COLOR TELEVISION THEORY

AND

TESTING PROCEDURES

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ABSTRACT

COLOR TELEVISION THEORY AND TESTING PROCEDURES

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In this report, the techniques and equipment employed for measuring and testing the signal chain in television broadcasting are reviewed.

A discussion of the standards of picture quality may seem irrelevant when the aim should be to transmit pictures of the highest standard that modern technology permits; and one would be inclined to agree if the economics have not to be considered.

As the equipment standard increases, the cost increases at a far greater rate and not merely the capital cost of an improvement, but also the cost of maintaining the higher standard.

In this report Chapter I describes how the color composite video signal is obtained and how the colorimetry works in a television system. Chapter II describes the test equipment for video quality measurement techniques and finally, Chapter III describes the most important video test procedures. It describes differential gain, differential phase, amplitude frequency response, 2T sine square pulse K factor, chrominance-to-luminance ratio and timing, signal to noise ratio and, finally, return loss.

TABLE OF CONTENTS

INTRODUCTION

The primary role of measurements in television broadcasting may be defined broadly as the checking and standardisation of all the apparatus and circuits in the signal chain, starting with the signal source (camera, video tape recorder, etc.) and ending with the transmitted signal, to ensure that the predetermined standards of quality are maintained. One would like to extend this to the very end of the chain, the screen of the viewer's home receiver; but, of course, this is quite impracticable except in so far as the planning and siting of the transmitters affect the received signal.

Measurements in television affect every aspect of operational engineering, and markedly influence cost and efficiency. It is important that correct measurements be carried out at every step, so as to maintain the system within the chosen tolerances, and that the most appropriate equipment and procedures be used.

The overall problem is threefold: the determination of the various types of distortion which can affect the final picture, the allocation of suitable tolerances to each of the components in the signal chain for each of these distortions, and the actual techniques and equipment employed for measuring the various distortions.

In the formative years of television broadcasting, standards were necessarily set in a largely empirical manner based on the experience and judgment of individual engineers. Although this could not be economically efficient, the relatively small scale of operations concealed the fact. Later, the need for guidance and standardisation on such matters led to these being provided by the CRTC (Canadian Radio and Television Commission).

CHAPTER 1

COLOR TELEVISION THEORY

1.1 Introduction.

The color system employed in Canada, U.S., Mexico, Japan and selected countries in Latin America is called the NTSC system after the National Television Standards Committee formed in 1950 to formulate a color system for the U.S.

The first requirement for a color system was monochrome compatibility, i.e., a color signal picked up by a black and white receiver must produce the brightness content of the signal correctly in black and white. The color information must cause no visible, unwanted component on the black and white receiver. The second requirement was reverse compatability, i.e., a black and white signal picked up by a color receiver must reproduce the signal correctly in shades of grey with no spurious color component. The third requirement was the use of existing TV bandwidths for pictures and sound carrier spacings as shown in Fig. 1-1.

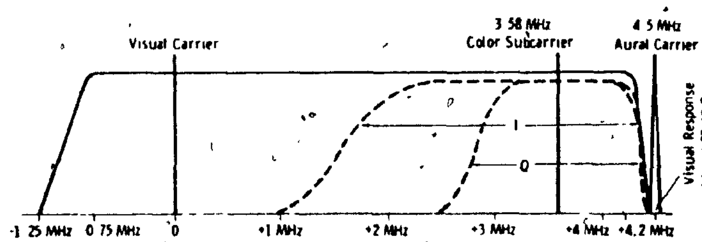


FIG. 1-1: BANDWIDTH OF COLOR PICTURE SIGNAL

Finally, the fourth requirement for a color system was transmission of color information only when color was being scanned, i.e., no color information transmitted when the color camera was scanning white, black, or shades of grey. When color information was being scanned the detail of color information transmitted should not exceed the color resolving capability of normal vision. The color system must also be capable of transmitting the complete range of color that the viewer with normal color vision can perceive.

1.2 Characteristics of Color

A colored object has three basic characteristics:-

a) Brightness (or luninosity).

b) Saturation (vividness, purity, or freedom from dilution by white).

c) Hue (wavelength).

Brightness of a color is a function of the response characteristics of the human eye. The eye has maximum sensitivity to green, moderate sensitivity to red and poor sensitivity to blue. Green energy produces high brightness and blue energy produces low brightness.

Saturation of a color is an indication of the purity of a color or absence of white. Saturated red (100% saturation) has no blue or green component. If 75% white is added, the resultant red (25% saturation) becomes pink. Pure colors have maximum saturation, pastel colors have much lower saturation.

Hue of a color is an indication of its predominant wavelength and therefore the color the eye perceives.

Of the three characteristics listed above, only brightness information may be used by a black and white receiver. All three characteristics must be available to the color receiver.

1.3 Additive Color System

In a color television system light is transformed into suitable voltage waveforms which are processed and transmitted. The receiver reverses the process and converts the voltage waveforms back to light. Three phosphors are used and depending on relative excitation can produce white, grey, black or any of the colors in the visible portion of the spectrum. By placing the phosphors very close together and making the individual phosphor dots very small (0.010" dia.) the dot structure of the picture is not visible at normal viewing distance and the color and brightness at any given instant is proportional to the absolute excitation of each of the three phosphor dots with respect to the other. Because the light is being generated at the color tube faceplate the system is an additive system of color (mixing of lights), unlike the subtractive process we are normally used to.

Normal color vision (color TV excluded) is a subtractive process. Visible light, sunlight or artificial light falls on a colored object. We perceive the color (orange for example) because the object absorbs all wavelengths of visible light except orange which is reflected. This is true not only of ojbects perceived in nature but of colored printing, color film, paints, etc.

The rules for an additive system, where discrete wavelengths of three primary colors are generated, are exactly the opposite of those for subtractive color. The primary colors are:

Red - of a wavelength of 615 µm (1 µm = 1 x 10^{-9} meters)
Green - of a wavelength of 532 µm
Blue - of a wavelength of 470 µm

These three primary colors were chosen because filters for the color camera for these wavelengths could be made, but more important, color phosphors with sufficient light output could be made for these wavelengths for use in the color picture tube.

1.4 Rules of Color Addition

While any three primary colors could have been chosen for the NTSC system, the three that were chosen give the widest gamut of color reproduction, about one-third greater than can be achieved by color printing or color film. The requirements for a primary for any color additive system is that it should not be duplicated by any combination of the other colors. The result of addition is given below:-

Red	+	Blue	+	Green	=	White
Red	+	Blue			=	Magenta
Magenta	+	Green			=	White
Red	+	Green			=	Yellow
Yellow	+	Blue			=	White
Green	+	Blue			=	Cyan
Cyan	+	Red			=	White

Yellow is the complement of Blue.
Magenta is the complement of Green.
Cyan is the complement of Red.

The accompanying picture displays the basic rule of Red, Green and Blue (R, G, B) additive color, along with the light spectrum and the luminosity response of the eye.

