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the technical journal of the broadcast-communications industry

Circle Item 1 on Tech Data Card

the technical journal of the broadcast-communications industry

Broadcast Engineering

Volume 9, No. 12 December, 1967

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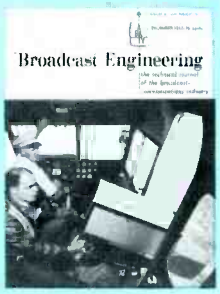
As every broadcast technician knows, not all programs originate from the network or station main studios. For details about the pickup shown in our cover illustration, turn to page 6. (Cover photo courtesy of the General Electric Co.)



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Look what your cameras can do with display units like this

CBS Laboratories' Digital Display Units are part of a low cost, compact system that works daily wonders in any size TV studio!

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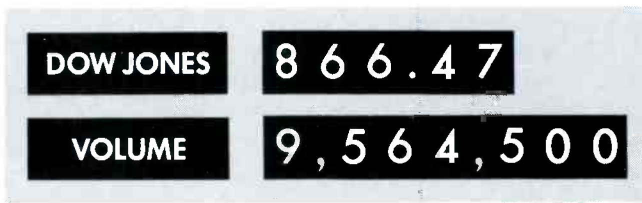
These modular units were designed specifically for TV use to give optimum clarity up to 70 feet — from any camera angle up to 145 degrees.



STOCK REPORTS–Excellent for the long pull.
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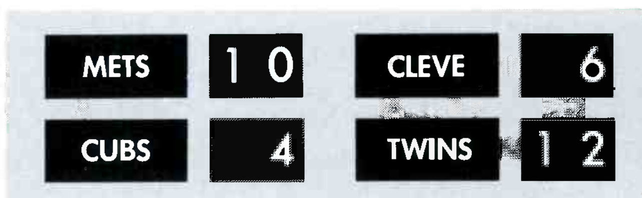
Only 2.7 watts required per unit, with no power between postings. Glare-free even under the strongest lighting conditions.



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And all operated by one Controller that can handle 192 units — as many as 12 groups of 16 units each. This means up to 12 two-candidate election races; or runs, hits and errors for all major league teams; or 40 local stock issues plus volume and Dow Jones closing. A one-time investment for the professional way to take care of all your daily display needs.

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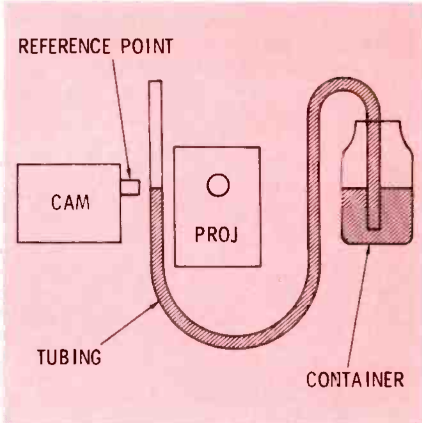
ENGINEERS' EXCHANGE

Aid to Optical Alignment

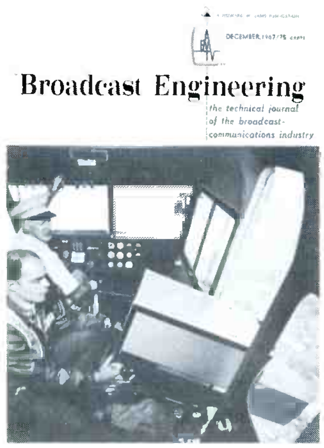
Recently, we installed a color film chain which employed one color camera, one monochrome camera, one slide projector, two 16-mm film projectors, and a universal multiplexer to mix the various units. The problem we encountered was determining what to use as a reference for positioning all the optical elements on the same plane. Installation instructions specify measurement from the floor, but our floor wasn't level. Even if the floor is level, how does one measure to the center of the optical elements?

To solve this problem, we devised a simple alignment method. The equipment needed is a container (quart jar or equivalent) and some clear tubing (transparent enough to see a water level through) long enough to reach all of the optical elements to be aligned. The procedure is as follows. First, establish a reference point; one of the optical elements is fine (we chose the mirrors in the multiplexer). The container should be positioned so that its center is on approximately the same level as the reference point. Place one end of the tubing in the container, and tape it so the end is near the bottom of the container. Add water to the jar, and start a siphon in the tubing to clear it of air. Once the siphon has started, raise the free end of the tubing so that no more water runs out. The water level should now be stationary at some point in the tubing. Hold the free end of the tubing next to the reference point and add or remove water from the container until the liquid level is the same as the level of the reference point. To level the remaining elements, move the free end of the tubing from one to another, setting the element to the water level. The only precaution is not to spill any water while moving the tubing from one position to another. This system can be used any time you need to level something of unusual shape or dimension.

—*D. Khalil Jones*

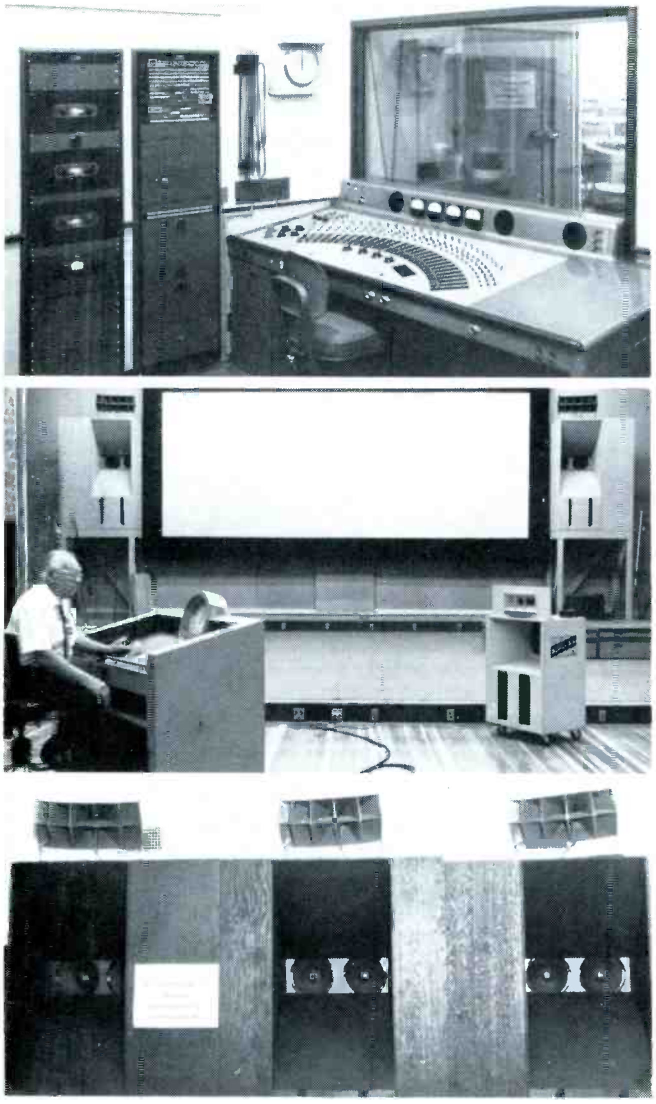


About the Cover



Beginning with the U. S. Open Golf Tournament over ABC-TV, the blimp views in major network sports and news events are being televised with this GE live color camera, purchased by The Goodyear Tire & Rubber Co. for use in both its blimps, "Columbia" and "Mayflower." Previously, cameras were supplied by the networks. The entire system, including camera head, rack equipment, converter, and microwave gear, weighs approximately 500 pounds; the only nonstandard item is a special rack made of aluminum instead of steel. The camera system can be installed or removed in about one hour, and it travels by truck between assignments.

Disney's Magic World of Sound... from Altec.



The magic that is Disney is not just a pat formula. It is a form of perfectionism that pervades everything which carries the Disney name. Certainly, there's a Disney look. But just as certainly there's a Disney sound. And that's where we come in.

For example, the new control console at the Disney Studio's orchestra stage is made up of 29 Altec slide-wire attenuators, 7 rotaries, and one 4-gang master. The works are powered by rack-mounted banks of Altec amplifiers. Monitoring in the control room is done in a big way—with three giant Altec A4 "Voice of the Theatre"® systems butted together in a single plane of the most powerful, pure sound you can get.

The stage itself uses three more A4's for monitoring, re-recording, and playback. (That's one good way to keep the musicians happy.) Eight caster-mounted A7 "Voice of the Theatre"® systems are mobile, may be moved where and as needed.

And that's not all. On the back lot Altec PA equipment provides the paging. Dialog stages at the Studios also use A4's, with Altec's space-saving 844A Monitor Speaker Systems in the compact transfer room. The list could go on, but the point is made.

So who listens when Altec Lansing sounds off at Disney? Everybody, that's who. And if you understand the remarkable expertise of Disney sound engineers, perhaps you should listen too. Let's hear from you.

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COLOR-TV BASICS —MAKE-UP OF THE COLOR PICTURE SIGNAL

The color signals must be combined in specified proportions to produce the transmitted signal required by the color system. Conclusion of a three-part series.

As has been shown in the first two parts of this series, the color picture signal consists of a luminance signal and a chrominance signal. The make-up of these two signals at the transmitter will be discussed in this, the concluding part of the series.

Shown in Fig. 1 is a simplified drawing of the basic components of a tricolor camera which employs three camera tubes and two dichroic mirrors for the separation of light. One of the camera tubes receives only the light frequencies corresponding to the color red and is called the red camera tube. Similarly, the other two tubes are designated the blue and green camera tubes.

To illustrate the operation, assume the color camera is focused on a scene. All the light frequencies pass through the objective lens, which is mounted on the turret, and through a pair of relay lenses to the dichroic mirrors. Each of these mirrors permits all the light frequencies of the spectrum to pass except those of the primary color which it is designed to reflect. By this means, light received from the scene can be separated into the three primary colors.

Through correct placement, only two dichroic mirrors are needed in the color camera. The blue dichroic mirror is positioned at a point indicated by A on the diagram. When light arrives at this point, all the light frequencies except those representing the color blue are passed through the mirror; the frequencies representing the blue portion of the spectrum are reflected. The tilt angle of the mirror at point A is such that the blue light is reflected to a front-surface mirror at point C, and then onto the face of the blue camera tube.

The light that was passed by the dichroic mirror at point A goes on to the red dichroic mirror at point B. This mirror is designed to pass all the light frequencies except those which represent red. The red light is reflected to a front-surface mirror at point D and then to the face of the red camera tube.

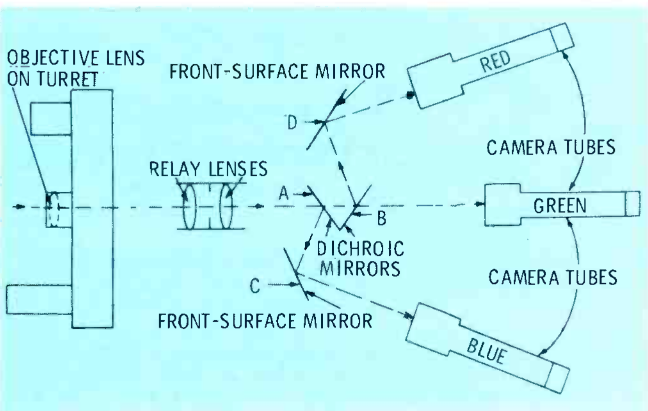

Fig. 1. Dichroic mirrors separate red, green, and blue.

Both the blue and the red portions of the incoming light have been removed, and only the green portion remains. This is allowed to fall directly on the face of the green camera tube.

