Chapter 2

Analog Video Fundamentals

2.1 Color Television

Color television relies on the light properties that control the visual sensations known as brightness, hue, and saturation.

- *Brightness* is defined as the characteristic of a color that enables it to be placed on a scale of from dark to light.
- *Hue* is defined as the characteristic of a color that enables it to be described as red or yellow or blue or any other identifiable color.
- *Saturation* is defined as the extent to which a color departs from the white of the neutral condition. Pale colors (pastels) are low in saturation, whereas strong, or vivid, colors are high in saturation.

Virtually any color can be matched by a proper combination of three primary colors. Green, blue, and red have been chosen as the primary colors for television. The proper combination of green, blue, and red produces white. Practical considerations, such as the relative ease with which relatively efficient color phosphors could be made, played an important role in the choice of television's primary colors.

In its simplest form, a color television system consists of three sensors that receive filtered green, blue, and red images. The three sensors scan the three respective images horizontally and vertically, in the conventional manner, and generate green, blue, and red electrical signals. These signals are transported in some manner to the receiver for display on three CRTs with, respectively, green, blue, and red phosphors. The three CRTs reverse the process and create a representation of the original picture by superimposing the three images. The reproduction of pictures with a diagonal measurement of less than about 40 in (100 cm) relies on the use of tricolor CRTs using three dedicated electron guns and an array of triad green, blue, and red phosphor dots or stripes on which the respective electron beams are caused to converge. In this way, three primary color images are produced on the screen of a tricolor CRT. The small dimension of the colored phosphor dots or stripes causes the observer to see a full-color image.

2.1.1 Colorimetry

The principles of colorimetry are based on Grassman's laws. These laws are

- The eye can distinguish only three kinds of differences or variations.
- In a two-component light mixture, the color mixture will change gradually if one component is steadily changed and the other is held constant.
- Sources of the same color produce identical visual effects in a mixture regardless of their spectral composition.
- The total luminance of the color is the sum of the luminances of each of the components.

In modern colorimetry, the colors are represented in a three-dimensional coordinate system (the color space) known as the *tristimulus chromaticity coordinate system.* The coordinates are designated X, Y, and Z and each possible color occupies a position in the three-dimensional system. The unit plane of this system ($X + Y + Z = 1$) contains all the coordinates of the various colors. The total area covered by the colors is called the *Planckian locus.* The color coordinates depend on the spectral characteristics of the illuminating light, the human eye response, and the spectral reflectance (or transmittance) of the observed color. The XYZ values of a color are defined by the following equations:

$$X = K \sum_{\lambda = 300}^{700} \bar{x}(\lambda)\, C(\lambda)\, L(\lambda)\, \Delta(\lambda)$$

$$Y = K \sum_{\lambda = 300}^{700} \bar{y}(\lambda)\, C(\lambda)\, L(\lambda)\, \Delta(\lambda)$$

$$Z = K \sum_{\lambda = 300}^{700} \bar{z}(\lambda)\, C(\lambda)\, L(\lambda)\, \Delta(\lambda)$$

where K = a normalizing factor given by

$$K = \frac{1}{\sum_{\lambda = 300}^{700} L(\lambda)\, \bar{y}(\lambda)\, \Delta(\lambda)}$$

$L(\lambda)$ = Light spectrum characteristics
$\Delta(\lambda)$ = Wavelength increase, nm

$C(\lambda)$ = Color spectrum characteristics used
$\bar{x}, \bar{y}, \bar{z}$ = the 1931 Standard Observer characteristics
λ = Light wavelength

In practice, the three-dimensional coordinate system is replaced by its projection on the XOY plane and is designated as the Planckian locus of the x-y coordinate system. The projection equations are

$$x = \frac{X}{(X+Y+Z)} \quad \text{and} \quad y = \frac{Y}{(X+Y+Z)}$$

Figure 2.1 shows a display of the two-dimensional Planckian locus along with the triangle formed by the SMPTE/EBU phosphors. Colors are represented by two coordinates, x and y.

As indicated by Grassman's laws, all visible colors are located inside, or on the edge of, the triangle formed by the three light sources. Color television uses three light sources in a CRT designated green, blue, and red phosphors. The respective phosphor coordinates (x, y) are located on the Planckian locus.

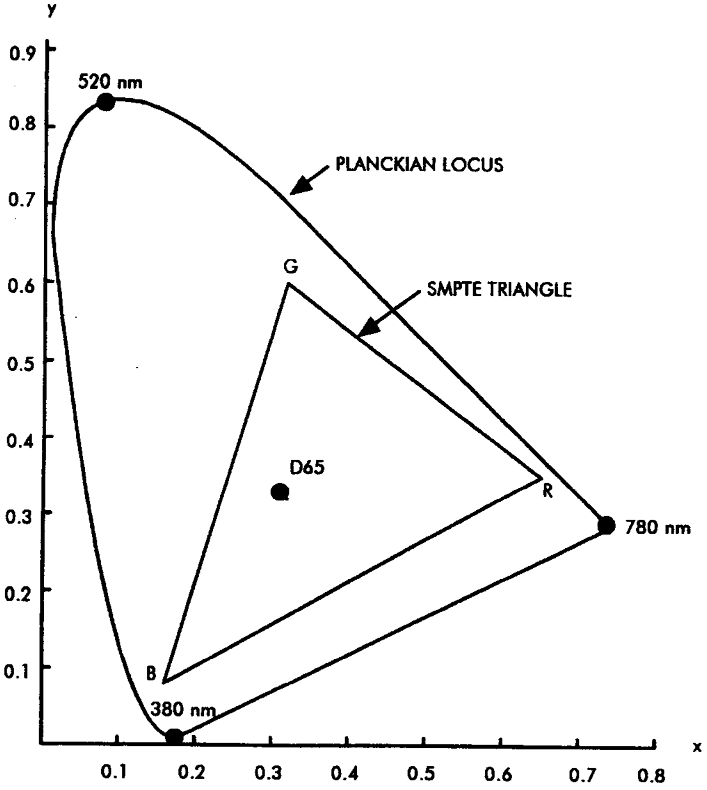


Figure 2.1 2D Planckian locus showing the location of the SMPTE phosphors and the D6500 reference white.

In the past there used to coexist two standard sets of phosphors known as SMPTE, used in North America, and EBU, used in Europe. Recently, the SMPTE and EBU phosphors have been normalized to identical values. The coordinates of the universal standard phosphors are

Green:	$x = 0.310$	$y = 0.595$
Blue:	$x = 0.155$	$y = 0.070$
Red:	$x = 0.630$	$y = 0.340$

An important consideration is the reproduced system reference white. This white, referred to as D6500, has been standardized to the following x-y coordinate values:

$$x = 0.3127 \qquad \text{and} \qquad y = 0.3290$$

2.1.2 Transfer characteristics

The electrooptical transfer characteristic of the CRT is inherently nonlinear. In order to achieve an overall linear transfer characteristic, it is necessary to compensate for the CRT nonlinearity by introducing a compensating nonlinearity, usually referred to as *gamma correction,* elsewhere in the system. Historically, the compensation has been carried out in the camera, where the green, blue, and red signals are predistorted to match the CRT. This results in signals that can be satisfactorily viewed on relatively simple color monitors or receivers as well as improved signal-to-noise ratio (SNR) under less than ideal receiving conditions. In order to achieve uniform results, it is necessary to define the reference CRT electrooptical characteristics. Various organizations use different reference CRT electrooptical characteristics and compensation methods. The standardized North American transfer characteristics of the reference reproducer and of those of the compensating reference camera, extracted from the ANSI/SMPTE 170M-1994 standard, are presented below.

2.1.2.1 Electrooptical transfer characteristic of the reference reproducer

$$L_T = \left[\frac{(V_r + 0.099)}{1.099}\right]^{\gamma} \qquad \text{for } 0.0812 \le V_r \le 1$$

$$L_T = \frac{V_r}{4.5} \qquad \text{for } 0 \le V_r \le 0.0812$$

where V_r is the video signal level driving the reference reproducer normalized to the system reference white and L_T is the light output from the reference reproducer, normalized to the system reference white and $\gamma = 2.2$.

2.1.2.2 Optoelectronic transfer characteristic of the reference camera

$$V_C = 1.099 \times L_C^{(1/\gamma)} - 0.099 \qquad \text{for } 0.018 \leq L_C \leq 1$$

$$V_C = 4.500 \times L_C \qquad \text{for } 0 \leq L_C \leq 0.018$$

where V_C is the video signal output of the reference camera, normalized to the system reference white, and L_C is the light input to the reference camera, normalized to the system reference white and $\gamma = 2.2$.