1.5 Make-up of the Color Picture Signal

The color picture signal represents the characteristics of color. This signal consists of two separate ones:- the luminance and the chrominance. Both must be transmitted correctly to meet the requirements stated in Section 1.1. The luminance signal carries the brightness information of the color scene and the chrominance of the color information (saturation and hue). In the following block diagram the basic components of a color camera are shown:-

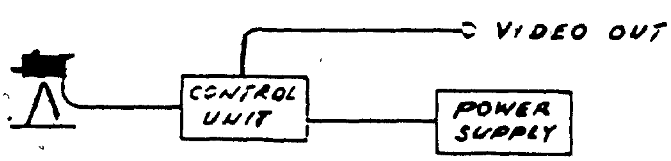


FIG. 1-2:- BLOCK DIAGRAM OF A TV CAMERA

It consists of three basic components:- the camera head, encoder and power supply. The camera head is that section which transforms the light from the televised scene into three primary electrical signals:- red, green and blue.

1.6 Derivation of Brightness or Y (Luminance Signal)

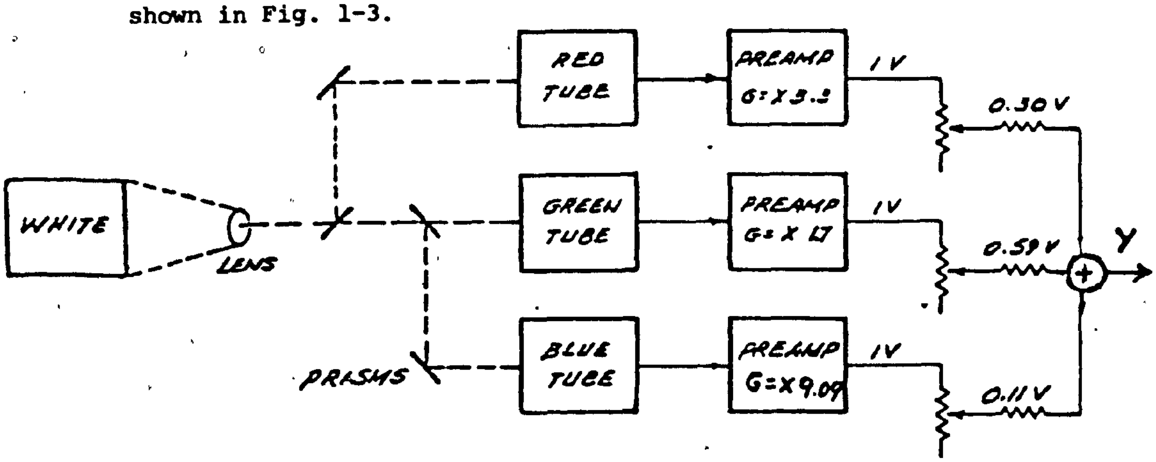
To meet the requirement of black and white compatibility, a full bandwidth signal representing the brightness components only of the colored scene must be derived from the color camera.

Based on the sensitivity of the eye, the brightness component of an RGB camera has been defined as:-

$$Y = 0.30R + 0.59G + 0.11B$$

As the sensitivities of the three pickup tubes are not the same, the gains of the associated preamps are adjusted so that when peak white is being scanned each preamplifier produces one volt peak-to-peak at its output, giving Y a value of 1V peak-to-peak. These preamplifiers are called gamma correction preamplifiers.

This mixture yields the most accurate monochromatic rendition of colored objects. A simplified block diagram for derivation of Y is shown in Fig. 1-3.



$$\text{Red Preamp Gain} = \frac{1.0}{0.30} = 3.3$$

$$\text{Green Preamp Gain} = \frac{1.0}{0.59} = 1.7$$

$$\text{Blue Preamp Gain} = \frac{1.0}{0.11} = 9.09$$

FIG. 1-3. SIMPLIFIED BLOCK DIAGRAM FOR DERIVATION OF Y

1.7 Derivation of Saturation and Hue (Chrominance)

For purposes of color transmission, a chrominance signal is required. This signal must convey energy which represents the primary colors. Color could be trans-mitted by three separate signals each representing a primary color, but a channel width of at least 12.75 MHz would then be required. Since this would eliminate compatability, color has to be represented in some other manner in order to utilize the standard 6 MHz channel bandwidth. To meet this requirement, two of the primary signals (Red and Blue) are mixed with the luminance signal in order to provide two new signals. These are known as color difference signals. They are generated in the encoder by adding -Y to the original color signals, as shown in Fig. 1-4.

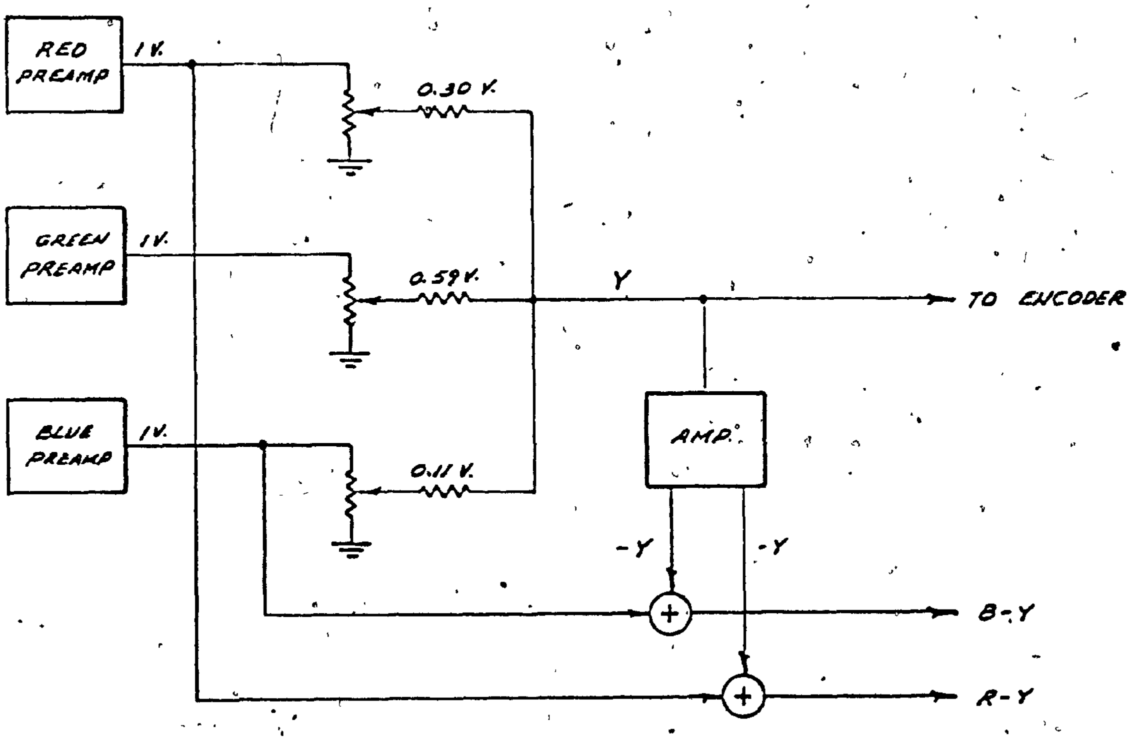


FIG. 1-4: BLOCK DIAGRAM FOR DERIVATION OF DIFFERENCE SIGNALS

Note that the complete Y signal is subtracted from the red and blue signals, therefore:

$$R - Y = 0.70R - 0.59G - 0.11B \quad \ldots (1.1)$$

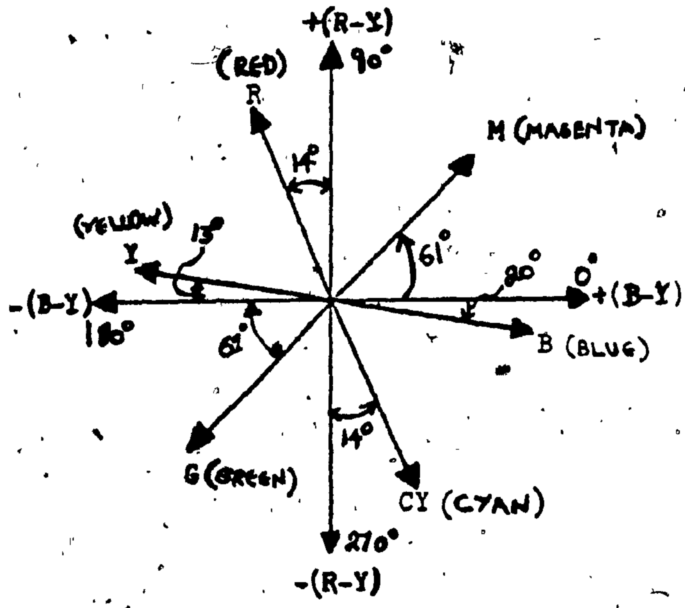
$$B - Y = -0.30R - 0.59G + 0.89B \quad \ldots (1.2)$$

The G-Y signal is not derived in the encoder because it can be re-constructed in the receiver by a combination of R-Y and B-Y, as follows:

$$G\text{-}Y = \frac{-0.30}{0.59}(R\text{-}Y) - \frac{0.11}{0.59}(B\text{-}Y) \quad \ldots (1.3)$$

$$G\text{-}Y = -0.51\,(R\text{-}Y) - 0.19\,(B\text{-}Y) \quad \ldots (1.4)$$

Fig. 1-5 shows the vector relationships of the 100% saturated colors with respect to B-Y and R-Y.



	R-Y	B-Y
R	+0.7	-0.3
G	-0.59	-0.59
B	-0.11	+0.89
CY	-0.7	+0.3
M	+0.59	+0.59
Y	+0.11	-0.89

Fig. 1-5: VECTOR RELATIONSHIPS OF 100% SATURATED COLORS

1.8 Choice of NTSC Color Sub-Carrier Frequency

The color subcarrier frequency choice was dictated by a number of considerations.

1. It had to be high enough to modulate ± 1.5MHz for the I signal and ± 0.5MHz for the Q signal.
2. It had to be high enough to provide minimum interference on a black and white receiver.
3. It had to bear an odd harmonic relationship with 1/2 the line rate and its beat with the sound carrier had to produce a minimum of deliterious effects.

Initial calculations indicated that a frequency 455 times half the line rate would be ideal. This frequency is:-

$$f_{sc} = \frac{15750}{2} \times 455$$

$$= 3.583125 \text{ MHz}$$

Unfortunately, this frequency produces an even harmonic of the line rate when it beats with the sound carrier of 4.5MHz, producing a visible picture interference depending on the audio content. A slight offset of the 4.5MHz sound carrier would have cured the problem but all black and white receivers would have had to be modified. For this reason the 4.5MHz sound carrier could not be used. Instead, the horizontal frequency was changed slightly from 15,750Hz to 15,734.264Hz. This change is well within the pull range of black and white horizontal automatic frequency control (AFC) circuits. As the field rate is counted down from the line rate the original 60Hz became 59.95Hz.

Taking the 455th harmonic, or half the new line frequency, gives:-

$$f_{sc} = \frac{15{,}734.264 \times 455}{2}$$

$$= 3.579545 \text{ MHz}$$

This subcarrier frequency produces a difference frequency which is an odd harmonic of the line rate when it beats with the 4.5MHz sound carrier and, therefore, sound interference is minimal.

1.9 I and Q Signals

Studies of human vision have shown that the response of the normal eye is not the same for all color combinations. Finer chrominance detail may be resolved in (approximately) orange and cyan hues than in green and magenta. To take advantage of this fact, the two chrominance subcarries are advanced by 33° from their (R-Y) and (B-Y) axes and they are termed I and Q axes respectively. Fig. 1-6 shows I and Q with respect to the other colors.

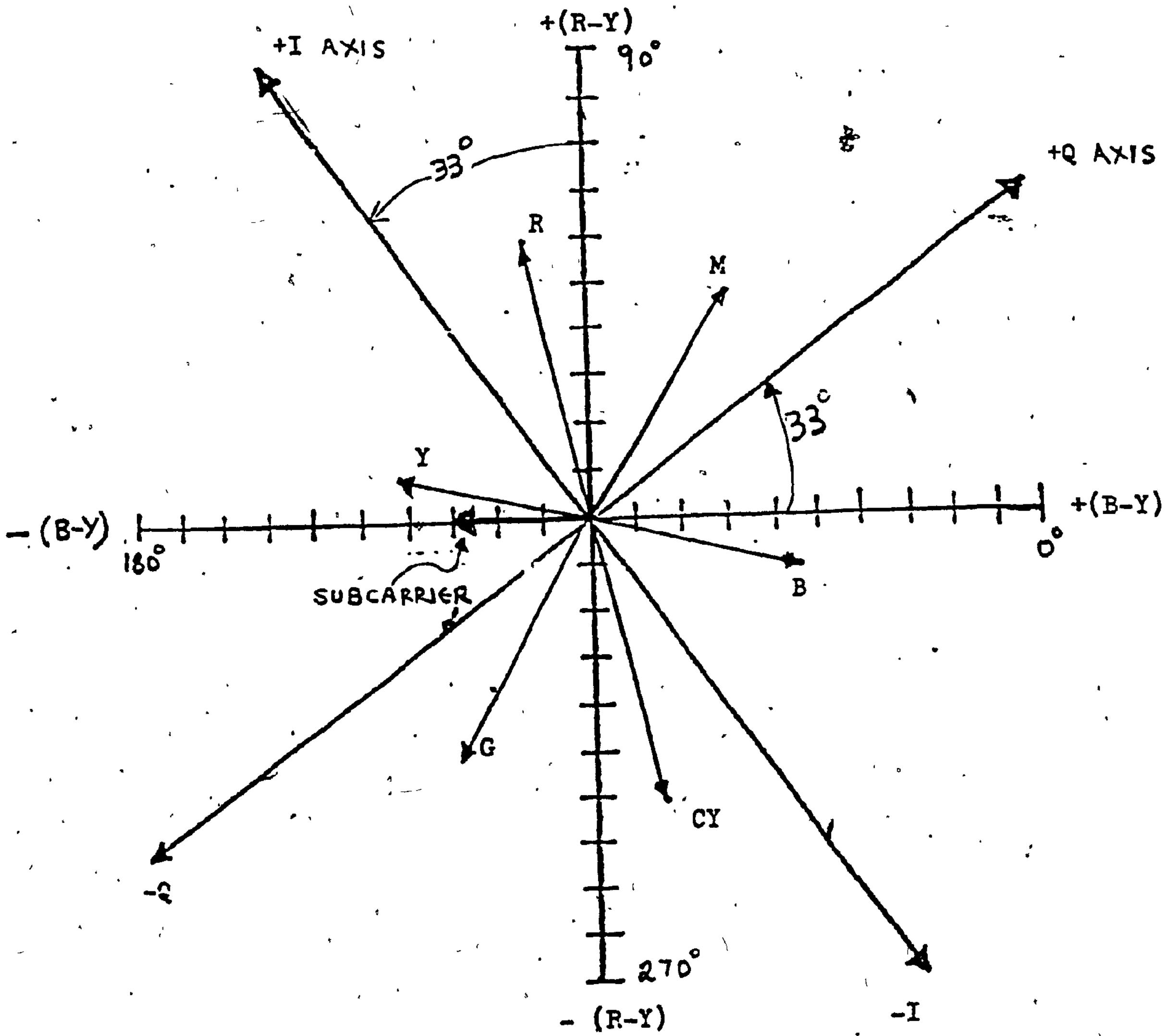


Fig. 1-6: I AND Q VECTORIAL PRESENTATION

The specifications for I and Q may be determined by projecting the (R-Y) and (B-Y) signals into the I and Q directions. From Fig. 1-7 we find that