At the output of the color camera, there are three voltages which are representative of the three colors. These voltages are designated as E_R, E_G, and E_B for red, green, and blue, respectively. From these voltages, the luminance and chrominance signals may be formed.

Luminance Signal

The luminance signal is the portion of the color picture signal utilized by monochrome receivers. For this reason, the luminance signal must represent the scene only according to its brightness. It is very similar to the video signal specified for standard monochrome transmission.

There are two types of color cameras in general use for broadcasting. In some models, a fourth pickup tube is used to generate the luminance signal. Other manufacturers have elected to use only three tubes, and to produce the luminance signal from a combination of the red, green, and blue signals. However, this mixing must be done in the proper proportions.

The luminosity responses of the eye to the three primary colors were considered when the specifications for the luminance signal were made. When red, green, and blue lights of equal intensity are superimposed, white light will be produced. When they are separated, the green light will appear to the average observer almost twice as bright as the red and from five to six times as bright as the blue. The red light will appear from two to three times as bright as the blue light. Thus the eye is most sensitive to green, less sensitive to red, and least sensitive to blue. (This effect was described in the first part of this series [October 1967 Broadcast Engineering], on colorimetry.)

The specifications for the luminance signal take into consideration the foregoing response characteristics of the eye. Definite proportions of each of the color signals from the camera are used to form the luminance signal. These proportions are: 59 per cent of the green signal, 30 per cent of the red signal, and 11 per cent of the blue signal.

The luminance signal is frequently called the Y signal, and its voltage is designated as E_Y. From the discussion above, it can be seen that the equation for E_Y may be expressed as:

$$E_Y = .30E_R + .59E_G + .11E_B \qquad (1)$$

where,

E_R = the voltage of the red signal,
E_G = the voltage of the green signal, and
E_B = the voltage of the blue signal.

The drawing in Fig. 2A illustrates the manner in which the luminance signal is formed. The scene to be televised consists of a card which has four vertical bars. The camera is adjusted so that each of the three color signals is one volt when the white bar is being scanned. In accordance with equation 1, the luminance signal will also be one volt at this time; consequently, a bright white bar would be produced on the screen of a monochrome receiver tuned to this signal.

When the red bar is being scanned, the blue and green color signals go to zero and the red signal remains at one volt. According to the equation, the luminance signal drops to .30 volt. A gray bar would appear on the screen of the monochrome receiver when this red bar is scanned. The green signal will be one volt and the blue and red signals will be zero when the green bar is scanned. The luminance signal will have a value of .59 volt and will produce a light gray bar on the screen of the monochrome receiver. Scanning of the blue bar will cause the blue signal to equal one volt and the voltages of the red and green signals to equal zero. The luminance signal will be .11 volt, and a dark gray bar will appear on the screen of the monochrome receiver.

Chrominance Signal

The chrominance signal must represent only the colors of a scene; therefore the luminance voltage is subtracted from each of the three output voltages of the color camera. As shown in Fig. 2B, this can be done by inverting the polarity of the luminance signal and then combining the resultant signal with each of the three camera signals. This results in three color-difference signals, $E_R - E_Y$, $E_G - E_Y$, and $E_B - E_Y$. If the expression for E_Y given in equation 1 is substituted for E_Y, an expression for each color-difference signal can be obtained in terms of the signals for the three primary colors. As an example, consider voltage $E_R - E_Y$.

Since

$$E_Y = .30\,E_R + .59E_G + .11E_B,$$

$$E_R - E_Y = E_R - (.30E_R + .59E_G + .11E_B)$$

$$= E_R - .30E_R - .59E_G - .11E_B$$

$$E_R - E_Y = .70E_R - .59E_G - .11E_B. \qquad (2)$$

Similarly,

$$E_G - E_Y = .41\,E_G - .30E_R - .11E_B, \qquad (3)$$

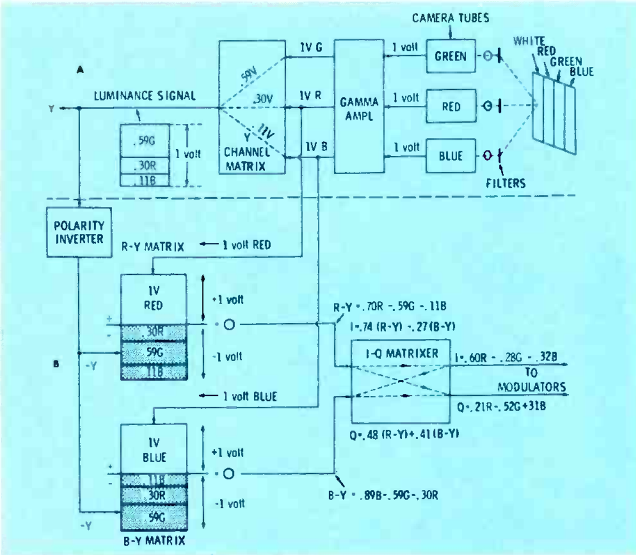

Fig. 2. Signals must be combined in specific proportions.

and

$$E_B - E_Y = .89E_B - .59E_G - .30E_R. \qquad (4)$$

The equations for each of the color-difference signals may also be obtained graphically. Refer to Fig. 2, and note that when the red bar is scanned, one volt of red signal is applied to the R − Y matrix. The luminance signal at the same time is .30 volt. Since this voltage is applied to the R − Y matrix through a polarity inverter, the value of the minus Y signal is −.30 volt. The combination of voltages fed to the R − Y matrix forms the R −Y signal, and during the scanning time of the red bar, the R − Y signal amplitude is 1.0 minus .30 (or .70 volt). Note that this value conforms with the coefficient of E_R in equation 2.

When the green bar is scanned, the voltage of the red signal is zero, and the luminance signal becomes .59 volt. The output of the R −Y matrix at the same time would be a combination of zero and −.59 (or −.59 volt). Note that this value agrees with the coefficient for E_G shown in equation 2.

When the blue bar is scanned, the voltage of the red signal is zero, and the minus Y signal is −.11 volt. These voltages are combined in the R − Y matrix, and the output voltage is −.11 volt. This is the coefficient of E_B in equation 2. The coefficients for the voltages of the color signals in equations 3 and 4 may be obtained in a similar manner.

It is interesting to note that when the white bar is scanned, the voltages of the color-difference signals are equal to zero (because for white $E_R = E_G = E_B$). It may be recalled from the discussion on divided-carrier modulation in Part 2 that, when both of the two modulating signals have zero voltage, the outputs of the balanced modulators also become zero. Thus, during the time that the color camera scans the white portions of a scene, no chrominance signal is developed, and these portions are represented only by the luminance signal.

The same condition is true for any value of gray. Consider that the brightness of the white bar has been reduced by 50 percent. The voltage of each of the three signals at the output of the color camera would equal

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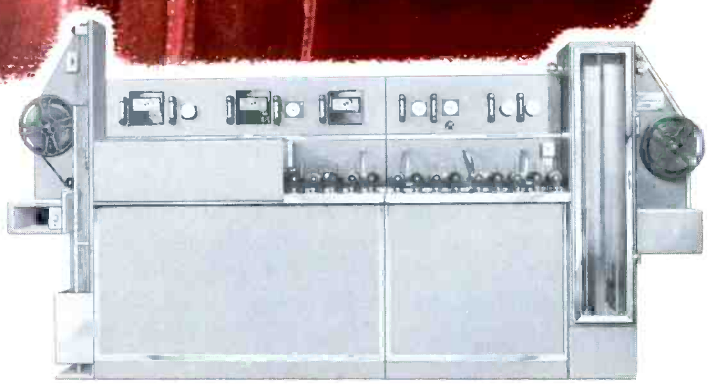

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.5 volt. The voltage of the luminance signal would be the sum of .15, .295, and .055 (or .5 volt), and the voltages of the color-difference signals would still be zero. The bar would be entirely represented by the luminance signal, but its amplitude would be only 50 per cent of the amplitude produced when the camera scans reference white. A monochrome receiver tuned to this signal would reproduce a value of gray which would be halfway between white and black.

It has been stated that only two signals are used to modulate the color subcarrier. These two signals must represent the colors denoted by the three color-difference signals. It was found that a signal equivalent to $E_G - E_Y$ could be reproduced in the color receiver by combining specific proportions of $E_R - E_Y$ and $E_B - E_Y$; therefore, $E_G - E_Y$ is not actually transmitted as such. The combination of $-.51\ (E_R - E_Y)$ and $-.19\ (E_B - E_Y)$ will produce a signal equivalent to $E_G - E_Y$. (The negative coefficients for these two quantities designate specific amplitudes of signals having negative polarities.) Thus:

$$E_G - E_Y = -.51\ (E_R - E_Y) - .19\,(E_B - E_Y).$$

The mathematical proof for this equation is as follows: From equations 2 and 4,

$$E_R - E_Y = .70E_R - .59E_G - .11E_B,$$

and

$$E_B - E_Y = .89E_B - .59E_G - .30E_R.$$

Substituting these quantities in the equation being proved gives

$$\begin{aligned} E_G - E_Y &= -.51\ (.70E_R - .59E_G - .11E_B) \\ &\quad -.19\ (.89E_B - .59E_G - .30E_R) \\ &= .41E_G - .30E_R - .11E_B. \end{aligned}$$

The value $.41E_G$ also can be expressed as $E_G - .59E_G$. Therefore,

$$\begin{aligned} E_G - E_Y &= E_G - .59E_G - .30E_R - .11E_B \\ &= E_G - (.30E_R + .59E_G + .11E_B) \\ &= E_G - E_Y. \end{aligned}$$

The two signals used to modulate the color subcarrier are called the I and Q signals. As shown in Fig. 2B, these two signals are formed by combining specific proportions of $E_R - E_Y$ and $E_B - E_Y$. This is done because a more faithful reproduction of colors can be obtained.

Shown in Fig. 3 are the chromaticity diagram and the NTSC triangle. The axes for the color-difference signals and the I and Q signals can be seen. Although it is not apparent in the two-dimensional drawing in Fig. 3, if these axes were observed on a three-dimensional representation, they would have a right-angle relationship. That is, the R − Y and B − Y axes are actually prependicular to each other, as are the I and Q axes. Along the axes of the color-difference signals are the colors that are represented by these signals. Colors from red to bluish-green are depicted along the R − Y axis, and colors from blue to greenish-yellow are depicted along the B − Y axis.

Colors from orange to cyan are depicted along the I axis, and those from magenta to yellow-green appear along the Q axis. Better reproduction of color is achieved along the I and Q axes than along the R − Y and B − Y axes. This is particularly true in the reproduction of flesh tones, since they lie along the I axis. It was also found that for small areas of color which are well centered in the field of vision, the chromaticity diagram degenerates to a single line. This line is the I axis; only two fully saturated colors, orange and cyan, are needed to reproduce colors under these conditions. (This phenomenon was described in Part 1 on colorimetry.)

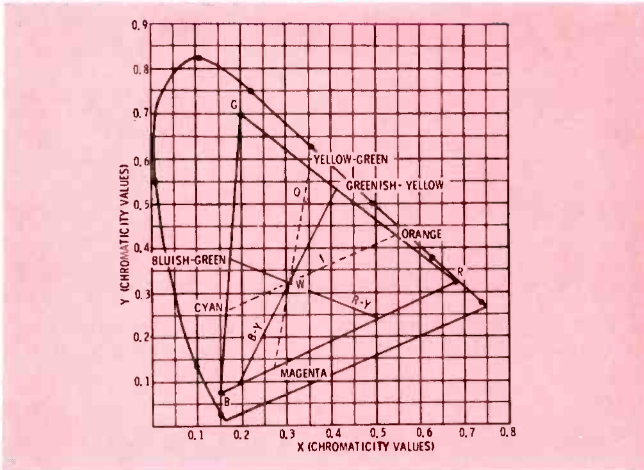


Fig. 3. R — Y, B — Y, I, and Q axes shown on color triangle.