Figure 2.2 shows the nonlinear transfer curve of a typical CRT and its correction.

2.1.3 The basic ingredients

All color television systems use the principle of additive colors with green, blue, and red as primary colors.

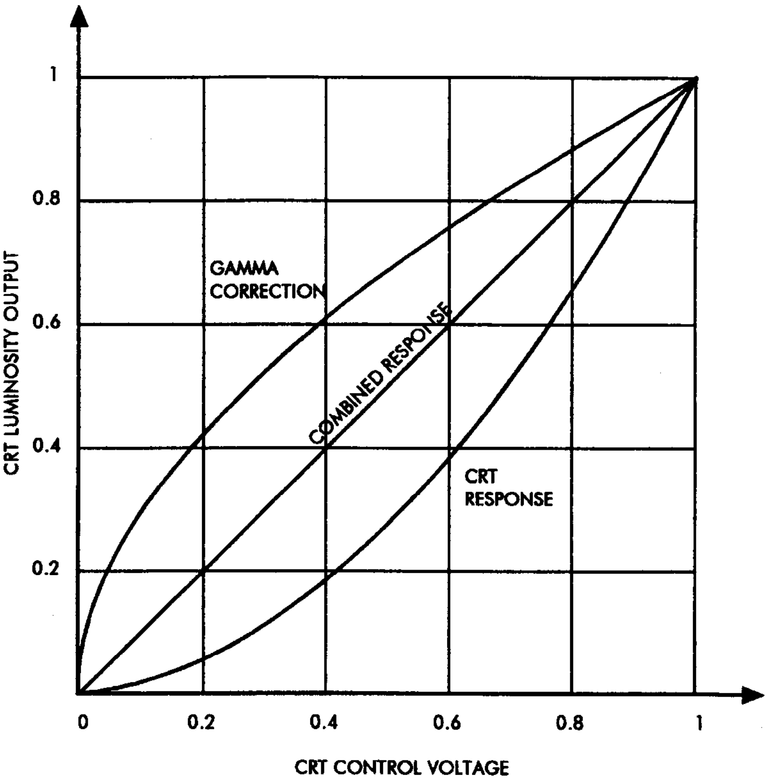


Figure 2.2 Correction of CRT nonlinear transfer curve.

2.1.3.1 Brightness information. Monochrome compatibility requires the generation and transmission of a full-bandwidth signal representing the brightness component of the televised scene. This component is called *luminance.* The mathematical expression for the luminance signal is

$$E'_Y = 0.587\,E'_G + 0.114\,E'_B + 0.299\,E'_R$$

where E'_Y = The gamma-corrected voltage corresponding to the luminance information

E'_G = The gamma-corrected voltage corresponding to the green information

E'_B = The gamma-corrected voltage corresponding to the blue information

E'_R = The gamma-corrected voltage corresponding to the red information

In a studio environment the bandwidth of the luminance signal is restricted only by the state of the art of the equipment used. Normally, the bandwidth of the luminance signal generated by a camera is at least 8 MHz, or a horizontal resolution in excess of 600 LPH. The typical analog composite videotape recorder bandwidth is 4.2 MHz in NTSC and 5 MHz in PAL. The luminance bandwidth of analog component videotape recorders is slightly worse. The transmitted luminance bandwidth is reduced by the analog transmission channel specification to 4.2 MHz in NTSC, and 5 MHz or 5.5 MHz in 625/50 PAL.

2.1.3.2 Chrominance information. The chrominance information is conveyed by two of the three primary signals minus the brightness component. These signals are known as the blue and the red color-difference signals. They are

$$E'_B - E'_Y = -0.587\,E'_G + 0.886\,E'_B - 0.299\,E'_R$$

and

$$E'_R - E'_Y = -0.587\,E'_G - 0.114\,E'_B + 0.701\,E'_R$$

The $E'_G - E'_Y$ signal can be re-created in the receiver by a suitable combination of the blue and red color-difference signals.

The color-difference signals are scaled in amplitude by suitable multiplication factors. The scaling of the color-difference signals varies with the application. The NTSC and PAL composite color television systems use identical scaling factors to avoid transmitter overloading. Component analog and digital standards use different scaling factors.

The NTSC and PAL scaled color-difference signals are:

$$E'_{B-Y} = 0.493\,(E'_B - E'_Y) \qquad \text{(Called } E'_U \text{ in PAL)}$$

and

$$E'_{R-Y} = 0.877\,(E'_R - E'_Y) \qquad \text{(Called } E'_V \text{ in PAL)}$$

The detail of the color-difference information reflects the resolving capability of normal vision. The bandwidth of the color-difference signals used in analog composite and component applications varies from system to system but never exceeds 1.5 MHz. Receivers and monitors rarely exceed 0.5-MHz chrominance bandwidth or a horizontal resolution of about 40 lines. The main difference between the analog composite systems lies in the manner in which the color-difference signals are modulating the respective subcarriers.

2.1.4 The color bars signal

The color bars signal is widely used and often misinterpreted. This book will make many references to color bars signals and waveforms and therefore a description of the basic signal is appropriate.

There are various versions of the color bars signals in general use. They all share a common overall form. The color bars signal provides a sequence of vertical bars in the picture area showing the saturated primaries and their complements as well as black and white. The active line is thus divided in eight equal parts. The first is occupied by a luminance reference bar, that is, a white bar of a standard amplitude. The last is a black bar, that is, black level only. In between are six bars representing the three primary colors and their complements. They are, in order, yellow, cyan, green, magenta, red, and blue. The standard order of presentation has been chosen to give a descending-order sequence of luminance values.

A color bar generator has three outputs corresponding, respectively, to the green, blue, and red primary color signals, E'_G, E'_B, E'_R. These signals consist of a sequence of flat-top pulses. By a suitable overlap of the pulses in certain portions of the raster and nonoverlap in others, the three saturated primary colors as well as the three saturated complementary colors are produced. These signals may be used in their original form, matrixed into E'_Y, $E'_B - E'_Y$, and $E'_R - E'_Y$ or encoded into an analog (NTSC, PAL, SECAM) or digital (component or composite) signal.

A number of different color bar signals exists. Many of them are application-specific, that is, reflect the operational requirements of the specific organization, like color bars optimized for use with amplitude-modulated transmitters. Others are typical of the respective analog composite encoding standard and contain, in addition to the color bars, various signals serving the purpose of color monitor alignment or various performance measurements.

Two groups of saturated color bar signals will be described in this chapter. They reflect the peculiarities of the two conventional television scanning standards (525/60 and 625/50) in terms of white and black signal levels. Each group comprises a full-amplitude (100%) and a reduced-amplitude (75%) color bar signal. The various pulse levels are described in percentages of the peak white level. Figure 2.3 shows the details of the four types of color bars.

Each type of color bar is identified with four numbers with an oblique stroke between them as follows:

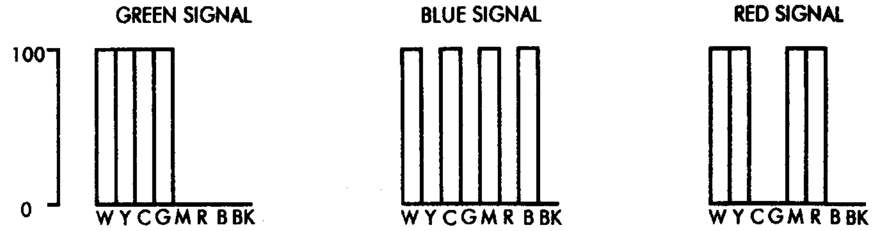
- The first number describes the primary color signal level during the transmission of the white bar, that is, the maximum value of E'_G, E'_B, and E'_R.
- The second number describes the primary color signal level during the transmission of the black bar, that is, the minimum value of E'_G, E'_B, and E'_R.
- The third number describes the maximum level of the primary color signal during the transmission of the colored color bars, that is, the maximum value of E'_G, E'_B, and E'_R.
- The fourth number describes the minimum level of the primary color signal during the transmission of the colored color bars, that is, the minimum value of E'_G, E'_B, and E'_R.

Figure 2.3a presents a fully saturated color bar signal with maximum signal levels of 100% and minimum signal levels of 0%. This type of color bar signal is called 100/0/100/0. Figure 2.3b shows a fully saturated color bar signal with maximum signal levels of 75% and minimum signal levels of 0%. This type of color bar signal is called 75/0/75/0. These types of color bar signals are typical of those used in 625/50 countries. They are representative of the signals used to feed a PAL encoder and would be obtained at the output of a properly adjusted PAL decoder.