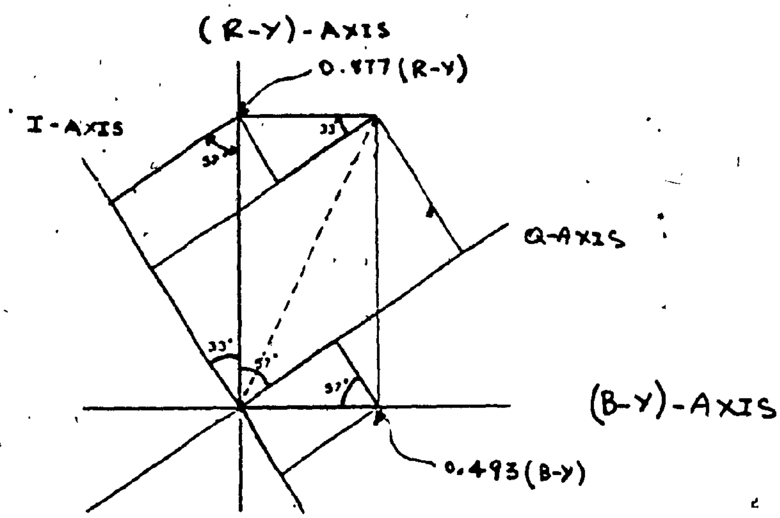


Fig. 1-7: I AND Q VECTOR ANALYSIS

$$I = 0.74\ (R-Y) - 0.27\ (B-Y) \qquad (1.5)$$

$$Q = 0.48\ (R-Y) + 0.41\ (B-Y) \qquad (1.6)$$

$$R = 1.00\ Y - 0.96\ I + 0.62\ Q \qquad (1.7)$$

$$G = 1.00\ Y + 0.27\ I - 0.65\ Q \qquad (1.8)$$

$$B = 1.00\ Y + 1.11\ I + 1.70\ Q \qquad (1.9)$$

Hence the I and Q signals are used to modulate the subcarrier, the I-signal using the high definition channel of 1.5 MHz and Q signal the low definition channel of 0.5 MHz. The luminance and I and Q signals are shown in Fig. 1-8. Also Fig. 1-8 shows the complete video signal bandwidths.

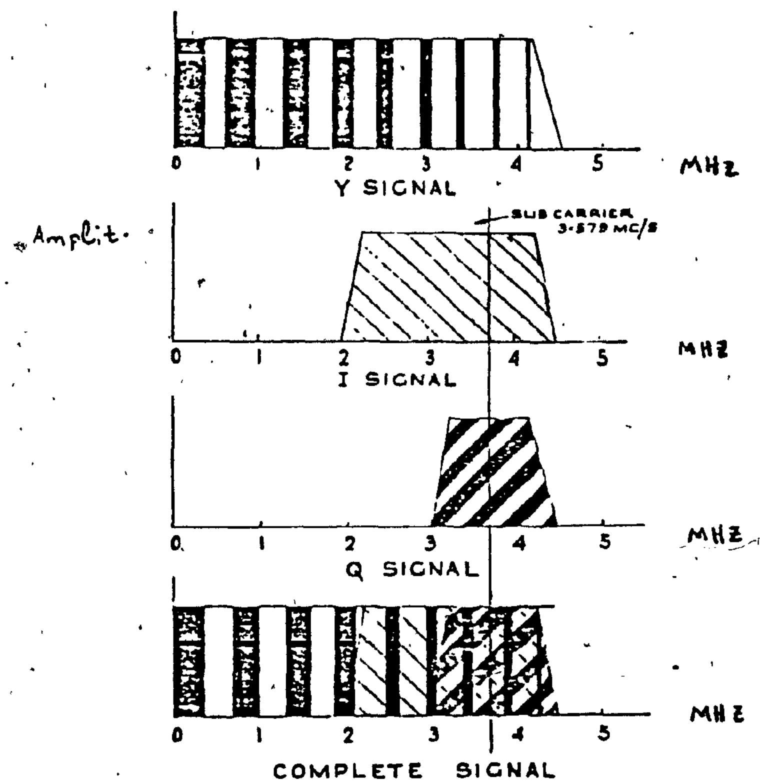


Fig. 1-8: MONOCHROME, I AND Q SIGNALS BANDWIDTHS.

1.10 Transmission of Chrominance Signals

Having fitted the subcarrier into the monochrome video band it is now necessary to modulate this in some way so that it carries two color-difference signals, I and Q. Actually, two carriers are used of the same frequency but with a phase displacement of 90°, one carrier being amplitude modulated with one chrominance signal and the other carrier being amplitude modulated with the other signal. Fig. 1-9 shows the I and Q modulators.