The equations for I and Q are

$$E_I = .74\ (E_R - E_Y) - .27\ (E_B - E_Y), \qquad (5)$$

and

$$E_Q = .48\ (E_R - E_Y) + .41\ (E_B - E_Y). \qquad (6)$$

If the expression given in equation 1 is substituted for E_Y in equations 5 and 6, equations for E_I and E_Q can be obtained in terms of the three color signals, as follows:

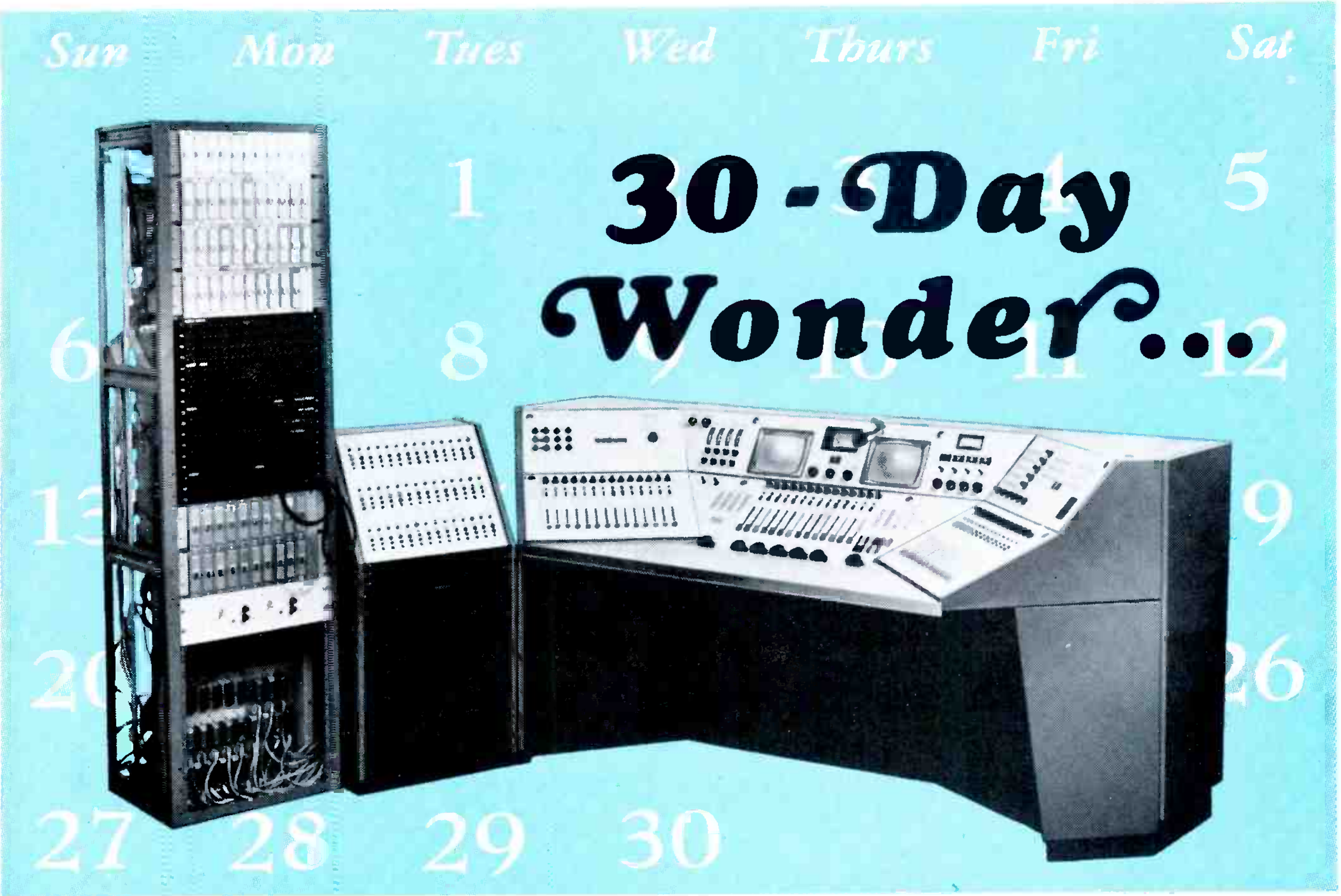
$$E_I = .60E_R - .28E_G - .32E_B, \qquad (7)$$

and

$$E_Q = .21E_R - .52E_G + .31E_B. \qquad (8)$$

The mixing of the three color voltages to form the luminance signal and the color-difference signals is performed generally as shown in Fig. 4. The output of the matrix consists of the luminance signal and the I and Q signals. It should be pointed out that signals from the color camera are gamma corrected by passing them through gamma amplifiers. This correction is to compensate for the nonlinear operation of the picture tube. Since gamma correction is also provided in monochrome transmission, no block for this operation is shown in Fig. 4.

From the matrix, the luminance signal is fed through a bandpass filter to the adder section. The I and Q signals are fed through bandpass filters to the modulator sections. The phase angles between the two subcarriers and between them and the color burst are shown in the diagram of Fig. 4; the phase reference, ωt, is the phase of the color burst plus 180 degrees. Note that the phase



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KAPPA SUPER-η VIDEO CABLE SIMULATOR GUIDE

ACTUAL SIZE

Model No.	Length of Cable Simulated* (in feet)	Package Length (x 7/8" square)	Approx. Delay Range (nsec.)	Max. Insertion Loss (db)	Price**
10A50	50	5"	78	0.5	$52.75
10A100	100	8"	157	1.0	$69.50
10A150	150	11"	235	1.5	$86.25
10A200	200	14"	314	2.0	$103.00
10A250	250	16"	392	2.5	$119.75

*±2 ft. or 2%, whichever is greater. **Additional discounts available for quantity orders.

SPECIFICATIONS OF KAPPA SERIES 10A SUPER-η DELAY LINES

Impedance: 75 ohms ± 2%
K factor: less than 0.25% for sin² T Pulse
Cross talk: less than 46 db

Size: 7/8" square x length required
Case material: Electro-tinned brass
Finish: Mil-spec gray lacquer

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Delay Line Specialists   Manufacturing Engineers

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Circle Item 13 on Tech Data Card

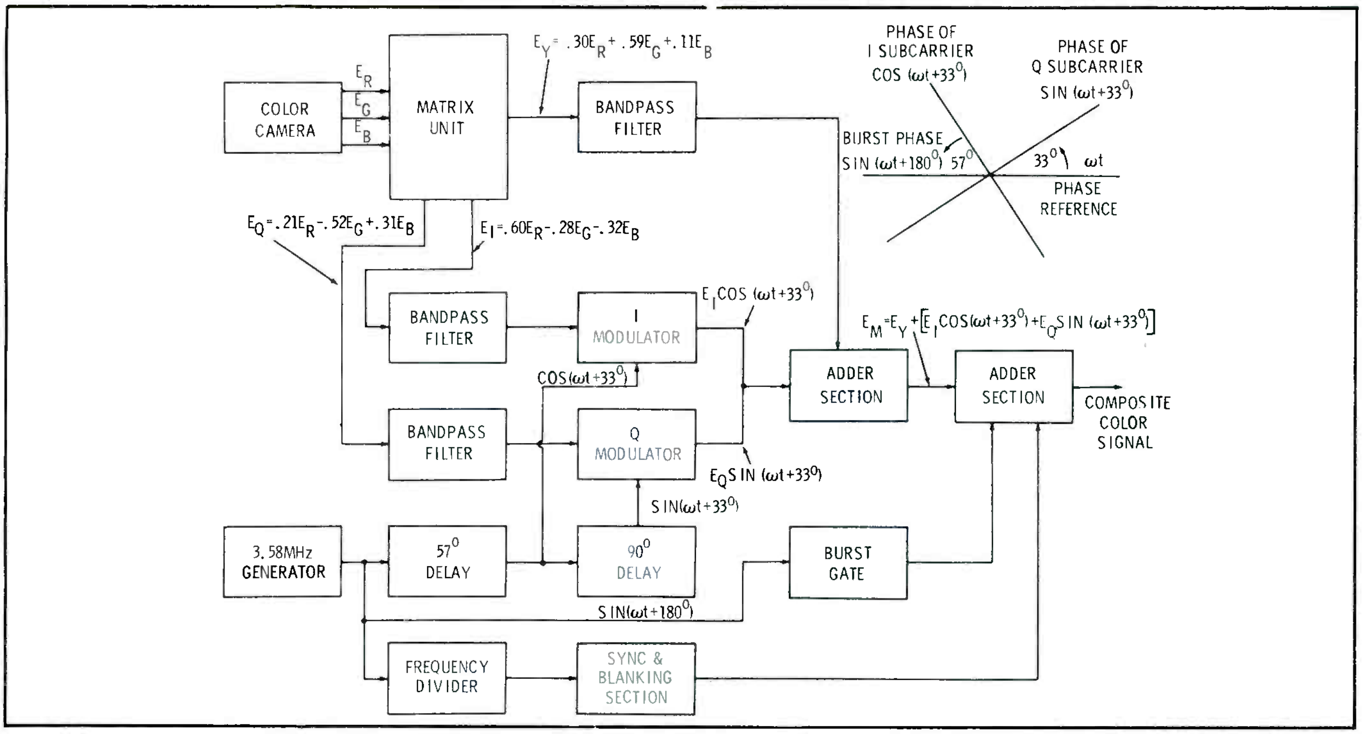


Fig. 4. Simplified diagram shows how the composite color signal can be developed from the color and other signals.

of the subcarrier modulated by the I signal is leading by 90 degrees the phase of the subcarrier modulated by the Q signal and is lagging the phase of the color burst by 57 degrees. These phase relationships must be maintained within a very close tolerance.

The outputs of the modulators are combined to form the chrominance signal. This signal is fed to an adder section where it is combined with the luminance signal. The output of this adder section is the color picture signal, which is specified by the NTSC standards as follows:

$$E_M = E_Y + [E_Q \sin(\omega t + 33^\circ) + E_I \cos(\omega t + 33^\circ)]. \tag{9}$$

The sync, blanking, and color-burst signals are added to the color picture signal; then the composite color signal is ready for transmission.

Bandwidths of Luminance and Chrominance Signals

The band limitations of the luminance and chrominance signals will now be considered. It has been stated before that the luminance signal in color transmission must retain the same specifications (within tolerance) that the video signal has in monochrome transmission, in order to meet compatibility requirements. Since the upper sidebands of the chrominance subcarrier extend to 4.2 MHz above the picture carrier, the sidebands representing the luminance signal can also extend to 4.2 MHz. This limit is approximately 0.2 MHz greater than the limit of the sidebands in monochrome transmission; consequently, a slight increase in fine detail is available with color transmission in comparison to monochrome transmission.

Before learning the band limitations of the chrominance portion of the color picture signal, it is necessary to examine the factors that led to the specific limitations placed upon the chrominance signal. These factors pertain to the characteristics of the human eye.