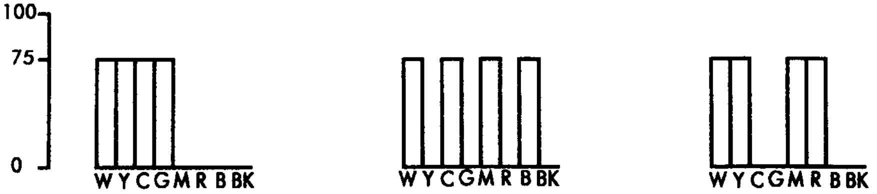
Figure 2.3c presents a fully saturated color bar signal with maximum signal levels of 100% and minimum signal levels of 7.5%. This type of color bar signal is called 100/7.5/100/7.5. Figure 2.3d shows a fully saturated color bar signal with maximum levels of 75% and minimum signal levels of 7.5%. This color bar signal is called 75/7.5/75/75. These types of color bar signals are typical of those used in 525/60 countries except Japan. They are representative of the signals used to feed an NTSC encoder reflecting the original philosophy behind the 1953 NTSC standard. In those days the primary signals (E'_G, E'_B, and E'_R) had the black level set at 7.5% of the peak white level (7.5 IRE setup) and their peak level was 714.3 mV (100 IRE). Current NTSC encoders use E'_G, E'_B, and E'_G without setup and, very often, with a peak amplitude of 700 mV, leaving it to the encoder to normalize the encoded signal to NTSC specifications. This allows for standard camera circuit designs irrespective of the analog composite encoding standard. The signal at the output of an NTSC decoder will, however, be as shown in Fig. 2.3c or d.

Figure 2.4 shows the position of the eight bars on a television screen.

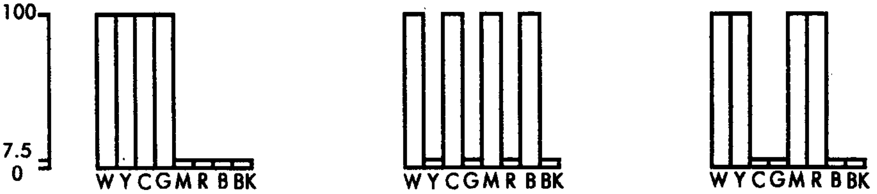
Figure 2.5 shows a graphic representation of the formation of the 100/0/100/0 color bars luminance component waveform E'_Y from the primary E'_G, E'_B, and



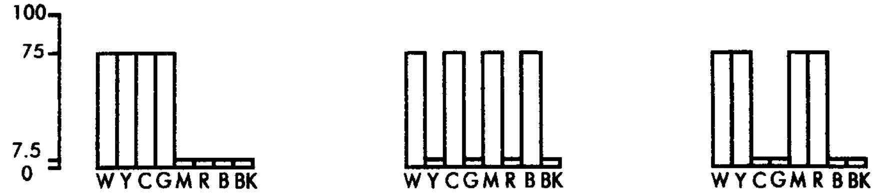
a 100/0/100/0 COLOR BARS



b 75/0/75/0 COLOR BARS



c 100/7.5/100/7.5 COLOR BARS



d 75/7.5/75/7.5 COLOR BARS

Figure 2.3 Relative amplitudes of components for four types of color bars.

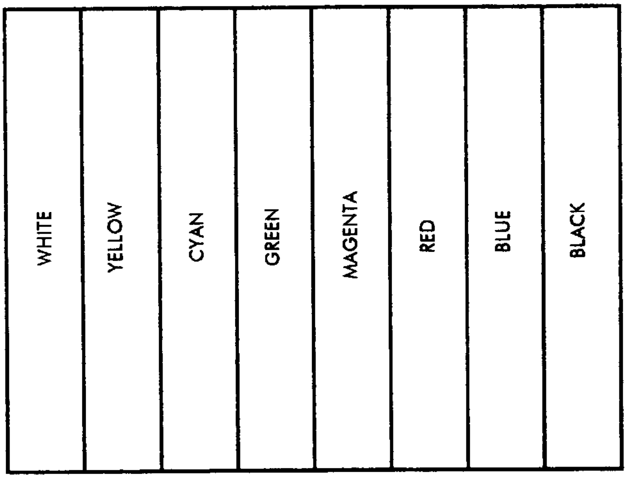


Figure 2.4 The position of the eight bars on the television screen.

E'_R signals. The signal is unipolar and has a descending-order sequence of luminance values as indicated earlier in this chapter. The amplitudes are expressed in percentages of the full-amplitude signal (that is, 700 mV). As shown, it has no synchronization (sync) added to it.

Figure 2.6 shows a graphic representation of the formation of the 100/0/100/0 color bars nonscaled blue color-difference component waveform $E'_B - E'_Y$ from the primary E'_G, E'_B, and E'_R signals. The scaled signal, $E'_{B\text{-}Y}$, has the same shape but a lower peak-to-peak amplitude. The signal is bipolar and has equal maximum positive and negative excursions with respect to the zero reference. The amplitudes are expressed in percentages of the full-amplitude signal (i.e., 700 mV).

Figure 2.7 shows a graphic representation of the formation of the 100/0/100/ color bars nonscaled red color-difference component waveform $E'_R - E'_Y$ from the primary E'_G, E'_B, and E'_R signals. The scaled signal, $E'_{R\text{-}Y}$, has the same shape but a lower peak-to-peak amplitude. The signal is bipolar and has equal maximum positive and negative excursions with respect to the zero reference. The amplitudes are expressed in percentages of the full-amplitude signal (i.e., 700 mV).

Figure 2.8 shows a graphic vector display representation of a 100/0/100/0 color bar signal. This display is obtained by feeding the $E'_{B\text{-}Y}$ (scaled blue color-difference) signal to the horizontal input and the $E'_{R\text{-}Y}$ (scaled red color-difference) signal to the vertical input of an oscilloscope.

A subset of the 75% color bar signals, identified, respectively, as 100/0/75/0 and 100/7.5/75/7.5, is being used by certain organizations. These signals are identical to the regular 75% color bar signals except that the luminance bar has an amplitude of 100%. They are generally being used to feed television transmitters and older analog composite videotape recorders.