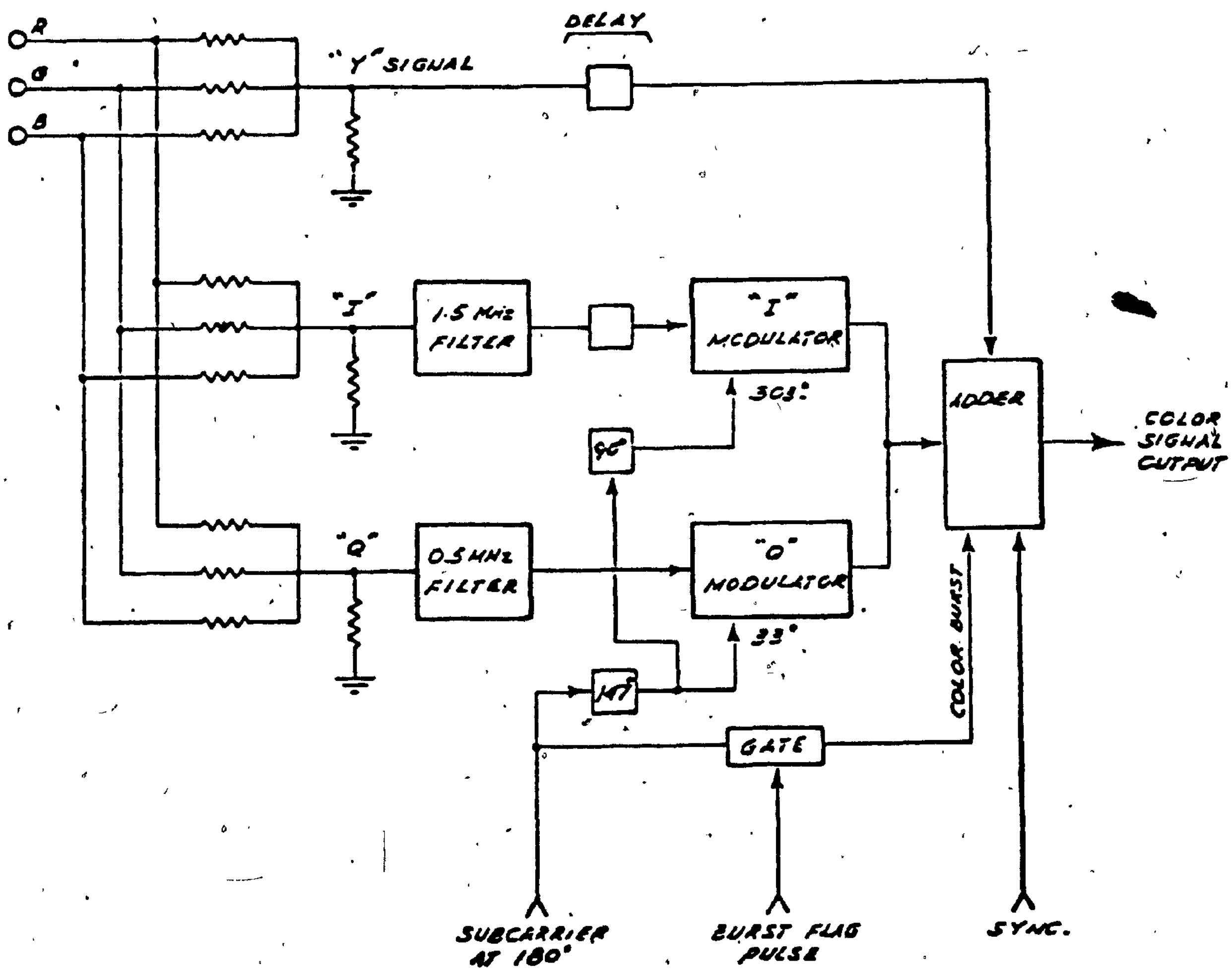


FIG. 1-9: I AND Q MODULATORS

The type of amplitude modulation used is known as "suppressed carrier modulation". In normal amplitude modulation, when the modulating voltage is zero, there is a carrier output voltage value A as in Fig. 1-10. When the modulating voltage is positive,

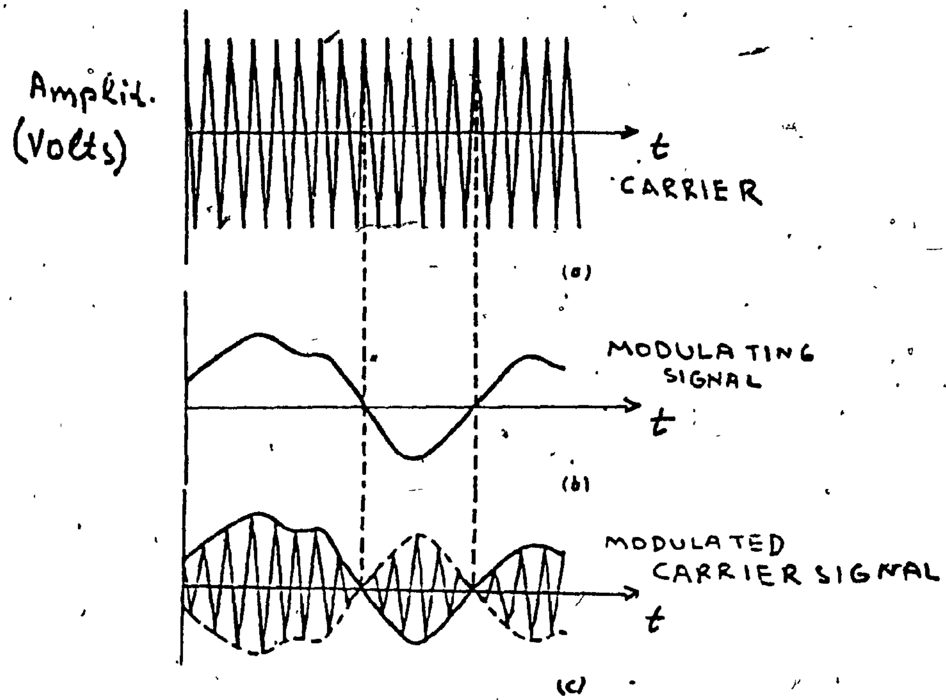


FIG. 1-10 NORMAL AMPLITUDE MODULATION

the carrier amplitude is increased and when it is negative the carrier is decreased. In both cases the increase and decrease are proportional to the modulating voltage. In a balanced modulator the output is as in Fig. 1-11. When the modulating voltage is zero there is no carrier output; when the modulating voltage goes positive the carrier increases in proportion to the modulating voltage. When the modulating voltage is negative again, the carrier is increased in proportion to the modulating voltage.

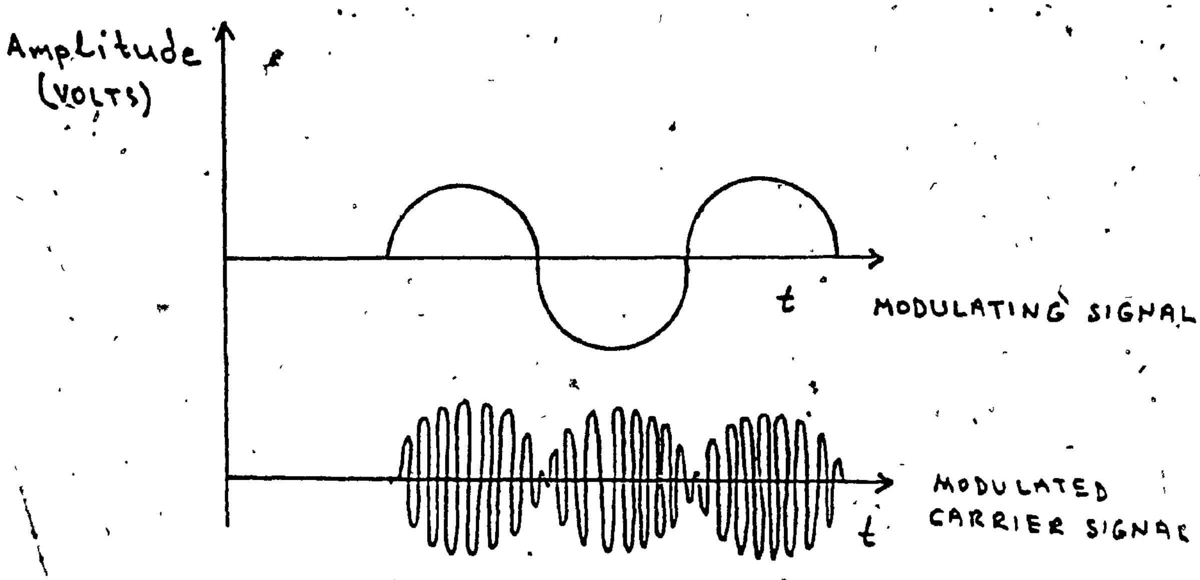


FIG. 1-11: SUPPRESSED CARRIER MODULATION

When the two different signals, separately amplitude modulated, are combined to form the resultant chrominance signal, the amplitude and phase of the signal vary in accordance with variations in the modulating signals I and Q. A change in amplitude of the chrominance signal represents a change in color saturation and a change in phase represents a change in hue.