From the results of colorimetry experiments performed prior to the advent of color television, it was known that fine detail in color cannot always be seen by the average observer. Tests were made in which colored objects were reduced in size and viewed at various distances. When this was done, a number of things were found to be true. First, blues become more and more indistinguishable from grays of equivalent brightness as distance increases or size decreases. Second, yellows become indistinguishable from grays. Within the same size range, browns become confused with crimsons and blues with greens, but reds remain clearly distinct from blue-greens. Colors with pronounced blue lose blueness; whereas colors lacking in blue gain blueness. Third, with a further decrease in size, reds merge with grays that have equivalent brightness, and blue-greens become indistinguishable from grays. Finally, when viewing extremely small colored objects, the ability to identify color is lost entirely and only a response to brightness remains. (See Part 1 of this series.)

From the foregoing data and from tests made with color receivers, the following choices of bandwidths were made:

1. Full-band transmission of the luminance (Y) signal for maximum detail.
2. Moderately wide-band, partly single-sideband transmission of a single color-mixture signal (I signal) which represents colors of orange and cyan.
3. Narrow-band, double-sideband transmission of an additional color-mixture signal (Q signal). This signal represents yellow-green and magenta.

Note how these choices of bandwidths correspond to the information about human vision. Since the eye can interpret only brightness variations in the fine-detailed areas of an image, these areas are represented

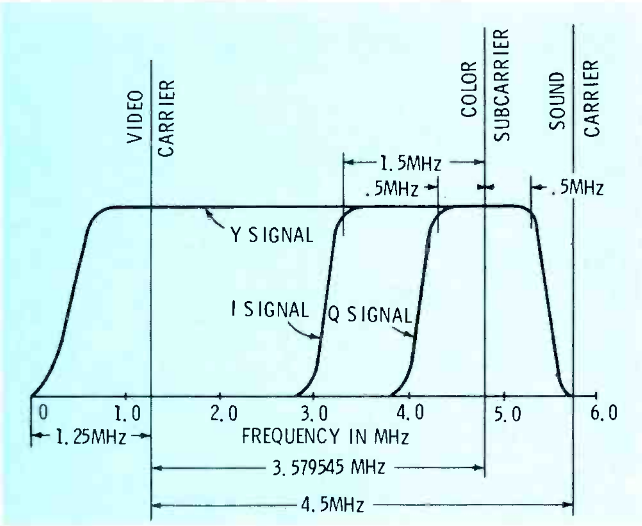


Fig. 5. Bandwidths of color-picture signal components.

only by the luminance signal. On the screen of a 21-inch color picture tube, the fine-detailed areas are those smaller than about ⅛-inch square.

The areas containing medium-sized detail are represented by both the luminance and I signals. On a 21-inch screen, picture elements which occupy a space at least ⅛-inch square but less than ⅜-inch square represent medium-sized detail. To the human eye, colors in this size range appear as hues of orange and cyan; therefore, only a two-color system is used to reproduce color in areas of this size.

The coarse-detailed and large areas of the image are represented by the two color-difference signals and the luminance signal and are therefore reproduced in full color. These areas would be ⅜-inch square and larger on a 21-inch screen. The eye can readily discern differences in color in this size range; consequently, full-color reproduction is provided.

Shown in Fig. 5 is the passband of the color picture signal. The Q signal is limited to .5 MHz, and both sidebands are transmitted. Both sidebands of the I signal are transmitted for frequencies up to .5 MHz, and only the lower sideband is transmitted for frequencies from .5 to 1.5 MHz.

When frequencies of 0 to .5 MHz are present, Y, I, and Q are being transmitted. A three-color system would therefore be in effect. For frequencies of .5 to 1.5 MHz, only the I signal and the luminance signal are being transmitted. A two-color (orange-cyan) system is in effect at these frequencies. For frequencies above 1.5 MHz, only the Y channel is transmitted. The Y signal conveys the fine detail of the picture in terms of brightness variations.

Color-Bar Pattern

The make-up of the color picture signal can be illustrated by a color-bar chart like the one in Fig. 6. Through the use of such a chart, the relative level of each component of the color picture signal can be shown. The colors in the chart are considered to be fully saturated, which means that they are completely free of white light. When these color bars are scanned by the color camera, a color signal is produced. The development of the color signal can be illustrated by showing the waveforms that are formed during the process.

The waveforms which are representative of each of the color signals are directly below the test bars in column I of Fig. 6. From these signals the color picture signal is formed.

In column II, the waveform for the luminance signal is shown; it is developed in accordance with equation 1. During the scanning of the red bar, E_Y reaches a level of .30 volt; for the green bar, it reaches .59 volt; and for the blue bar, it reaches .11 volt.

The next signals to be formulated are the three color-difference signals shown in column III. The expressions $E_R - E_Y$, $E_G - E_Y$, and $E_B - E_Y$ for these color-

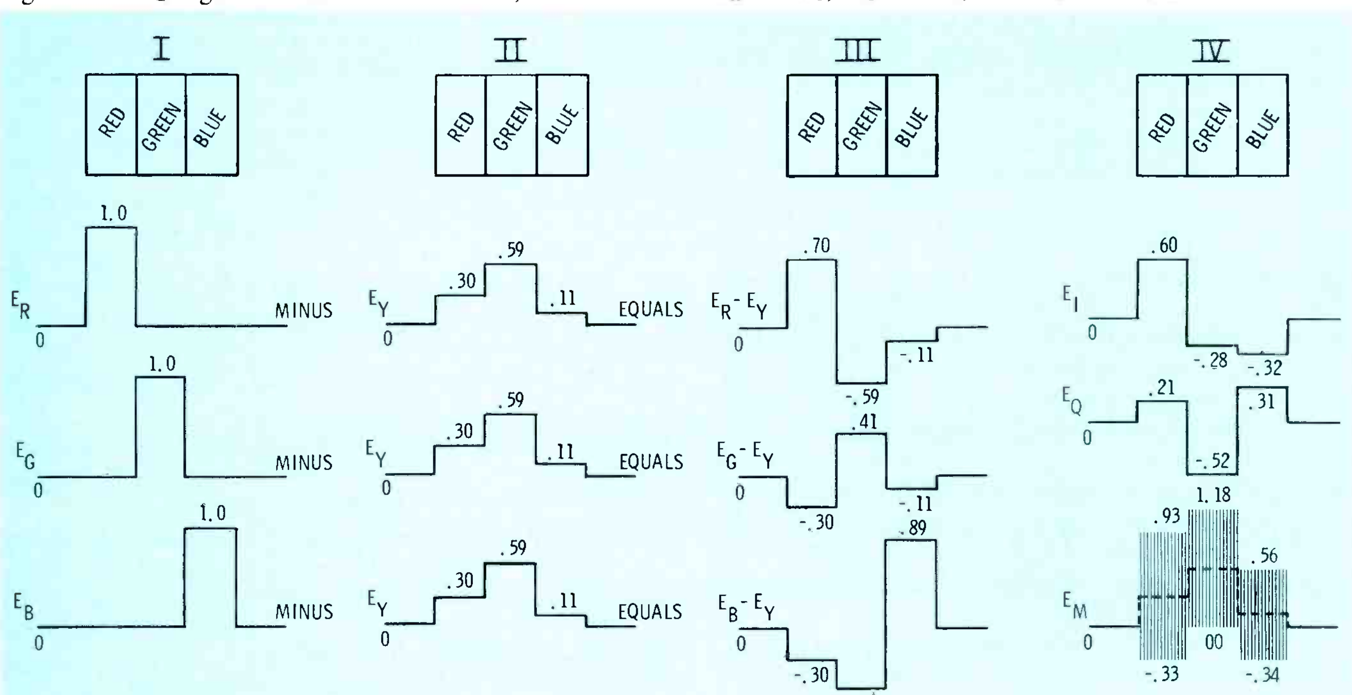


Fig. 6. Development of the waveforms resulting when a color-bar chart consisting of red, green, and blue is scanned.

difference signals signify that the voltage value of the luminance signal is subtracted from the voltage values of the color signals. Subtraction of the instantaneous value of the luminance signal from the instantaneous value of E_R will give the instantaneous voltage value for $E_R - E_Y$. Subtraction of .30 volt from 1.00 volt leaves a value of .70 volt for the $E_R - E_Y$ signal during the scanning of the red bar. During the scanning of the green and blue bars, $E_R - E_Y$ will be negative because there is no voltage from the red output in the camera. It will be $-.59$ volt during the scanning of the green bar and $-.11$ volt during the scanning of the blue bar. The same method is followed for obtaining the values of $E_G - E_Y$ and $E_B - E_Y$. Note that the values which appear on the waveforms are the same as those which appear in equations 2, 3, and 4.

It has been stated that the color-difference signal $E_G - E_Y$ is not transmitted, but is obtained in the receiver by combining $-.51$ $(E_R - E_Y)$ and $-.19$ $(E_B - _Y)$. The manner in which $E_G - E_Y$ is obtained can be shown graphically by using the waveforms of the color-difference signals. If the numerical values of the $E_R - E_Y$ waveform shown in Fig. 6 are multiplied by the factor $-.51$, waveform A of Fig. 7 can be obtained. Waveform B in the same figure is the result of multiplying the numerical values of the waveform for $E_B - E_Y$ in Fig. 6 by the factor $-.19$. The addition of waveform A and waveform B in Fig. 7 results in waveform C. This is the same waveform that is shown in Fig. 6 for $E_G - E_Y$. By an example, it has been shown again that the color-difference signal which represents green can be recovered by proportionately mixing the other two color-difference signals.

In column IV of Fig. 6, waveforms for the I and Q signals are presented. The I waveform is obtained by adding .74 of the $E_R - E_Y$ signal and $-.27$ of the $E_B - E_Y$ signal. The Q waveform is formed by combining .48 of the $E_R - E_Y$ signal and .41 of the $E_B - E_Y$ signal. The numerical values shown in Fig. 6 for the I and Q signals correspond to those previously given in equations 7 and 8.

The last waveform in Fig. 6 represents the color picture signal, E_M, that is transmitted. The numerical values shown with the E_M waveform specify the levels of the maximum excursions of the chrominance signal. To determine these levels, the values of I and Q are added together vectorially (they combine at a phase angle of 90°); then the results are added to and subtracted from the luminance levels. Fig. 8 shows how the red portion of the signal is formed by this vectorial method. The resultant vector which represents the red portion is found by marking off the values of I and Q on their respective axes. As shown on the waveforms for I and Q, the I value for red is .60 and the Q value for red is .21. The resultant vector is drawn from the origin of the vectors to the opposite corner of the parallelogram. The magnitude of the resultant vector is found by taking the square root of the sum of the squares:

$$\sqrt{I^2 + Q^2}\ .$$

Then substituting the values for I and Q and solving gives

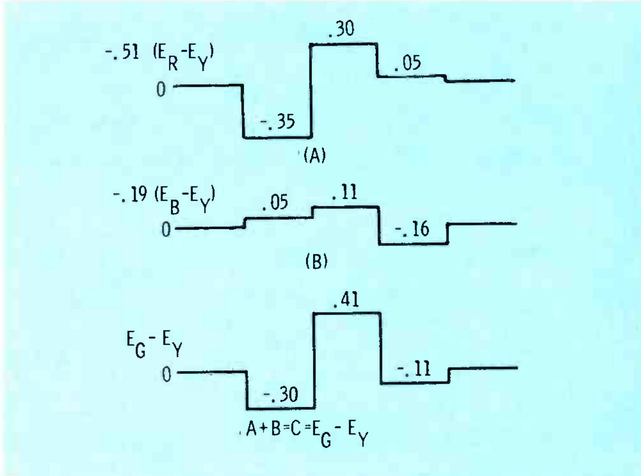


Fig. 7. Formation of $E_G - E_Y$ is shown by these waveforms.

$$\sqrt{(.60)^2 + (.21)^2} = .63.$$

The same procedure has been followed for determining the magnitude of the chrominance signal when it represents fully saturated colors of green and blue. When a fully saturated green is transmitted, the chrominance signal has a relative amplitude of .59; and when a fully saturated blue is transmitted, the chrominance signal has a relative amplitude of .45. These numbers represent the peak values of the alternating voltage represented by the bracketed term in equation 9.