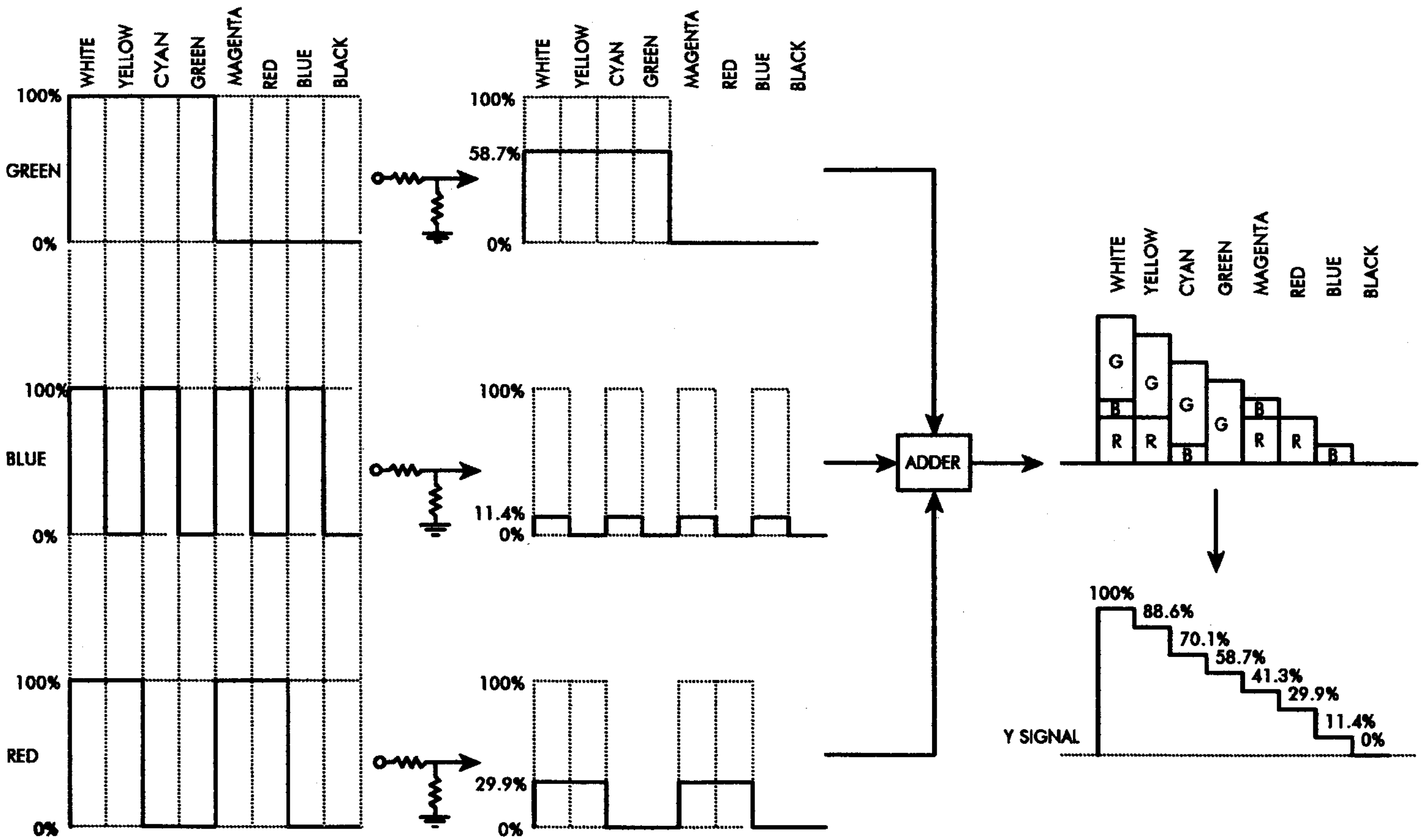


Figure 2.5 Graphic representation of the formation of 100/0/100/0 color bars Y signal from the primary green, blue, and red signals.

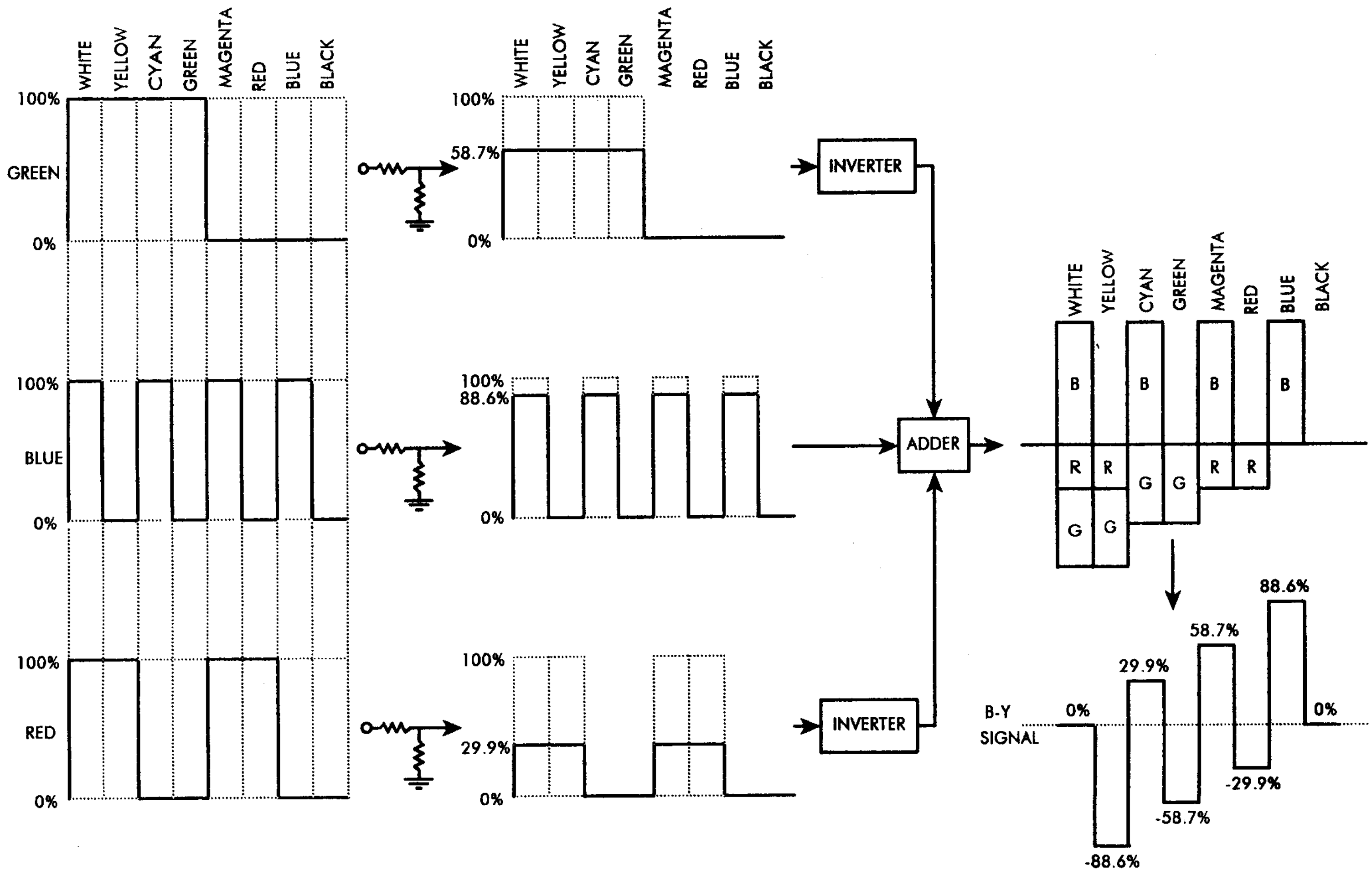


Figure 2.6 Graphic representation of the formation of 100/0/100/0 color bars blue color-difference signal from the primary green, blue, and red signals.

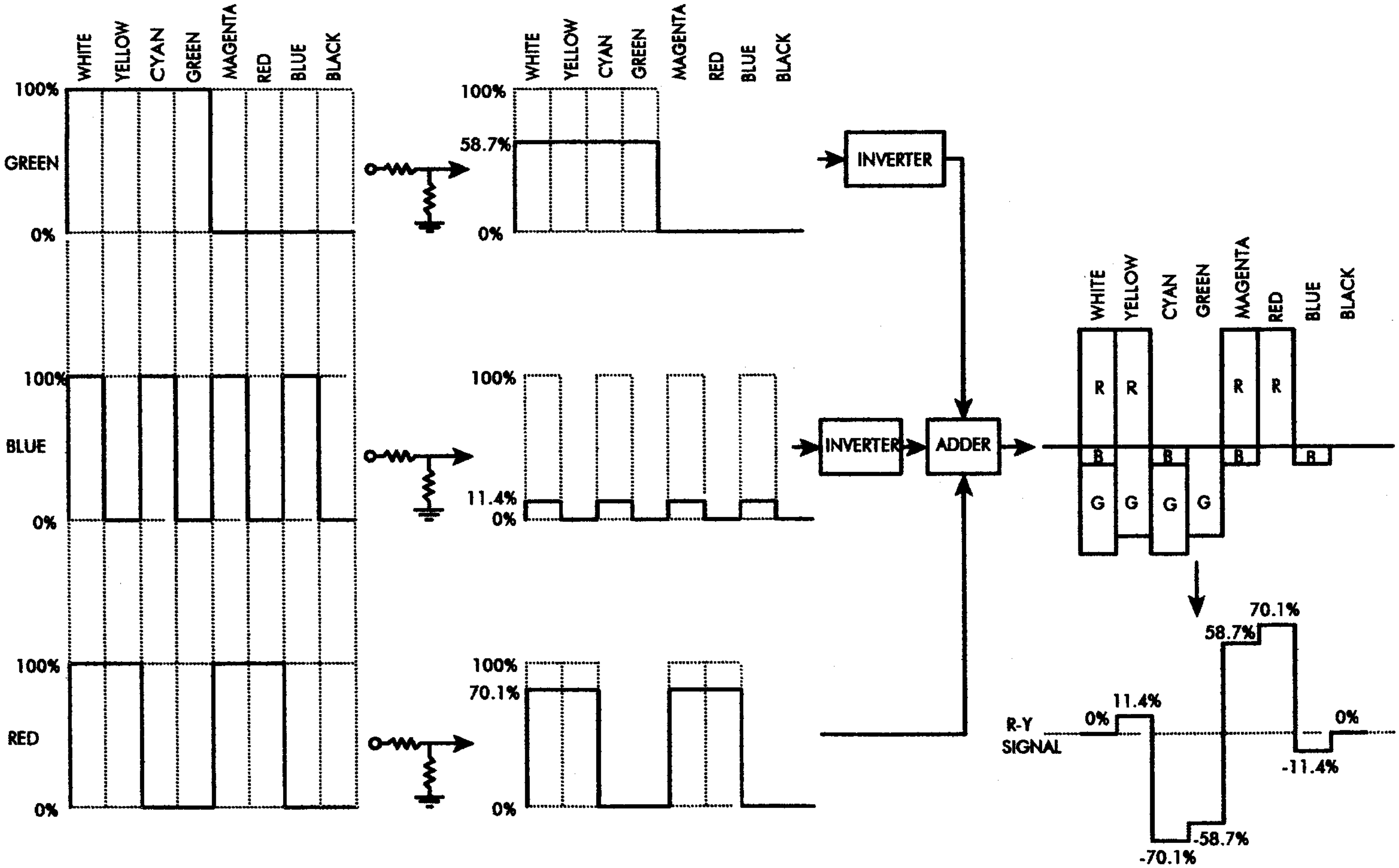


Figure 2.7 Graphic representation of the formation of 100/0/100/0 color bars red color-difference signal from the primary green, blue, and red signals.

