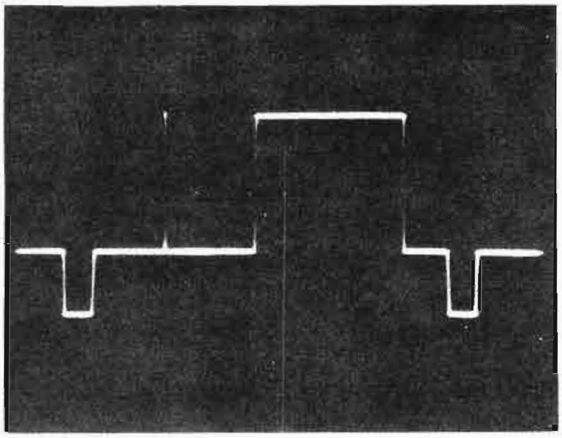

Fig. 74. Monochrome sine-squared pulse and bar. (Picture courtesy of Marconi Instruments, Division of English Electric Corp.)

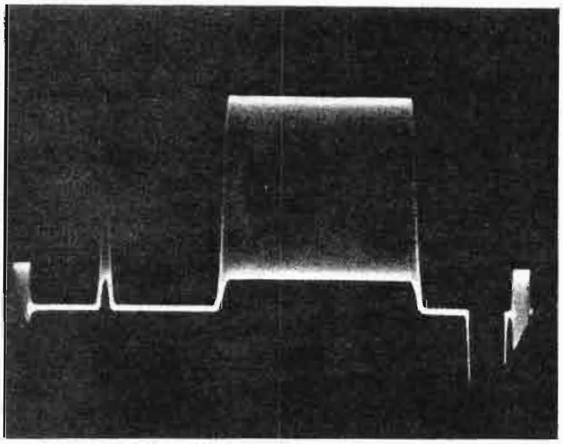

Fig. 75. Gain inequality indicated by combined luminance and chrominance sine-squared pulse and bar. Compare with waveforms of Fig. 73. (Picture courtesy of Marconi Instruments, Division of English Electric Corp.)

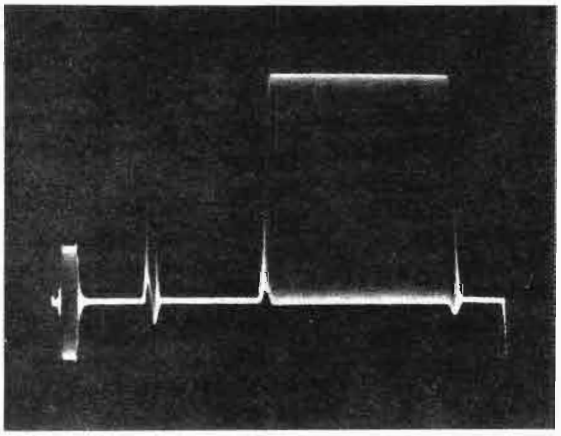

Fig. 76. Delay inequality indicated by the combined luminance and chrominance sine-squared pulse and bar. Compare with waveforms of Fig. 73. (Picture courtesy of Marconi Instruments, Division of English Electric Corp.)

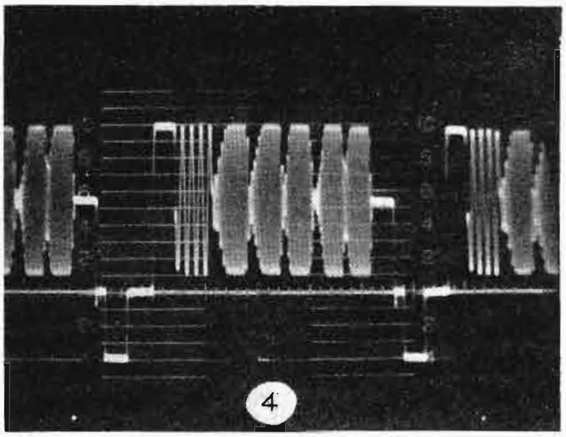

Fig. 77. Multiburst test signal with burst at 0.5 MHz, 1, 2, 3, and 4 MHz. (Picture courtesy of Marconi Instruments, Division of English Electric Corp.)