Now consider the waveforms produced when scanning a color-bar chart which includes not only the three primary colors but also their complementary colors. Such a color-bar chart and the associated waveforms are shown in Fig. 9. The colors represented are green, yellow, red, magenta, blue, and cyan. These colors are assumed to be fully saturated.

The waveforms of first concern are those of the three color voltages. During scanning of the green bar, only a green signal is produced. When yellow is scanned, both red and green signals are present; this is to be expected because yellow contains both red and green light.

While the red bar is scanned, only a red signal is present. Magenta is a combination of red and blue; therefore, both red and blue signals are present while the magenta bar is being scanned. Similarly, during the scanning of the third primary color, blue, there is

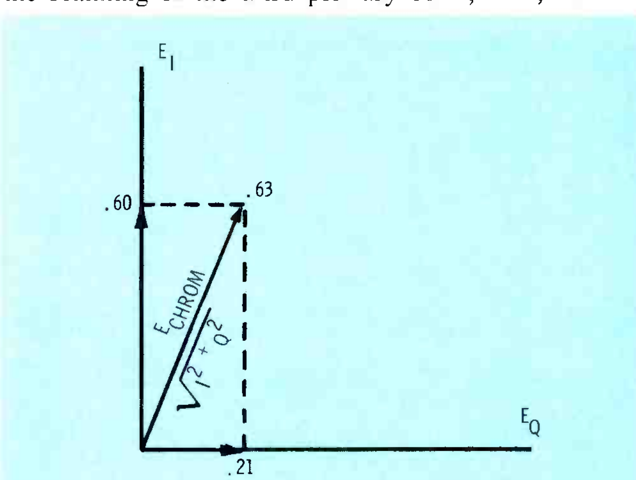


Fig. 8. I and Q vectors determine chrominance amplitude.

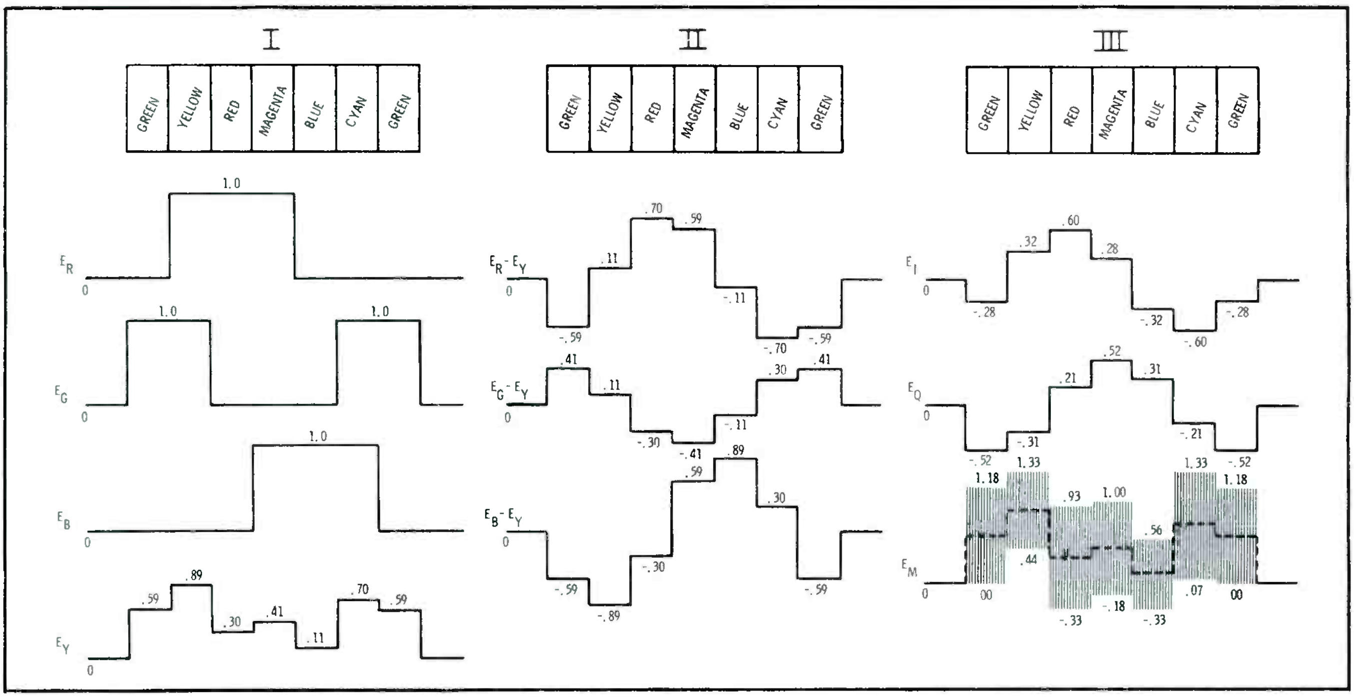


Fig. 9. Development of waveforms resulting when chart consisting of three primaries and their complements is scanned.

only a blue signal. There is an output at both the green and blue camera tubes while the cyan bar is being scanned.

The next waveform shown in Fig. 9 is the luminance signal. The levels of this signal for red, green, and blue are the same as those shown in Fig. 6. Yellow, however, produces a luminance value of .89, which is made up of 59 per cent of green plus 30 per cent of red. Magenta has a luminance level of .41, or 30 per cent of red plus 11 per cent of blue. Cyan contains blue and green; therefore, the luminance level for cyan consists of 11 per cent of blue plus 59 per cent of green and has a value of .70. Yellow has the highest luminance level, and blue has the lowest luminance level.

The color-difference waveforms are formed in the same manner as before by subtracting the luminance signal from each of the three color signals. If this is done with the waveforms shown in Fig. 9, the resultant waveforms will be as shown in column II for $E_R - E_Y$, $E_G - E_Y$, and $E_B - E_Y$.

The waveforms for I and Q are obtained by proportionately mixing color-difference signals $E_R - E_Y$ and $E_B - E_Y$, in accordance with equations 5 and 6.

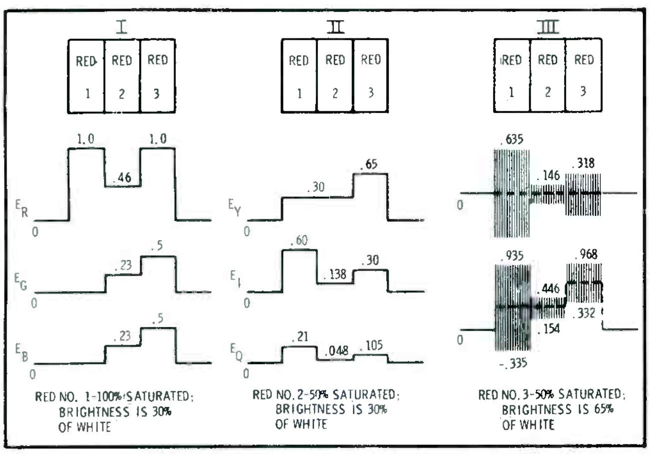


Fig. 10. Signals as brightness, saturation are changed.

The chrominance signal combined with the luminance signal is shown as the last waveform of Fig. 9. The chrominance values of this waveform were determined by vector addition of the I and Q signals, and the resultant values were added to and subtracted from the luminance values, as previously described.

The relative saturation of a color is conveyed by the ratio between the amplitudes of the chrominance and the luminance signals. The more highly saturated the color, the higher the ratio becomes. Moreover, the ratio remains fixed for a color with a given saturation regardless of the brightness of the color.

Shown in Fig. 10 is a color-bar pattern together with the various signals which are produced at the color transmitter as the camera scans the pattern. The pattern consists of three bars which are all red and which have specific saturation and brightness levels. Red No. 1 is a fully saturated red with a brightness that is equivalent to 30 per cent of white. Red No. 2 has the same brightness as the bar on the left, but it has a saturation of only 50 per cent. Red No. 3 is a red with a saturation of 50 per cent, but it has a brightness level of 65 per cent of white.

In column II of this figure, the value of the brightness or luminance signal, E_Y, for each bar is shown to be as specified. Waveforms of the three color signals are pictured in column I. During the scanning of fully saturated red No. 1, the amplitude of the red signal is unity and the blue and green signals are at zero. For each of the bars with a saturation of 50 per cent, the green and blue signals are shown to have equal amplitudes, and the red signal is shown to have twice the amplitude of either of the other two.

This result may be explained as follows. Any color which is less than fully saturated contains white light. Since white light is produced by a combination of equal values of the three primaries, a desaturated color may be defined as a mixture of a pure color and its complementary color. A color that has a saturation of 50 per cent is produced when one half of the total light is contributed by the primary color and the other half is contributed by the complementary color. Since the complement of red is produced when blue and green are combined in equal amounts, it can be established that for a red having a saturation of 50 per cent:

$$\frac{E_R}{2} = E_G = E_B.$$

The brightness value of red No. 2 in Fig. 10 is .30; therefore, the value of E_R can be determined by substituting $\frac{E_R}{2}$ for E_G and E_B in equation 1. Thus:

$$E_Y = .30E_R + .59E_G + .11E_B$$

$$.30 = .30E_R + \frac{.59E_R}{2} + \frac{.11E_R}{2}$$

$$.30 = .65E_R$$

$$E_R = .46$$

E_G and E_B are both equal to $\frac{E_R}{2}$; consequently, the value of each of these signals during the scanning of red No. 2 is .23. The values of E_R, E_G, and E_B during the scanning of red No. 3 (when $E_Y = .65$) may be determined through the use of the same equation. These values are shown in column I to be 1.0, .5, and .5, respectively.

The values shown in column I can be substituted in equations 7 and 8 to obtain the values of E_I and E_Q shown in column II for each bar. Adding E_I and E_Q vectorially gives the peak values of the color subcarrier, and then the color picture signal, E_M, is formed when the color subcarrier is superimposed on the luminance signal, E_Y. See column III.

The chrominance-signal amplitude during the scanning of a color is not necessarily a measure of the saturation of that color. Instead, the saturation is dependent upon the ratio of the chrominance amplitude to the luminance amplitude. In going from red No. 3 to red No. 1, for example, the chrominance amplitude increases and the luminance amplitude decreases. This definitely indicates an increase in saturation. (The ratio of chrominance to luminance increases.) In going from red No. 2 to red No. 3, however, the chrominance and luminance amplitudes both increase. Without considering the ratio of the chrominance amplitude to the luminance amplitude, the observer cannot assume that the saturation has increased. Actually, these two colors have the same saturation because this condition has been established.

In the foregoing example, only the color red has been considered. The ratio of chrominance to luminance for a fully saturated red is:

$$\frac{.635}{.3} = \frac{2.1}{1}$$

As the hue varies, the ratio will also vary. Table 1 is a list of the chrominance and luminance values and the ratios for the three primary colors and their complements under fully saturated conditions.