1.11 The Composite NTSC Color Video Signal

Entering the transmitter or Video Tape Recorder (VTR), the composite NTSC color video signal may be divided into five components:-

1) Luminance
2) Chroma
3) Blanking
4) Sync
5) Color Burst

Luminance is the portion of the signal which will be used by black and white receivers to display the brightness information of the color camera signal. It consists of the following proportions of the three pickup tubes:-

$$Y = 0.30R + 0.59G + 0.11B \quad \text{..........} \quad (10)$$

It will be combined with the decoded color difference signals in the color receiver to give the original RGB signals which existed at the color camera outputs before encoding.

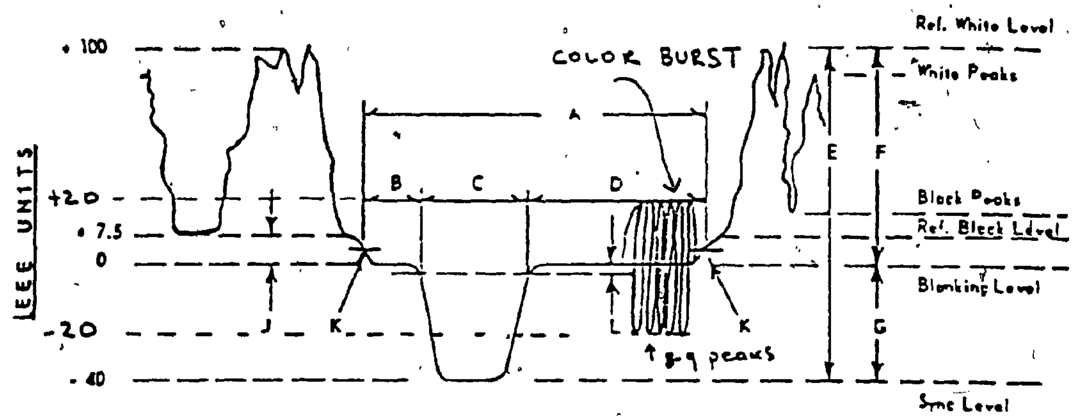
Chroma or chrominance consists of sideband information generated by a suppressed subcarrier modulator which is quadrature modulated by a wideband color difference signal (I) and a narrow band color difference signal (Q). The instantaneous phase of the chroma signal defines hue; the instantaneous amplitude of chroma defines saturation. The chroma signal cancels out in a black and white receiver because of the 1/2 line offset between subcarrier and line rate causing the chroma phase to reverse itself at a frame rate. The chroma signal in a color receiver is decoded to its original (R-Y) and (B-Y) components; the mission (G-Y) is developed by combining portions of R-Y and B-Y (see Section 1-7) and the three color difference signals (R-Y); (G-Y) and (B-Y) are combined with the luminance signal +Y to give R, G & B signals to drive the individual guns of the tricolor shadow mask tube.

Blanking, as in a black and white receiver, cuts off the beam in the receiver during horizontal and vertical retrace.

Sync, as in a black and white receiver, keeps the receiver in horizontal and vertical synchronization with the transmitter.

Color Burst consists of 8 - 11 cycles of the 3.579545 MHz subcarrier inserted in back porch of horizontal blanking at an amplitude of 40 IEEE divisions peak to peak. Its function is to phase lock a 3.579545 MHz crystal oscillator in the color receiver to the encoder to permit correct resultant hue on the color receiver after decoding.

Fig. 1-12 shows the composite [1] video signal identifying each item:



ITEM	DESCRIPTION	DURATIONS (1) % H	MICROSECONDS (Nominal)	RANGE
A	Horizontal-Blanking Interval	17.8	11.00	10.48 – 11.10
B	Front Porch (2)	2.0	1.27 min.	1.27 – 2.00
C	Horizontal-Sync Pulse	7.5	4.75	4.44 – 5.08
D	Back Porch		5.00	4.10 – 5.47
-	Rise and Decay Times of Items A and C	0.3 max.	0.20 max.	

ITEM	DESCRIPTION	AMPLITUDE VOLT	RANGE	IEEE UNITS	RANGE
E	Peak-to-Peak Amplitude	1.0		140	
F	Picture Amplitude	0.71	0.695 – 0.725	100 (±2)	98 to 102
G	Horizontal-Sync Pulse Amplitude	0.29	0.260 – 0.320	40 (±4)	-36 to -44
J	Setup	0.053	0.036 – 0.071	7.5 (±2.5)	5.0 to 10.0
K	Half-Setup Point	0.025		3.75 (±1.25)	2.5 to 5.0
L	Negative Reading Point	0.029		-4	

(1) H = one Line = 63.5 microseconds

(2) Front Porch shall be kept as close to the min. value as possible in order to provide enough Back Porch for proper clamping.

Fig. 1-12: COMPOSITE VIDEO SIGNAL

CHAPTER 2

WAVEFORM AND VECTORSCOPE MONITORS

2.1 INTRODUCTION

The waveform and vectorscope monitors are instruments which are used to measure the video signal, signal levels, insertion test signals, line-repetitive test signals, hum interference, and often random noise as well.

The waveform monitor is a high standard of performance which carries out a number of specialised functions under operational conditions, and it is consequently imperative that no time should be lost by the operator in having to work out how to use the instrument for a particular purpose, or in precise adjustments of the controls to obtain the required display. Anything which simplifies the operation is likely to reduce errors, particularly since it may have to be used on occasions under conditions of stress or local difficulty.

The vectorscope differs completely from the waveform monitor since its primary function is to provide a vector display of the amplitudes and relative phase angles of the chrominance components of the video signal, thus making it possible to determine, with a standardized signal, whether the encoding process has been correctly carried out.

2-2 WAVEFORM MONITOR

The waveform monitor is a specialized oscilloscope with special triggering and vertical characteristics for accurate measurement of the composite video signal. Fig. 2-1 shows a waveform monitor.

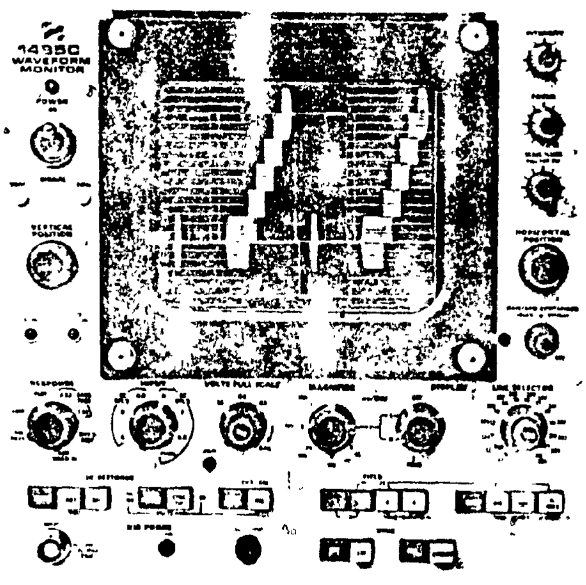


FIG. 2-1: WAVEFORM MONITOR

Waveform monitors must display subtle errors which accumulate in complex systems to become visible errors to the TV viewer. Because one must see subtle errors, waveform monitor vertical amplifiers have very carefully controlled responses necessary for video system signal fidelity.

The waveform monitor performs two vital fuctions:

1. It is used to measure systems performance.
2. It is used to monitor picture signal.

Any video component of the composite video signal that can be displayed in time reference can be defined in terms of amplitude, period and duration with a waveform monitor. Chroma, luminance and sync are among the video components that are often measured.