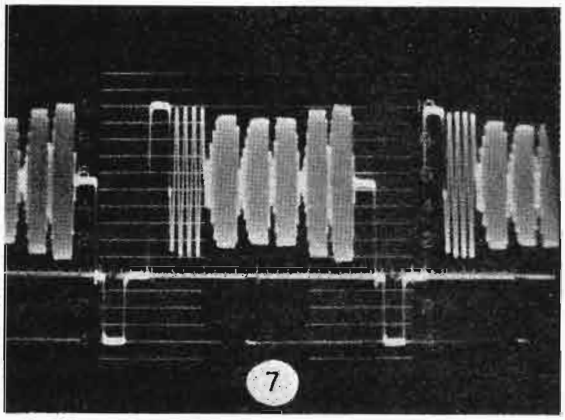

Fig. 78. Multiburst output signal from amplifier having distortion. Compare with Fig. 77. (Picture courtesy of Marconi Instruments, Division of English Electric Corp.)

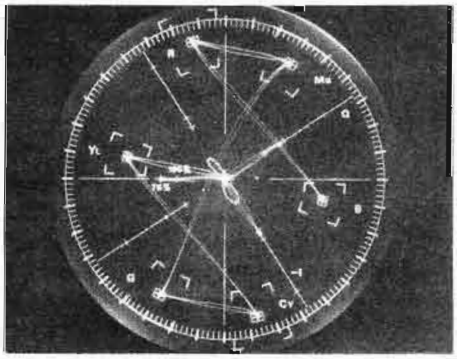

Fig. 79. Vector display. Split field color bars 75 percent amplitude 100 percent white reference, 10 percent set up. Conforms to EIA specification RS 189. (Picture courtesy of Tektronix, Inc.)

sweep signals which sequentially sample all frequencies in the video pass band. However, it is more convenient to use and to interpret in routine frequency response tests of broadcast equipment.

## Vectorscope

The vectorscope[8] is a measurement instrument developed especially for color TV system test and monitoring. Its essential feature is the polar or vectorial display of chrominance information in which the radial deflection is proportional to saturation of a color and the angular position is equal to the phase angle of that color subcarrier with respect to the color burst. The 360° polar coordinate display corresponds to a complete cycle of color subcarrier or 280 nanoseconds in a time display. By convention, the color burst is normalized at 180°. If the color bar signal described in Fig. 64 and Fig. 66 is applied to the input to the vectorscope and the burst is normalized at 180°, the display shown in Fig. 79 is obtained on the graticule.

It is noted that for standard signal levels each color vector in the color bar sequence falls within its appropriately marked box on the graticule. The outer boxes define the FCC maximum permissible errors of ± 10° in phase and ±20 percent in amplitude. The inner boxes correspond to ±2.5° phase error and 2.5 percent amplitude error.

A feature of the vectorscope color bar technique is that it gives immediate reassurance on system performance with a color bar test signal display.

By alternating two signal sources at the input, one can obtain direct readings on differential phase and amplitude behavior of any selected picture sources.

## Vertical Interval Reference and Test Signals

A development which has important long-range possibilities is the use of a special signal transmitted in a specific line of the vertical blanking interval. The Vertical Interval Reference "VIR" signal, consists of a chrominance bar having the same phase as color burst, together with an appropriate luminance pulse and a black level interval. The Vertical Interval Reference signal is added to the main video signal and is in fact a certification that at the time it is added all conditions are normal. If various distortions occur to this Vertical Interval Reference, it can be corrected, with the expectation that the main signal will also be corrected. Thus more rigorous control and compensation of system errors is possible. A "VIT" or Vertical Interval Test signal is used to verify transmission conditions using multiburst, sine-squared or stair-step test signals. Such signals can be used for continuous monitoring of TV system performance, and in the future will probably find application in automatic control or correction of color system performance.

## Test Charts

There are available several pictorial charts which serve to optically generate special test signals useful for color camera alignment and system adjustment. These were developed by industry technical commitees and are available as opaques from EIA[9] or from equipment manufacturers for live cameras and as 2 X 2 in. slides from SMPTE for color TV film chains.

They are:
EIA Resolution Chart,
EIA Linear Gray Scale Chart,
EIA Logarithmic Gray Scale,
EIA Registration Chart,
RCA Multiburst Chart,
SMPTE Resolution Slide,
Registration Slide,
Linearity Slide.

The development of TV test signals and facilities is one which continually strives to increase the information to be obtained on systems performance, preferably on a continuous basis and without taking the system out of service. The "VITS" and "VIPS" concepts appear capable of providing a major step forward in test and measuring techniques.

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[8] Tektronics Model 520 vectorscope is widely used for these measurements.

[9] EIA—Electronic Industries Association.