Table 1. Chrominance-to-Luminance Ratios For Fully Saturated Colors

Color	Chrominance Value	Luminance Value	Ratio
Red	.63	.30	2.10 to 1
Yellow	.45	.89	.50 to 1
Green	.59	.59	1.00 to 1
Cyan	.63	.70	.90 to 1
Blue	.45	.11	4.05 to 1
Magenta	.59	.41	1.44 to 1

Vector Relationship of Color Signals

A change in hue causes a corresponding change in the phase difference between the chrominance signal and the color burst. Fig. 11 contains vector diagrams showing the phase displacement of chrominance signals as they are related to the reference burst. It can be seen that each signal is associated with a particular phase angle. A change in phase of the chrominance signal is the only way a change in hue can be conveyed.

Each vector shown in Fig. 11 specifies a position of the chrominance signal at a certain instant during the scanning of a scene. Actually, the chrominance vector and the reference vector are constantly rotating during the time that color is being transmitted. The chrominance vector changes in phase whenever there is a change in hue, and it changes in length in accordance with changes in brightness or saturation.

Assume a color-bar pattern such as the one in Fig. 6 is being scanned. The vectors will have the following phase relationships. While the red bar is being scanned, the phase relationship between the chrominance signal

• *Please turn to page 62*

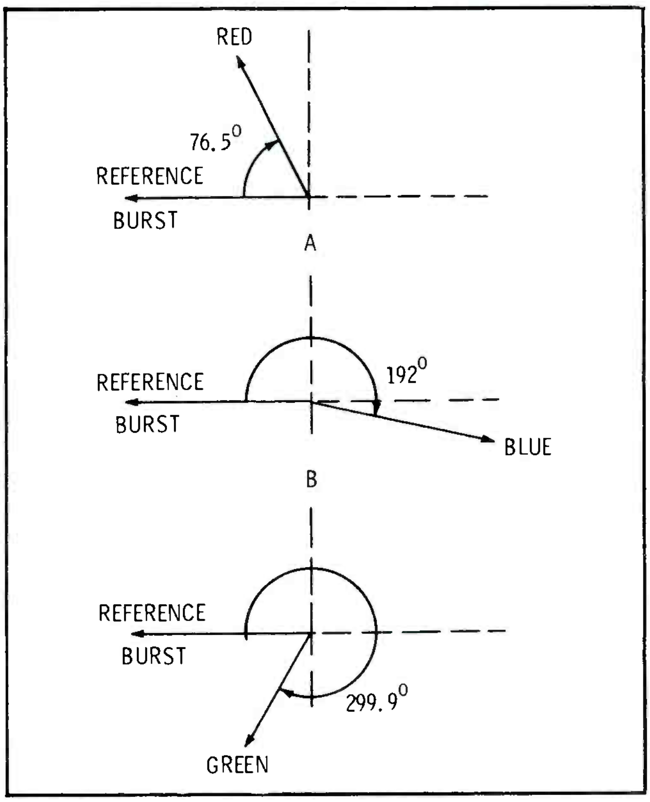
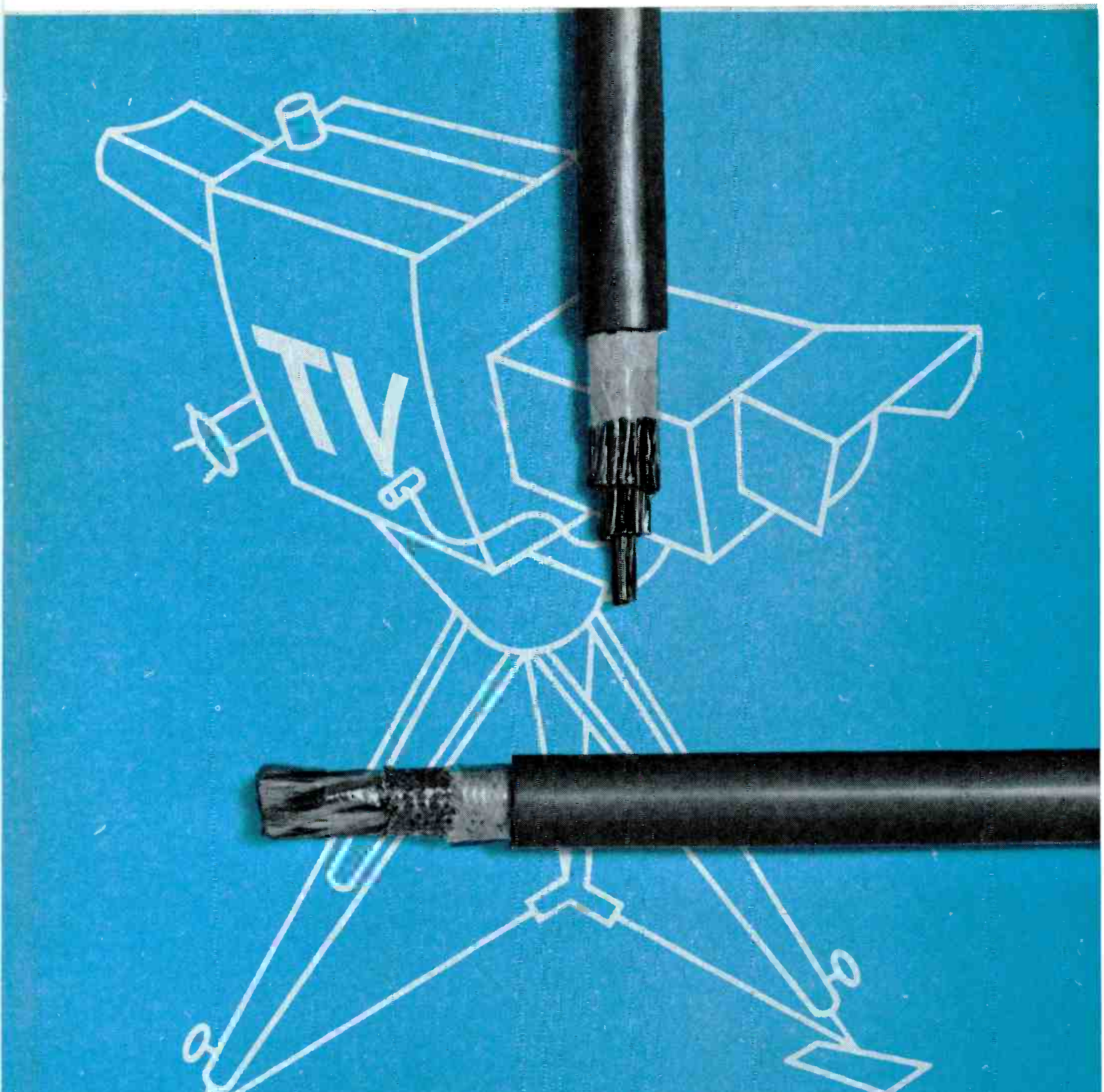


Fig. 11. Vector diagrams show phases for primary colors.



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BELDEN

K-FACTOR TESTING

by Joseph Roizen* —Analysis of waveforms provides an indication of video system performance.

To test completely the electrical characteristics of a video system, it usually is necessary to employ several instruments. Bandpass and frequency response can be determined by using a sweep generator. Transient response usually is tested with some form of step-function signal, such as square waves. Differential gain and phase require specialized equipment with appropriate display devices. The process is time consuming and complex, and it requires costly equipment for both generation and interpretation of the test signals. In most cases, if the equipment under test is in good condition, nothing but the fact that no defect exists is proven.

To simplify video-systems testing and reduce the time involved, a method using a single signal (with a proper interpreting device), the $\sin^2$ pulse and bar method, has been developed. A special graticule attached to an oscilloscope allows interpretation of the signal on a percentage-performance basis, providing a direct readout method that can be assessed easily.

Basically, the $\sin^2$ pulse and bar consists of a test signal that is generated as a narrow pulse and a step-function square wave (Fig. 1). The signal is then passed through the proper gaussian-response filter with linear phase and smooth rolloff. The output of the filter consists of a pulse and bar with characteristics as shown in Figs. 2 and 3. For a half-amplitude duration (h.a.d.) of 0.125 microsecond, an upper-frequency component of 8 MHz will be present to form the corners of the waveform. A 2T pulse, which is more commonly used in normal American standard television systems, has a half-amplitude duration of 0.250 microsecond, and its corner frequency is 4.0 MHz. Foreign standards, such as the 625/50 TV system, would use a half-amplitude duration of 0.2 microsecond, and a corner frequency of 5 MHz. The rise time of the bar is very nearly the half-amplitude duration of the pulse, and therefore this rise has essentially the same slope (Fig. 3). The low-frequency bar has been included in this test signal since the $\sin^2$ pulse alone would not be adequate for the complete check. This particular signal is especially suitable for measuring video tape-recorder systems because it has energy only in the bandpass area of the recorder.

It is difficult to test a video recorder with square waves because a pulse with very short rise time will encounter what may be described as the "brick-wall response" of the filters, and the limitations of the modulator in the recorder. In this case, the output of the recorder will contain severe overshoots and ringing (Fig. 4), which will give no indication of system performance at the desired frequencies. If, however, the applied test signal is within the bandpass characteristics of the recorder, and a properly calibrated

*Ampex Corporation

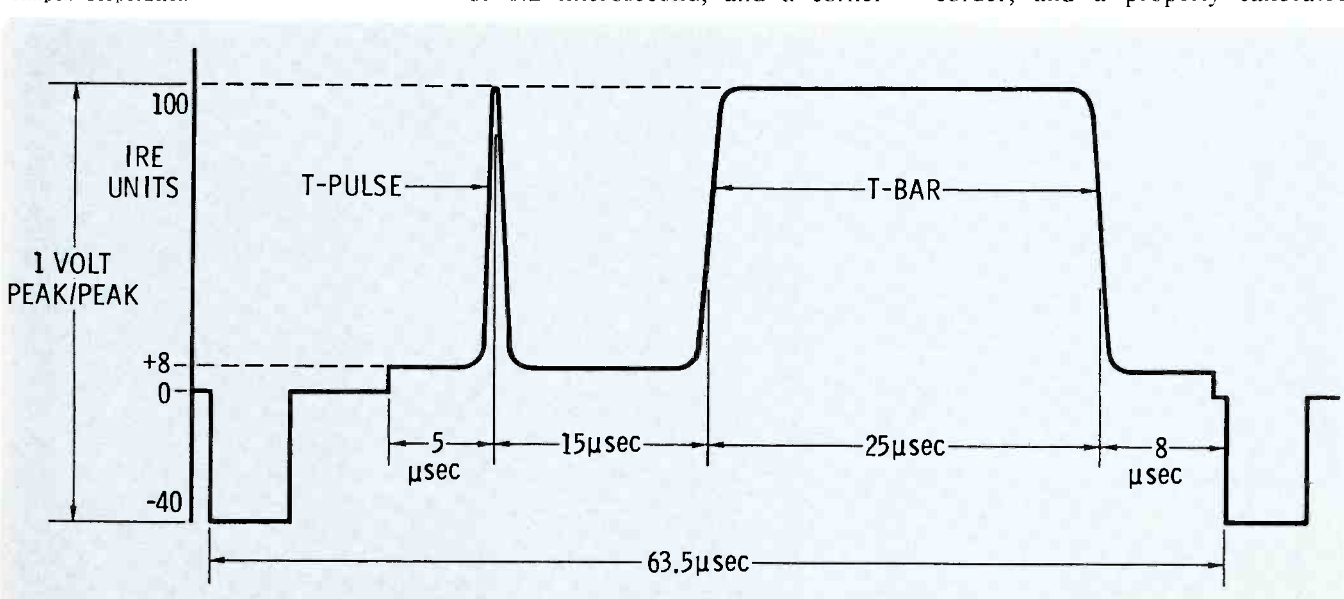


Fig. 1. Waveform, with times and amplitudes indicated, of a typical T-pulse and bar signal used in K-factor testing.