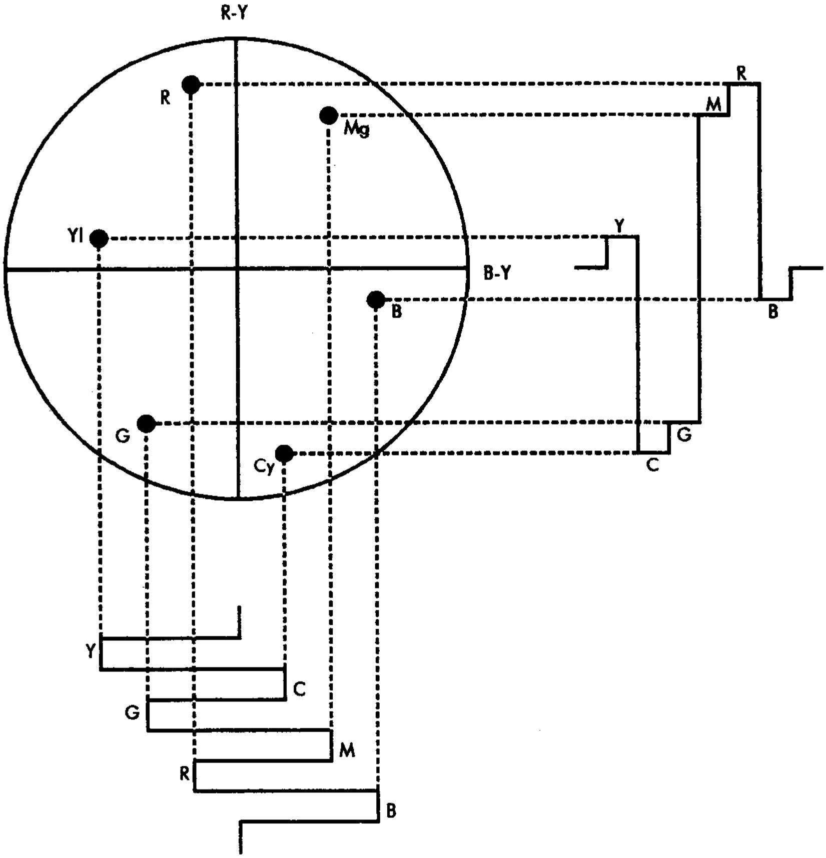


Figure 2.8 Graphic representation of the formation of a vector display of the 100/0/100/0 color bars chrominance components.

2.2 Composite Video

Composite video describes a signal in which luminance, chrominance, and synchronization information are multiplexed in the frequency, time, and amplitude domain for single-wire distribution.

2.2.1 Common characteristics

All current broadcast color television systems, namely NTSC, PAL, and SECAM, share a number of basic features.

2.2.1.1 Compatibility requirements. The main consideration in the development of the major color television standards (NTSC, PAL, and SECAM) was compatibility with the existing monochrome television standard. There are several aspects to this concept. These are

- Monochrome compatibility: A monochrome receiver must reproduce the brightness content of a color signal correctly in black and white with no visible interference from the color information.
- Reverse compatibility: A color receiver must reproduce a monochrome signal correctly in shades of gray with no spurious color components.
- Scanning compatibility: The scanning system used for color transmissions must be identical to the one used by the existing monochrome service.
- Channel compatibility: The color system must fit into the existing monochrome TV channel and use the same spacing between the vision and sound carriers.

2.2.1.2 Frequency division multiplexing. In current broadcast usage, primary green, blue, and red (G,B,R component) signals, generated by a camera, are processed to produce an analog composite video signal (NTSC, PAL, or SECAM). All systems use as the main ingredients a wideband luminance (*Y*) signal and two narrowband color-difference signals (B-Y and R-Y). The chrominance signals each modulate an assigned subcarrier in a manner peculiar to the specific television system. The frequency of the subcarriers is relatively high for reduced visibility. The approximate values are 3.58 MHz for the 525/60 scanning system and 4.43 MHz for the 625/50 scanning system. The chrominance and luminance signals are frequency-division-multiplexed to obtain a single-wire composite video signal with a total bandwidth suited to the specific transmission standard.

Figure 2.9 shows the simplified block diagram of a generalized encoder. The matrix serves to derive the luminance and color-difference signals from the primary signals through a process of linear amplification, addition, and subtraction. The delay introduced in the luminance path matches the delays

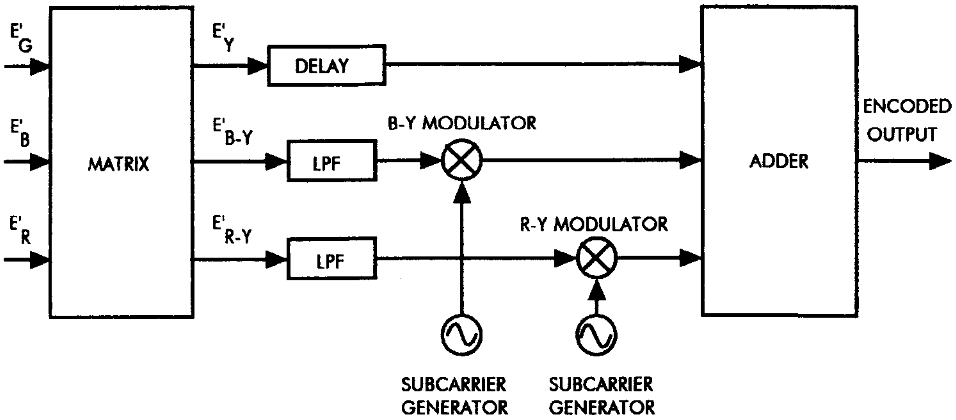


Figure 2.9 Simplified block diagram of generalized encoder.

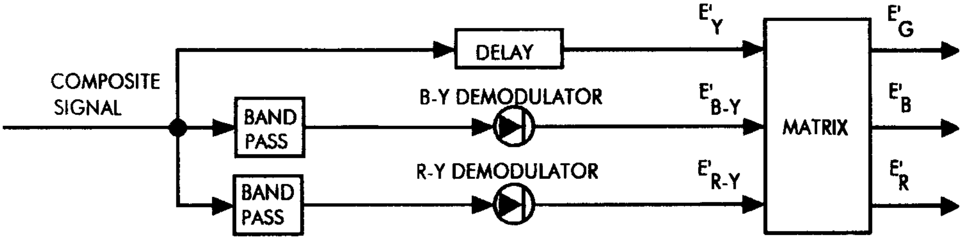


Figure 2.10 Simplified block diagram of generalized decoder.

suffered by the reduced-bandwidth color-difference signals and helps achieve proper timing of the luminance and chrominance signals at the input of the adder. Each of the band-limited color-difference signals is fed to a modulator. The two radiofrequency (RF) signals are added to the luminance signal to obtain the composite color signal. This basic encoder diagram is deliberately simplified, and in this form applies equally well to each of the three color television systems.

Figure 2.10 shows a simplified block diagram of a generalized decoder. To decode a color television signal into green, blue, and red components, the reverse generalized process is required. First, the composite signal has to be separated by filters into chrominance and luminance components. The chrominance component is subsequently demodulated in a manner peculiar to the respective color television system to yield the color-difference signals. The luminance signal is delayed to achieve proper timing with respect to the narrow-bandwidth color-difference signals. The three signals are fed to an active matrix. By a process of amplification, addition, and subtraction, the primary color signals are recovered at the output of the matrix. This basic decoder diagram is deliberately simplified, and in this form applies equally well to each of the three color television systems.

2.2.2 The NTSC system

The NTSC (National Television System Committee) color television system is a single-channel television concept. Luminance, chrominance, and synchronization information are combined to be transmitted in a 6-MHz RF channel originally specified for monochrome transmissions. The transmission of color takes advantage of the characteristics of the spectrum of monochrome video as detailed in Chap. 1. Essentially, the chrominance information is transmitted in the spectrum "holes" of the monochrome information. The concept uses a wideband (4.2-MHz) luminance signal and two narrowband chrominance signals.