Most of the waveform measurement techniques described in this report are based on the Institute of Electrical and Electronics Engineers' scale units which is shown in Fig. 2-2. A video signal with amplitude of one volt corresponds to a signal with amplitude of 140 IEEE units.

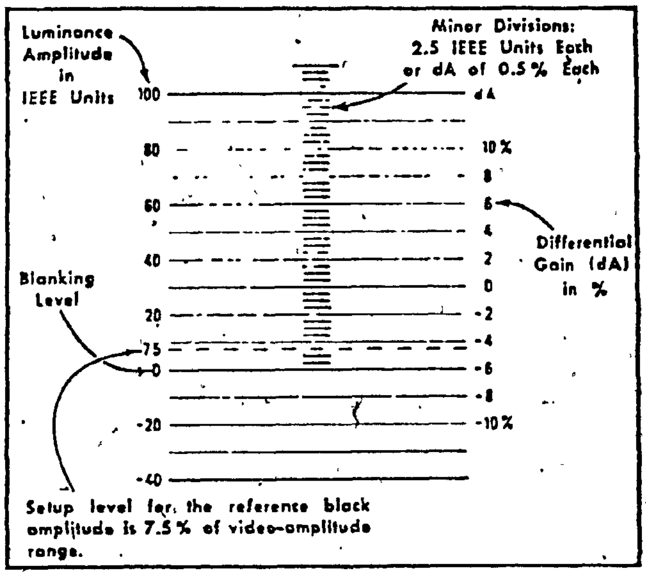


FIG. 2-2: The I.E.E.E. SCALE UNITS

2-3 VECTORSCOPE

Vectorscopes are used to display and examine the chrominance signal. The vectorscope is an oscilloscope with a circular time base. It displays a polar plot in which the radius is a function of chrominance amplitude and the angle is a function of chrominance phase. The chrominance phase is measured with respect to burst or a reference subcarrier.

A vectorscope can measure luminance amplitude, differential phase and differential gain which will be discussed in a later chapter. Fig. 2-3 shows a vectorscope.

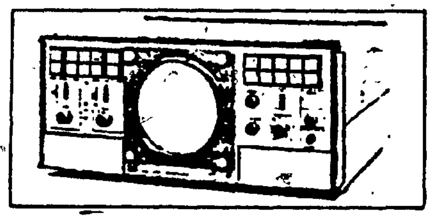


FIG. 2-3:- VECTORSCOPE MONITOR

A basic block diagram is shown in Fig. 2-4. Line termination, amplifiers and attenuators have been omitted for simplification. An input of color subcarrier signal (3.579545 MHz ±1Hz for NTSC), is fed into two balanced demodulators. These ideally have infinite attenuations in the absence of any signal being applied at the chroma input.

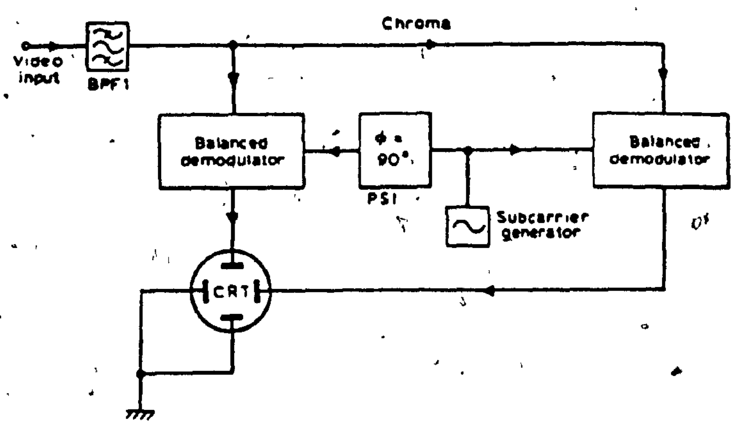


FIG. 2-4:- BASIC DIAGRAM FOR A VECTORSCOPE

In operation, the chroma input is at the same repetition frequency as the subcarrier, but at any instant it may have any phase relationship to it. The phase relationship of the chroma to the subcarrier determines the direction in which the spot is deflected from the screen centre. The magnitude of the chroma component determines the distance that the spot is deflected from the screen.

To identify the chrominance signal coordinates the graticule (see Fig. 2-5) has points which correspond to the proper phase and amplitude of the primary and complementary colors:
R (Red), B (Blue), G (Green), Yl (Yellow) and Mg (Magenta)

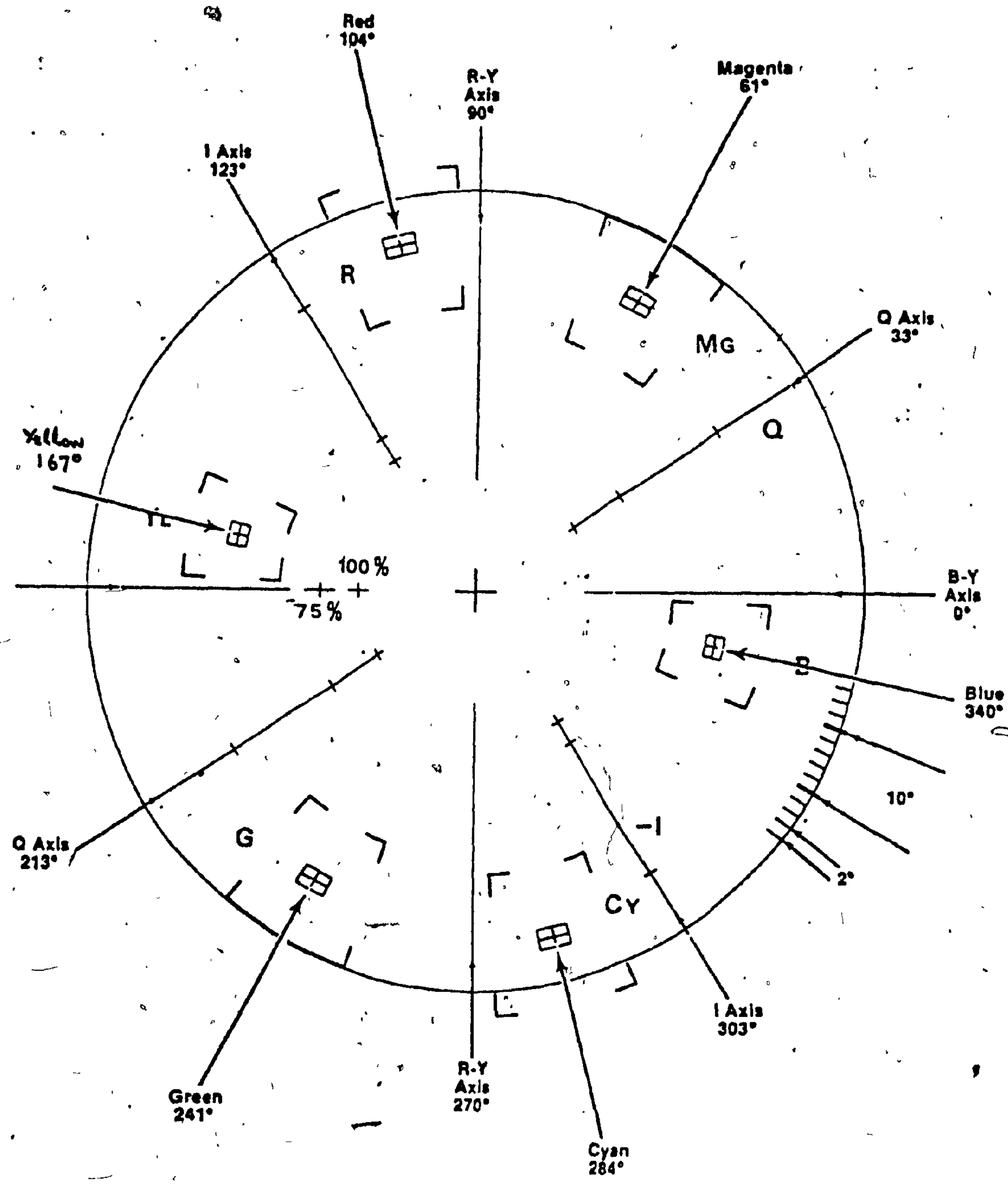
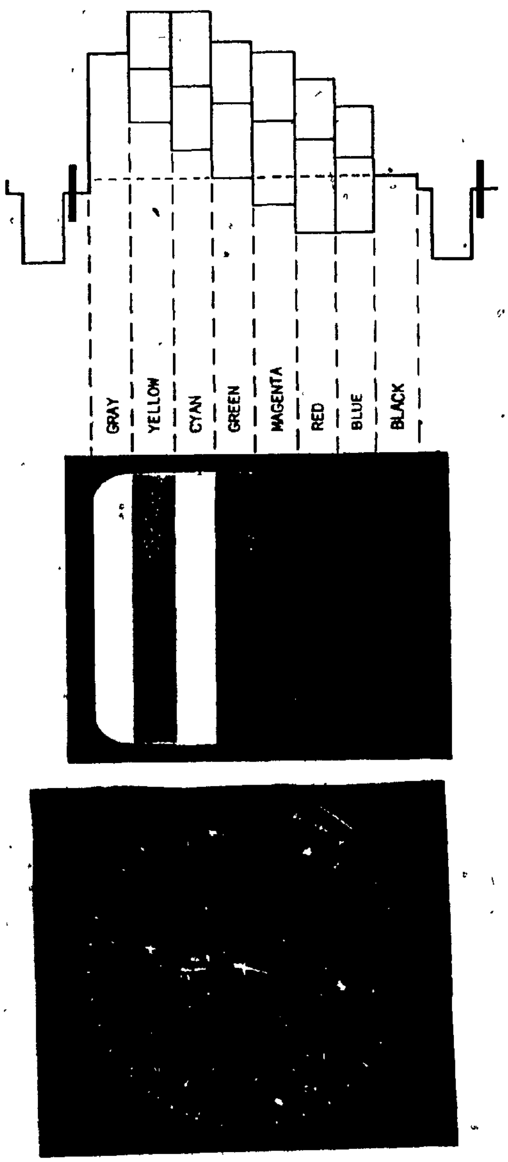