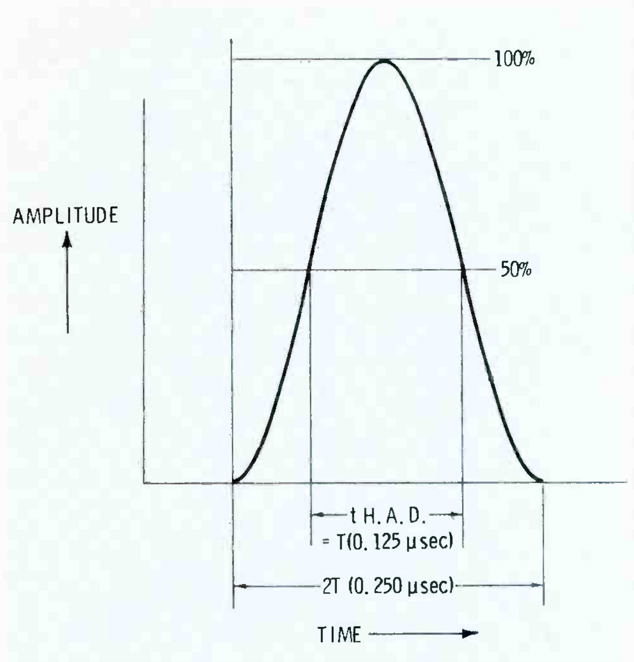


Fig. 2. T-pulse signal in which t is 0.125 microsecond.

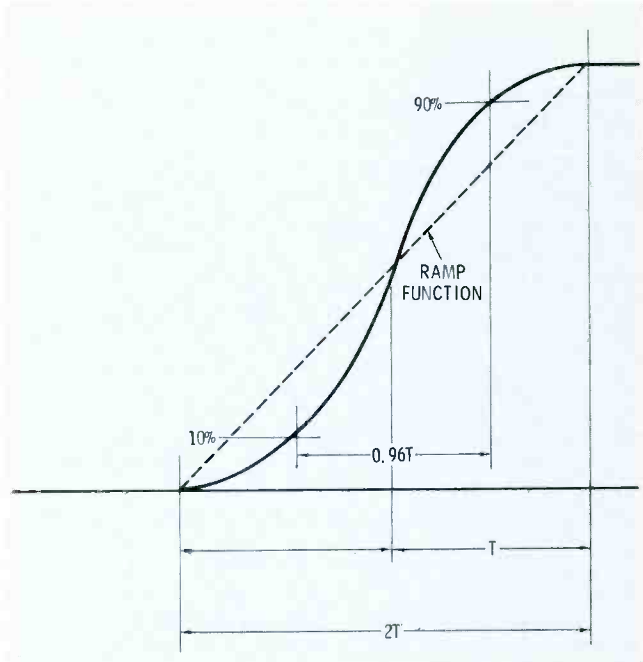


Fig. 3. Characteristics of leading edge of T-bar signal.

graticule is applied to the scope, it is simple to determine a K rating factor which gives the overall performance of the machine through analysis of the pulse shape, the bar shape, and the pulse-to-bar ratio.

In transverse video tape recorders especially, where four channels are being considered, the comparison of the pulse and bar signal from each of the four head channels allows the operator to optimize the channels to each other. The test signal is first adjusted so that the half-amplitude points on the scope match those required by the graticule. Modern waveform-monitoring oscilloscopes have proper sweep rates which produce the correct half-amplitude duration on the graticule supplied with the scope. Once the pulse and bar have been adjusted to the correct amplitude and width, the output of the recorder may be utilized to determine how accurately the machine is reproducing the signal. The K factor is then determined by where the pattern for the reproduced signal falls with respect to the various calibrated lines on the graticule (Fig. 5). A 2% K factor would be considered very excellent and 4% reasonably adequate for video-bandwidth systems. Anything falling beyond these limits should be considered suspect, and other maintenance checks must be applied to determine where the defect exists.

K-factor testing, therefore, is mainly a very rapid means of evaluating the performance of a system without requiring a great number of complex and time-consuming operations. It is important that the input signal be of the proper shape and amplitude and not have any ringing built into it, since this would greatly affect the ability to read out accurately the performance of the system under test. For testing color television systems, new K-factor signals including subcarrier mixed in with the test pulses are being developed. ▲

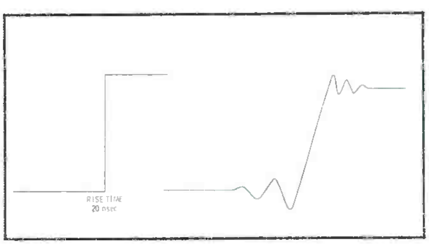


Fig. 4 "Brick-wall" filter response causes ringing of sharp waveforms.

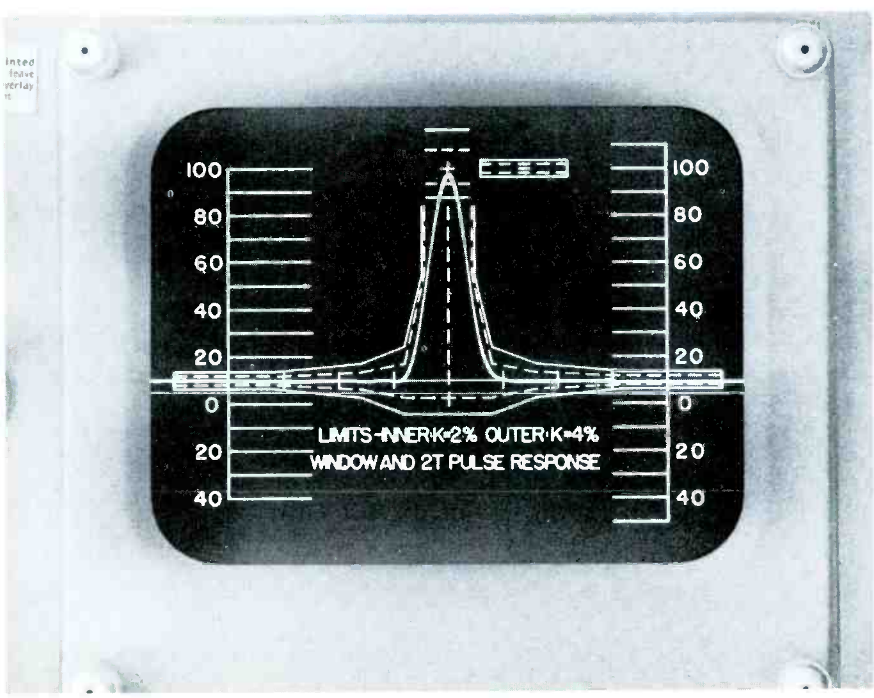
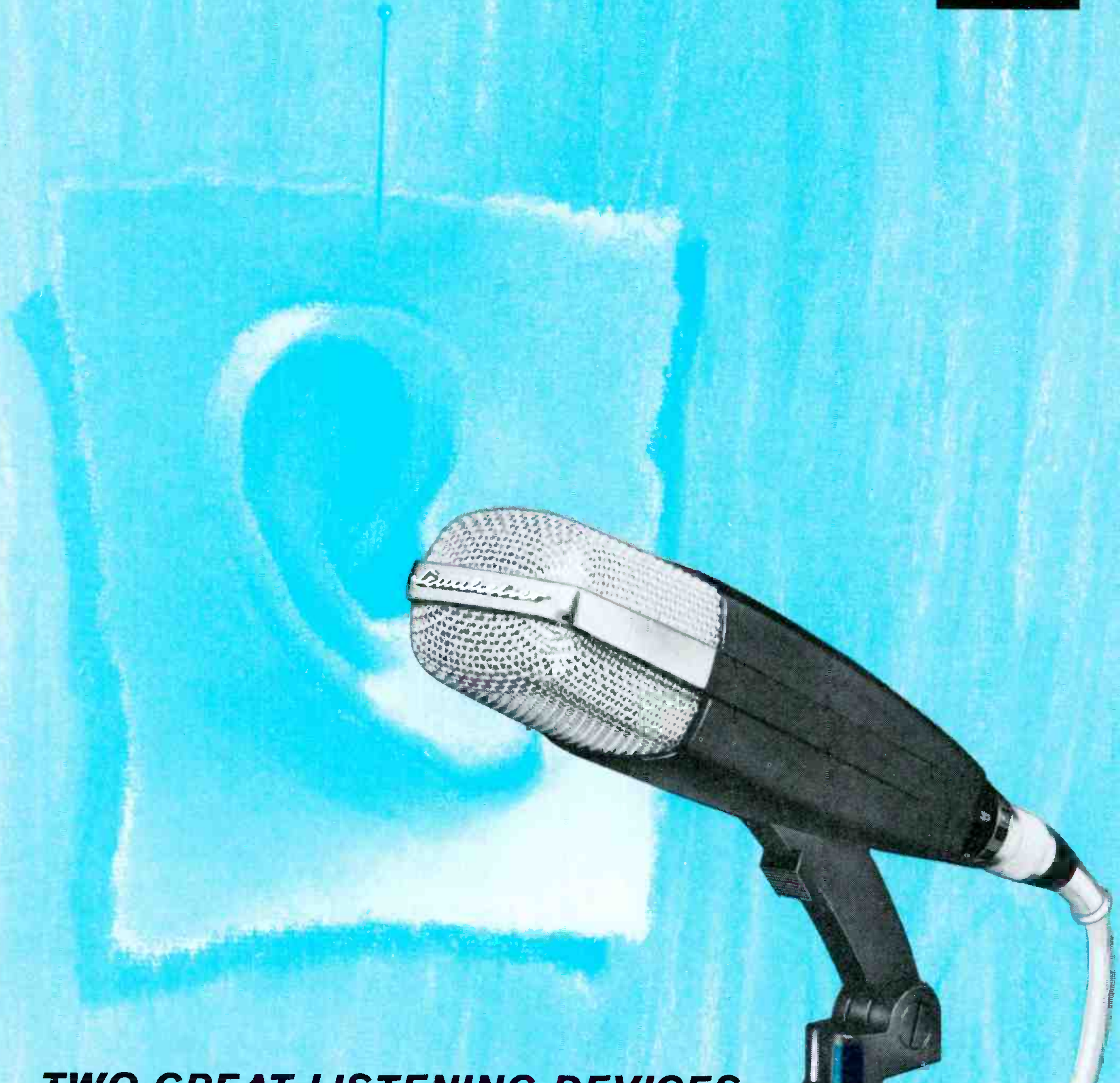


Fig. 5. Special graticule aids in the evaluation; 0.75% K factor is shown.



SELECTING COAXIAL LINE

by Richard E. Fiore

The electrical characteristics of coaxial line must be weighed to make a proper selection.

In order to select the proper size of coaxial line to meet specific design requirements, consideration should be given to all of the electrical parameters associated with coaxial line. These parameters in order of importance are:

(a) Power-handling capabilities,
(b) attenuation per unit length,
(c) cutoff frequency limit for higher-order modes, and
(d) figure of merit, Q.

Perhaps one's first comment after reviewing items (a) through (d) would be to say, "Isn't the line characteristic impedance an important consideration?" The answer to the statement is, of course, "Yes"; however, consideration of the optimum impedance unfortunately is influenced by all of the items listed above, and each parameter must be considered before an impedance is chosen. The reason for this statement should become self-evident as this article is read.

The characteristic impedance, Z_0, of a coaxial transmission line may be obtained from the expression:

$$Z_0 = \frac{138}{\sqrt{\varepsilon}} \log_{10} \frac{b}{a}$$

where,

ε = relative dielectric constant of propagating medium between inner and outer conductor (1 for dry air at atmospheric pressure),
b = radius of outer conductor, and
a = radius of inner conductor.