The contemporary characteristics of this system, as defined in the SMPTE 170M standard, are summarized in Table 2.1.

The encoder processes a wideband (≥4.2-MHz) luminance (monochrome) signal and two narrowband color-difference signals of equal bandwidth. The color-difference signals may be B-Y and R-Y or I and Q, as in the original

TABLE 2.1 Summary of NTSC Signal Characteristics

1. Assumed chromaticity coordinates for primary colors of receiver	$\begin{array}{lcc} & x & y \\ \text{Green} & 0.310 & 0.596 \\ \text{Blue} & 0.155 & 0.070 \\ \text{Red} & 0.630 & 0.340 \end{array}$
2. Chromaticity coordinates for equal primary signals	Illuminant D_{65}: $x = 0.3127$; $y = 0.3290$
3. Assumed receiver gamma value	2.2
4. Luminance signal	$E'_Y = 0.587\,E'_G + 0.114\,E'_B + 0.299\,E'_R$
5. Chrominance signals	$E'_{\text{B-Y}} = 0.493\,(E'_B - E'_Y)$ and $E'_{\text{R-Y}} = 0.877\,(E'_R - E'_Y)$ or $E'_Q = E'_{B\text{-}Y}\cos 33^\circ + E'_{R\text{-}Y}\sin 33^\circ$ and $E'_I = -E'_{B-Y}\sin 33^\circ + E'_{R\text{-}Y}\cos 33^\circ$
6. Equation of complete color signal	$E_M = 0.925\,E'_Y + 7.5 + 0.925\,E'_{B\text{-}Y}\sin(2\pi f_{\text{SC}}t) + 0.925\,E'_{\text{R-Y}}\cos(2\pi f_{\text{SC}}t)$ or $E_M = 0.925\,E'_Y + 7.5 + 0.925\,E'_Q\sin(2\pi f_{\text{SC}}t + 33^\circ) + 0.925\,E'_I\cos(2\pi f_{\text{SC}}t + 33^\circ)$
7. Type of chrominance subcarrier modulation	Suppressed-carrier amplitude modulation of two subcarriers in quadrature
8. Chrominance subcarrier frequency, Hz	Nominal value and tolerance: $f_{\text{SC}} = 3{,}579{,}545 \pm 10$ Relationship to line frequency f_H: $f_{\text{SC}} = (455/2)f_H$
9. Bandwidth of transmitted chrominance sidebands, kHz	$f_{\text{SC}} \pm 620$ or $f_{\text{SC}}\ +620/-1300$
10. Amplitude of chrominance subcarrier	$G = \sqrt{(E'^2_{B-Y} + E'^2_{R-Y})}$ or $G = \sqrt{(E'^2_I + E'^2_Q)}$
11. Synchronization of subcarrier	Subcarrier burst on blanking backporch

1953 specifications of the NTSC system. The bandwidth of each of the color-difference signals may be 600 kHz or 1.3 MHz. The wider bandwidth is useful in studio environments where there is no significant bandwidth limitation. Transmission and reception constraints result in color television receivers using a 600-kHz chrominance bandwidth, hence the excess chrominance bandwidth is wasted. Figure 2.11 illustrates the chrominance bandwidth versus transmitted bandwidth relationship.

Each of the scaled color-difference signals modulates a subcarrier. The two subcarriers are of identical frequency but of different phase. The phase difference between the two subcarriers is 90°, so the original signals modulating the two carriers can be recovered without crosstalk. The two subcarriers are obtained from a common crystal-controlled oscillator. The type of modulation used is suppressed-carrier amplitude modulation. The modulation system is consequently called suppressed-carrier quadrature amplitude modulation. Since the subcarrier is suppressed, only the sidebands are obtained at the output of the modulators. This results in the complete cancellation of the chrominance signal when no colors are present.

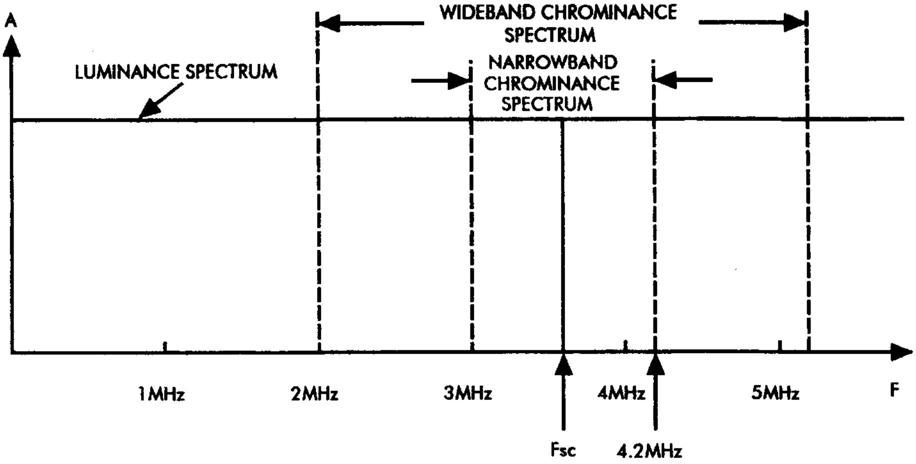


Figure 2.11 NTSC composite signal bandwidth.

The frequency of the chrominance subcarrier is an odd multiple of the half horizontal scanning frequency. This results in the interleaving of the luminance and chrominance spectra. The type of spectrum interleaving used in NTSC is called half-line offset. The frequency of the subcarrier is equal to

$$f_{SC} = \frac{455}{2} f_H = 3{,}579{,}545 \pm 10 \text{ Hz}$$

This leads to slightly modified horizontal (15,734.25 Hz) and vertical (59.94 Hz) scanning frequencies. These frequencies are within the capture range of the receiver scanning circuits.

Figure 2.12 shows the spectrum of an NTSC signal. Note a peak of energy around the suppressed subcarrier at 3.58 MHz. Figure 2.13 shows a detailed view of the spectrum around the suppressed chrominance subcarrier. Note the chrominance sideband components spaced at f_H intervals. Low-level luminance spectral components are interleaved at $f_H/2$ intervals. The subcarrier amplitude is 20 dB lower than its significant sideband components. Normally the subcarrier should not be visible. Its low-level presence is due to the low-energy subcarrier burst transmitted as a frequency and phase reference.

A burst of 9 cycles of frequency and phase reference subcarrier is transmitted during the backporch of the horizontal blanking interval. Figure 2.14 shows details of the horizontal blanking period with the subcarrier burst. The purpose of the burst is to synchronize the receiver local crystal oscillator. This oscillator feeds a reconstituted subcarrier to the synchronous B-Y and R-Y demodulators used for the recovery of the color-difference signals. The phase of the burst is 180° with respect to the system phase reference ($E'_B - E'_Y$).

Figure 2.15 shows a simplified block diagram of an NTSC encoder using B-Y/R-Y color-difference signals. Green, blue, and red signals are fed to a resis-