A curve of b/a vs Z_0 is given in Fig. 1.

Power-Handling Capabilities

The optimum impedance to use when a high average power level is to be transmitted is approximately 38 ohms, whereas the optimum impedance to use when a high peak power level is to be transmitted is approximately 70 ohms. The industry has standardized on a characteristic impedance of 50 ohms. Most power-handling problems can be solved utilizing the correct line size for the rating required. If, however, in special cases power-handling problems become critical, it is best to choose the optimum line impedance for the particular application and use impedance transformers where required.

Fig. 2 gives power-handling capabilities for various line sizes and characteristic impedances as a function of operating frequency. All of the transmission lines listed are conservatively rated based upon a 42°C rise above ambient for the outer conductor and a 62°C rise above ambient for the inner conductor.

Peak Power

The peak power-handling capability of a given line is given as that value for zero frequency (for practical purposes, the value of the left abcissa of the graph).

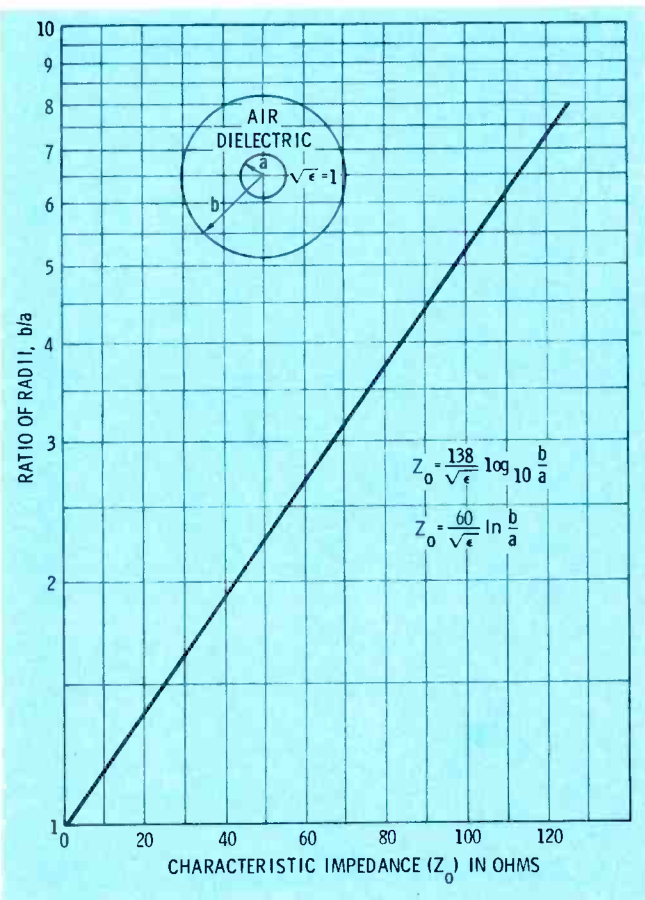


Fig. 1. Chart of coaxial-line characteristic impedance.

The peak power-handling capability is independent of frequency, since it is purely a function of the maximum peak voltage that a given line can handle without evidence of breakdown. Since, at electrical breakdown, deionization of the air dielectric causes voltage corona leading to eventual arc-over, the peak power capability for any given line size is derated by as much as 2 to 1. In addition to this built-in safety factor, a further derating should be applied for those lines operating into mismatched loads. The derated power-handling value can be determined from:

$$\begin{matrix}\text{Derated}\\ \text{pk or avg}\\ \text{rating}\end{matrix} = \left[\begin{matrix}\text{Actual peak or}\\ \text{average power}\\ \text{rating from Fig. 2}\end{matrix}\right]\left[\frac{\text{VSWR} + 1}{2 \times \text{VSWR}}\right]^2$$

For example, if the actual average power rating from Fig. 2 is 100 kw and the terminating load VSWR is 1.10, then the derated average power rating would be:

$$\left[100 \text{ kw}\right] \times \left[\frac{1.1+1}{2(1.1)}\right]^2 \cong 91 \text{ kw}.$$

Once the peak power rating for a given line size has been determined, various pressurization techniques may be utilized to improve the rating if it is determined that the selected line size (for a given Z_0) is marginal.

The use of dry air (air that has been processed by means of a dehydrator) under pressure increases the peak power rating of a line by a considerable degree. A good rule of thumb is:

1. An increase of one atmosphere of pressure (15 psig) increases the power rating by a factor of 2.
2. An increase of two atmospheres of pressure (30 psig) increases the peak rating by a factor of 4.

Pressure levels in excess of two atmospheres may be used; however, care should be exercised to insure that the mechanical structure of the line can withstand the forces without hazard to the operating personnel, and the gas barriers normally located at each end of the system can handle the new pressure.

For extremely high power-handling capabilities, sulphur hexafluoride gas may be utilized.

1. At one atmosphere of SF_6 (15 psig), the peak power rating is increased by a factor of 4.
2. At two atmospheres of SF_6 (30 psig), the peak power rating is increased by a factor of 10.

Extreme caution should be exercised in utilizing SF_6 as a pressurizing agent, since electrical discharge in a dielectric medium of SF_6 produces toxic oxides of fluorine. For this reason one should *not attempt* to investigate peak-power failure in a transmission-line system utilizing SF_6 in poorly ventilated or closed areas.

Average Power

The maximum average power is determined by the maximum permissible temperature rise of the inner conductor. The average power rating for a given line size cannot be increased substantially without the use of forced air or liquid cooling. Either of these methods is difficult to utilize in pressurized line systems and requires special techniques.

As can be observed from the curves of Fig. 2, the average power-handling capability for a given coaxial-

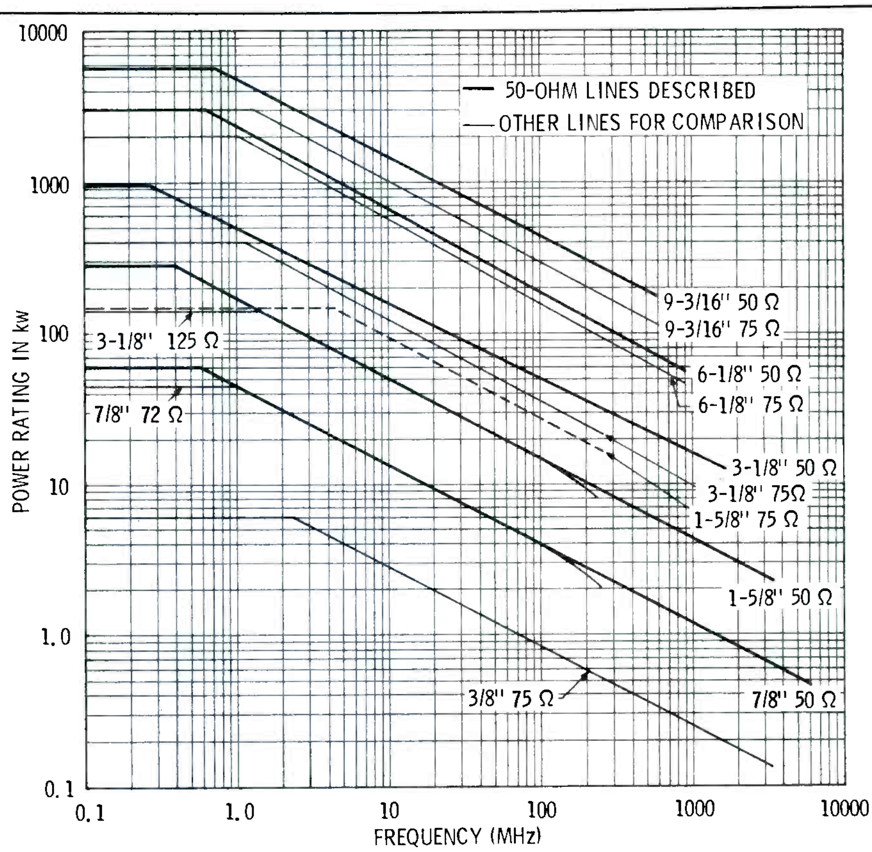


Fig. 2. Power ratings of coaxial transmission lines of various sizes and impedances shown as a function of frequency.

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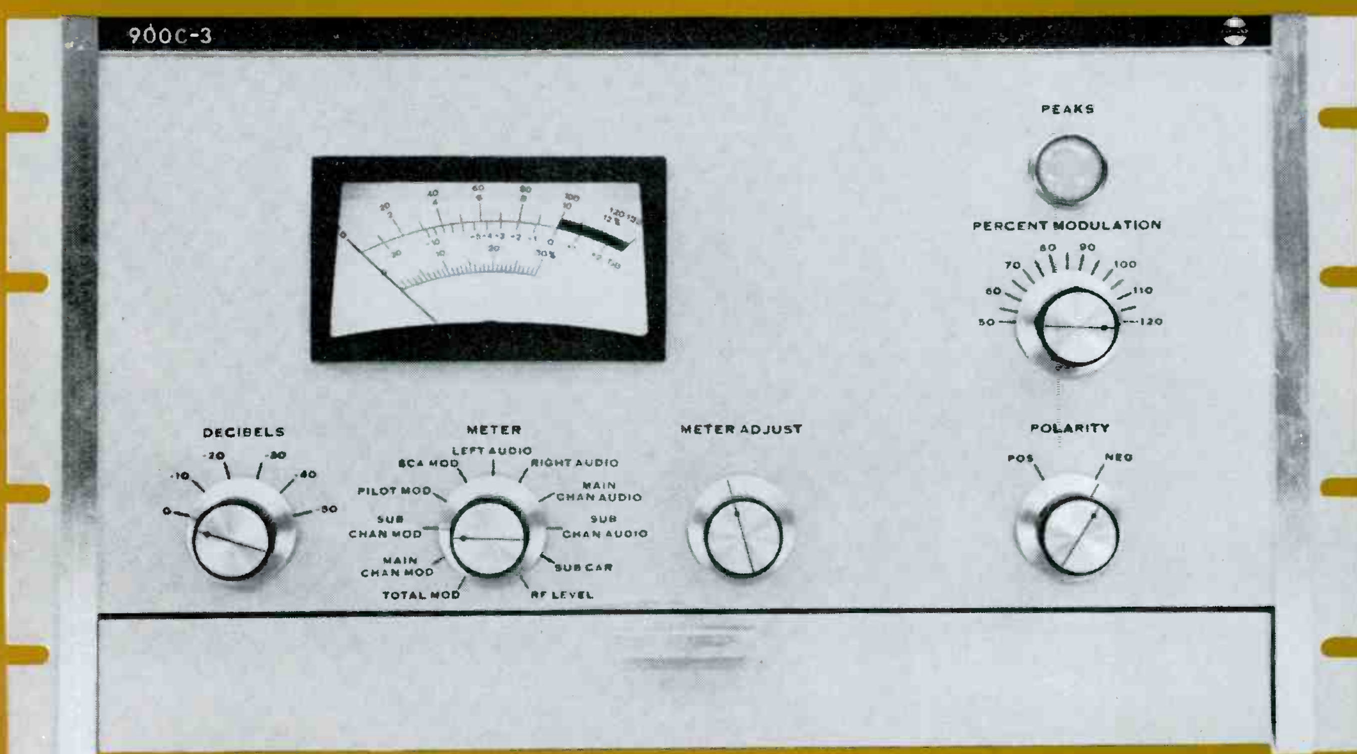

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