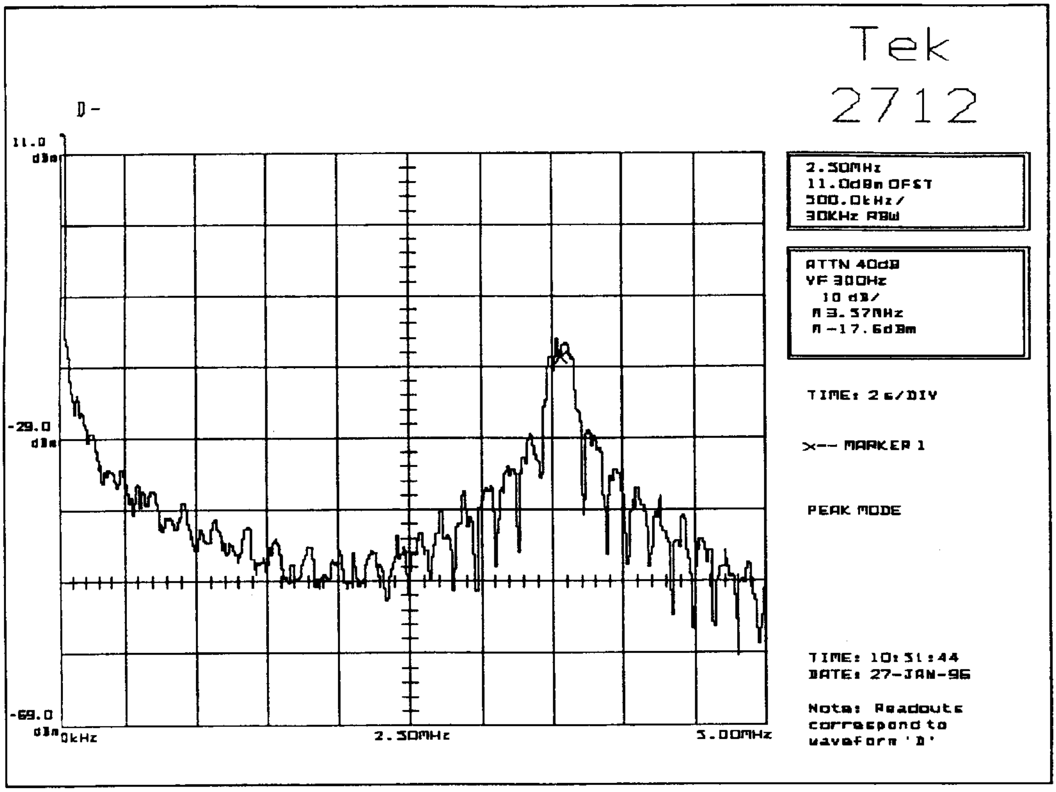


Figure 2.12 Spectrum of 100/7.5/100/7.5 NTSC color bars signal. Note a peak of energy around the suppressed 3.58-MHz subcarrier. Horizontal resolution: 500 kHz/division.

tive matrix that algebraically combines percentages of these primary color signals to form the luminance (Y) signal and the two color-difference signals. Each of the color-difference signals is band-limited before being fed to the respective balanced modulators. A 3.58-MHz subcarrier feeds the B-Y modulator and, through a 90° phase-shift network, the R-Y modulator. The Y signal is delayed to compensate for the chrominance delay introduced by the color-difference low-pass filters. The adder combines the luminance, chrominance sidebands, composite sync, and a 180° phase-shifted gated subcarrier burst into a composite color signal.

Figure 2.16 shows a phase-domain representation of the $E'_{B\text{-}Y}$ (reference) subcarrier and the $E'_{R\text{-}Y}$ subcarrier (+90°). A third subcarrier identifies the synchronizing burst (+180°).

Figure 2.17 shows a vector representation of the chrominance subcarrier modulation process. A given color, described by a given set of $E'_{B\text{-}Y}$ and $E'_{R\text{-}Y}$ signal values, is represented by two amplitude-modulated subcarriers in phase quadrature. The instantaneous values of the two modulated subcarri-

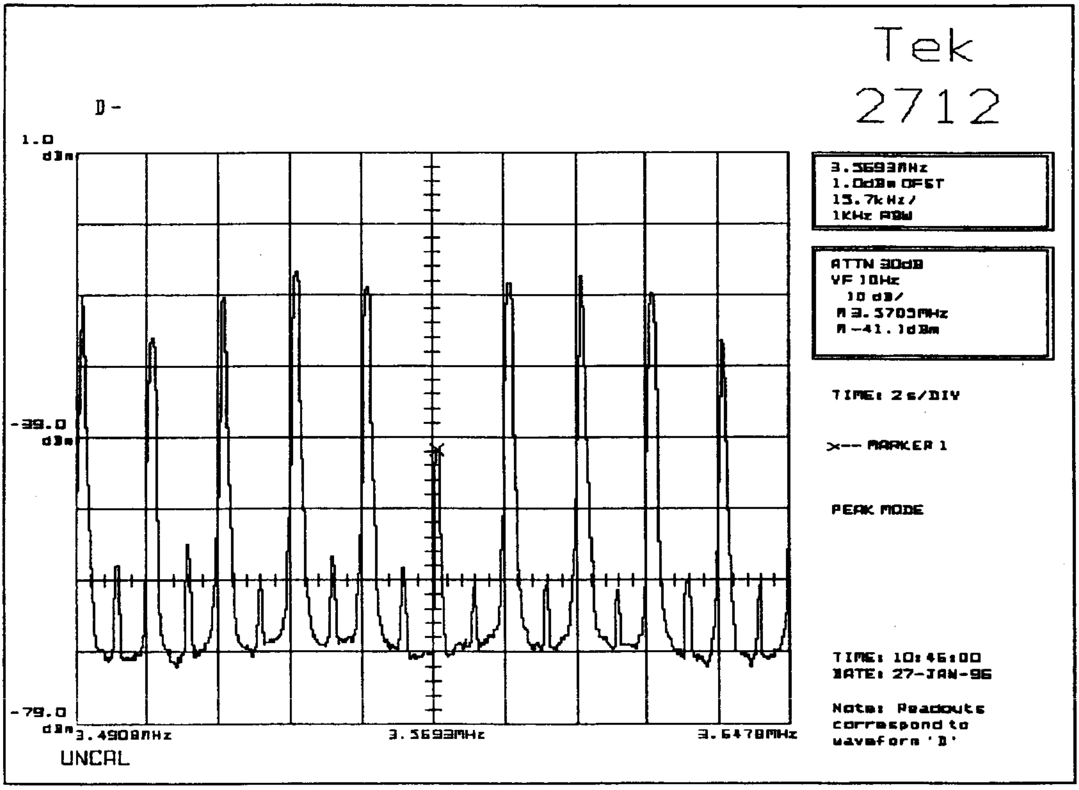


Figure 2.13 Detailed spectrum of NTSC 100/7.5/100/7.5 color bars signal around the suppressed chrominance subcarrier. Note chrominance sideband components at f_H intervals. Low level luminance spectrum components are interleaved at $f_H/2$ intervals. Horizontal resolution: 15.7 kHz/division.

ers result in a vector described by its amplitude and phase angle with respect to the B-Y subcarrier reference phase. The vector amplitude represents the color saturation and its phase angle represents the hue.

Figure 2.18 shows a 100/7.5/100/7.5 (100%) color bar-signal waveform resulting from the addition of luminance and chrominance components. Note that the peak positive signal excursion is 130.8 IRE, which is beyond the overload level of a television transmitter. Figure 2.19 shows a vectorscope display of the 100% color bar signal.

Figure 2.20 shows the waveform of a 75/7.5/75/7.5 (75%) color bar signal resulting from the addition of luminance and chrominance components.

Tables 2.2 and 2.3 list the details of the color bar signal luminance and chrominance values as well as the phase angles of the six colors.

The 75/7.5/75/7.5 color bar signal is used for transmitter tests. Studio equipment can accept either of the two color bar signals. It is important to remember that peak amplitude green, blue, and red primary signals will generate composite color signal levels equivalent to the 100% color bar signal. Since

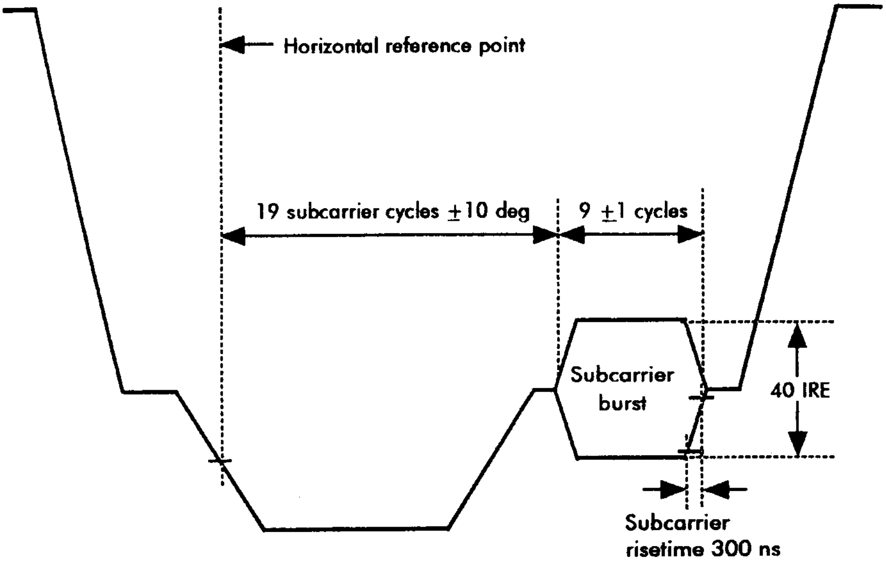


Figure 2.14 NTSC horizontal blanking interval showing details of color burst.

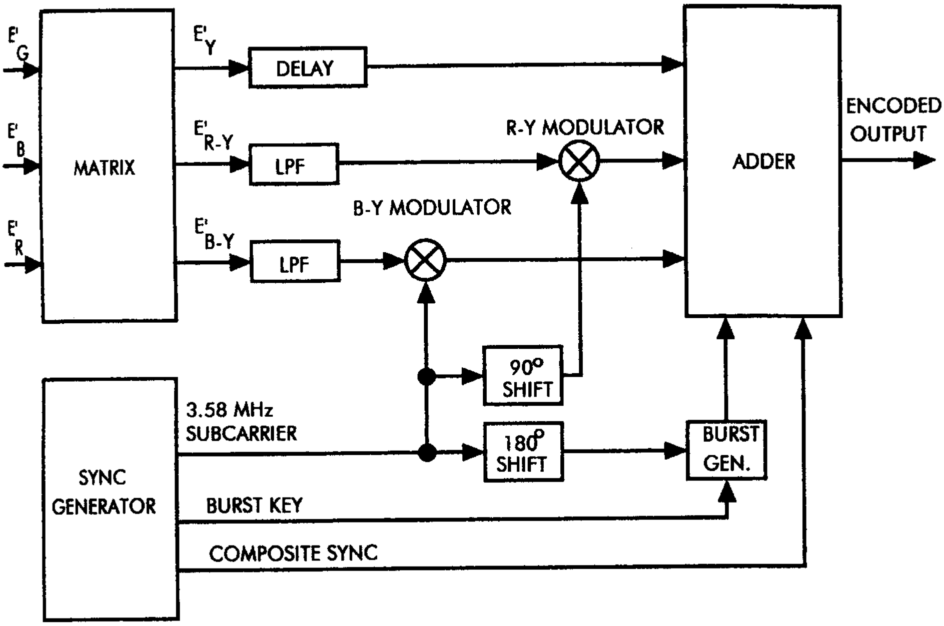


Figure 2.15 Simplified block diagram of NTSC B-Y/R-Y encoder.

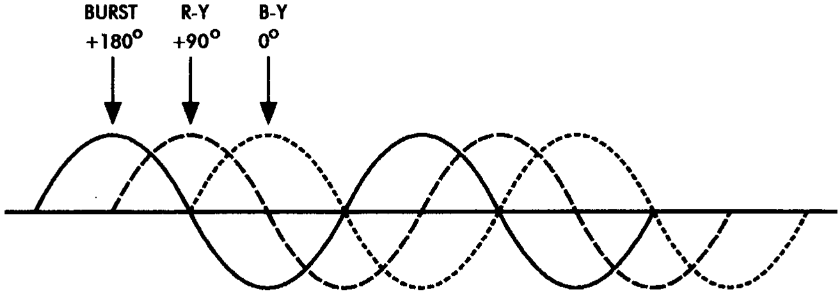


Figure 2.16 Phase domain representation of the two significant equal-frequency subcarriers. The third subcarrier represents the synchronizing burst.

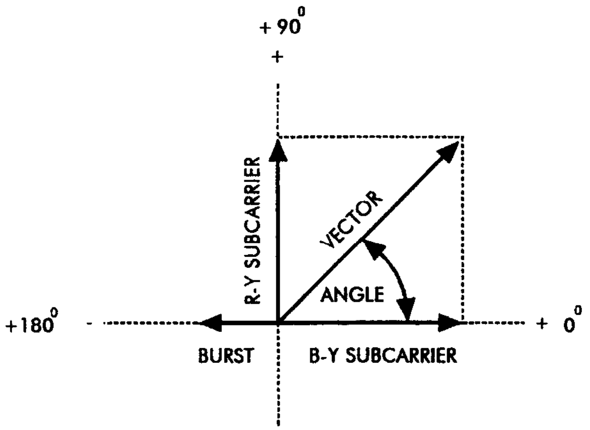


Figure 2.17 The instantaneous amplitudes of the subcarrier result in a vector whose amplitude represents saturation and phase represents hue.

there are no highly saturated yellow and cyan colors in nature, the probability of transmitter overload under normal operating conditions is very low. Problems occur, however, with synthetic signal sources, such as character generators and graphic systems, which can create primary signals resulting in excessive amplitude composite color signals and lead to transmitter overload.

Figure 2.21 shows a simplified block diagram of an NTSC B-Y/R-Y decoder. The chrominance sidebands are separated through a bandpass filter and fed to two synchronous demodulators as well as to a burst separator. The burst separator is gated by a burst key derived from the horizontal sync. Its output synchronizes a local crystal-controlled subcarrier generator through a phase-locked loop. The subcarrier generator feeds the B-Y demodulator and, through a 90° phase shift network, the R-Y demodulator. A "hue" control allows for the manual adjustment of the phase of the reconstituted subcarrier with respect to that of the color burst to obtain the correct phase relationship. The demodulated color-difference signal as well as the delayed luminance signal are fed to

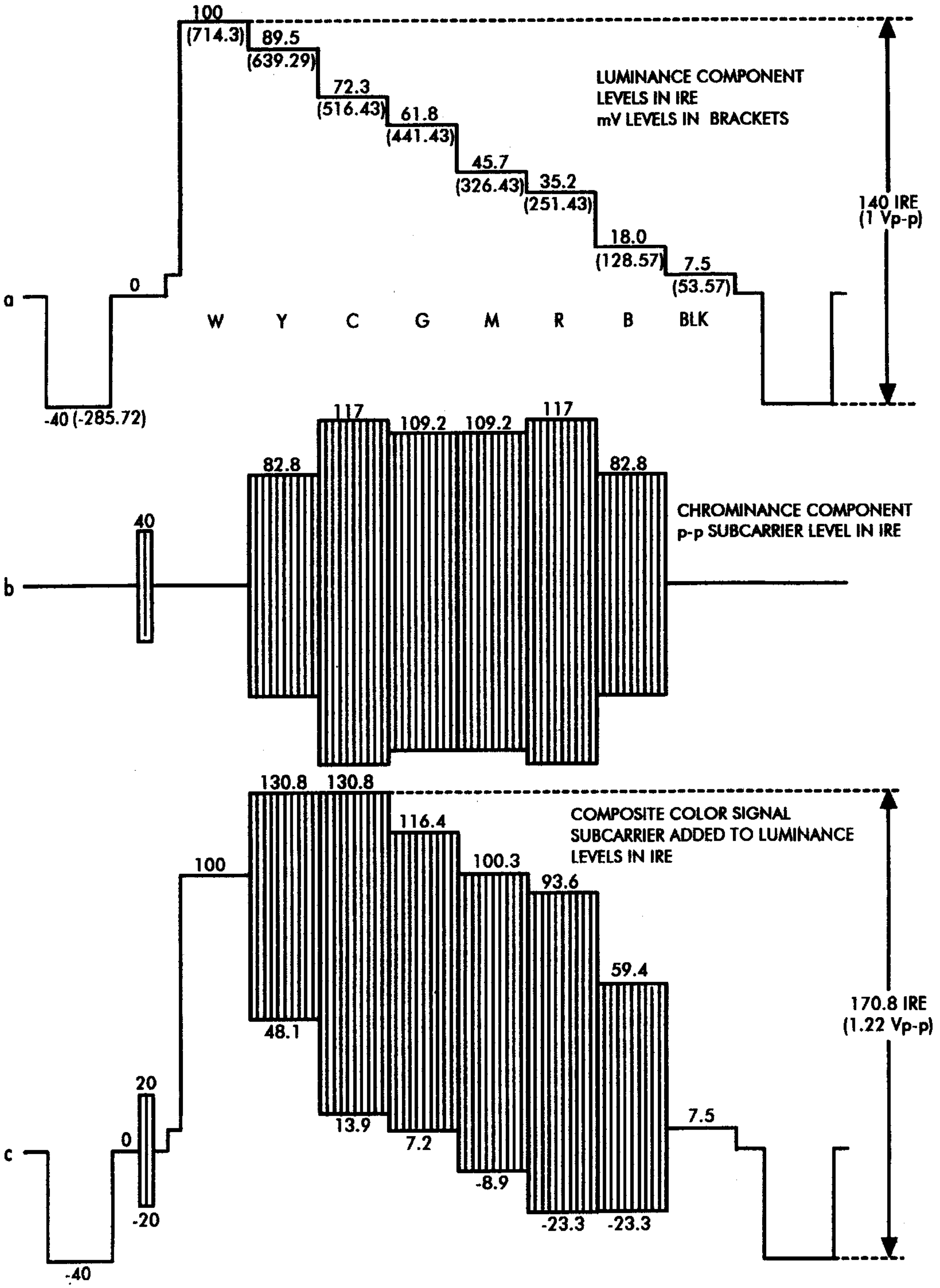


Figure 2.18 NTSC 100/7.5/100/7.5 color bars signal waveform.