FIG. 2-5: VECTOR DISPLAY OF THE PRIMARY & COMPLEMENTARY COLORS

Any errors in the color encoding, video tape recording or transmission processes which change the phase and/or amplitude relationships cause color errors in the television receiver picture.

The polar display permits measurement of hue in terms of relative phase of the chrominance signal with respect to the color burst. The outer boxes around the color points correspond to phase and amplitude error limits (±10°, ±20%). The inner boxes indicate ±2.5° and 2.5%. Fig. 2-6 shows the waveform and vector display of the colour bar signal.



(a) Waveform display of colour bars

(b) Colour bars as shown on home TV receiver

(c) Vector display of colour bars

Fig. 2-6 WAVEFORM AND VECTOR DISPLAY OF COLOUR BARS

CHAPTER 3

VIDEO TESTING PROCEDURES

3.1 Introduction

Video distortions in a television video signal can be divided into three basic classes: linear distortion, non-linear distortion, and interference (signal to noise ratio, crosstalk). Linear distortion is any distortion independent of the signal amplitude, providing this amplitude is within the normal operating range of the equipment. Non-linear distortion is a form of distortion which is amplitude-dependent, within the normal amplitude of the equipment. Linear video distortion can be divided further into two basic classes: (1) amplitude versus frequency and (2) phase versus frequency.

The linear and non-linear distortion measurement techniques that will be covered in this Chapter are:

Non-linear Distortions

Differential Gain

Differential Phase

Linear Distortions

Amplitude-to-Frequency response

2T Size square pulse K factor

Chrominance-to-Luminance ratio

Return Loss

3.2 Differential Gain

The differential gain is the change in the amplitude of the chrominance signal as a function of the amplitude of the associated luminance signal.

The modulated 10-rise staircase[1] portion of the composite test signal shown in Fig. 3-1 is used when measuring differential gain. The test signal's amplitude at each step level must be accurately adjusted at the sending end prior to the commencement of the test. Similarly the waveform monitor at the receiving end should be properly calibrated.

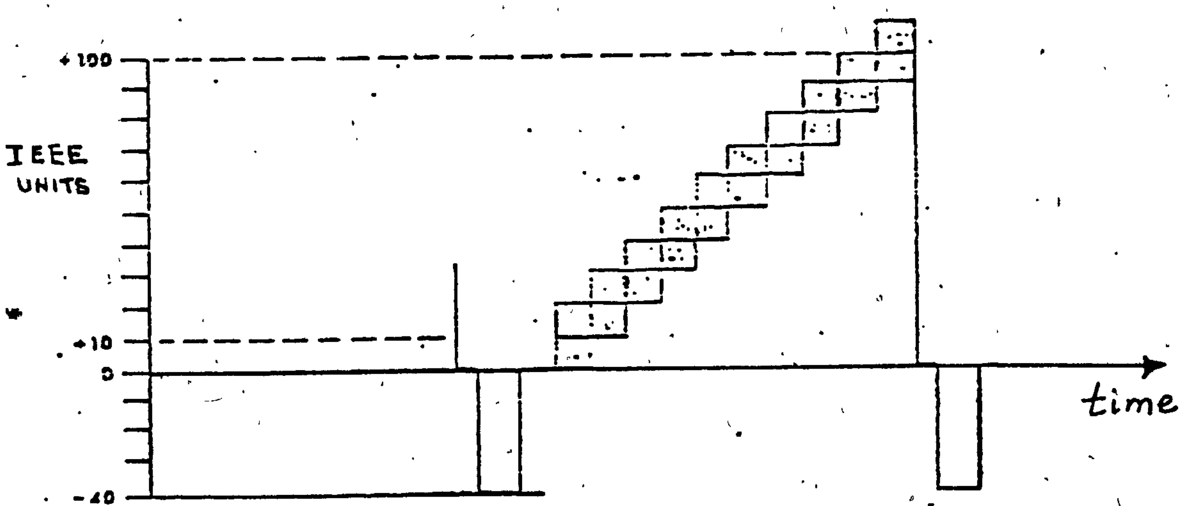


FIG. 3-1: 10-RISER STAIRCASE

Following this, the test signal is fed into the input of the equipment under test and the output through a high-pass filter to the waveform monitor being used for the measurement.

The gain of the waveform monitor is then adjusted until the highest sub-carrier peak to peak amplitude is exactly 100 IEEE units.

Fig. 3-2 shows the expected signal at the output of the high-pass filter after the highest sub-carrier peak to peak amplitude is adjusted to read a total of 100 IEEE units.

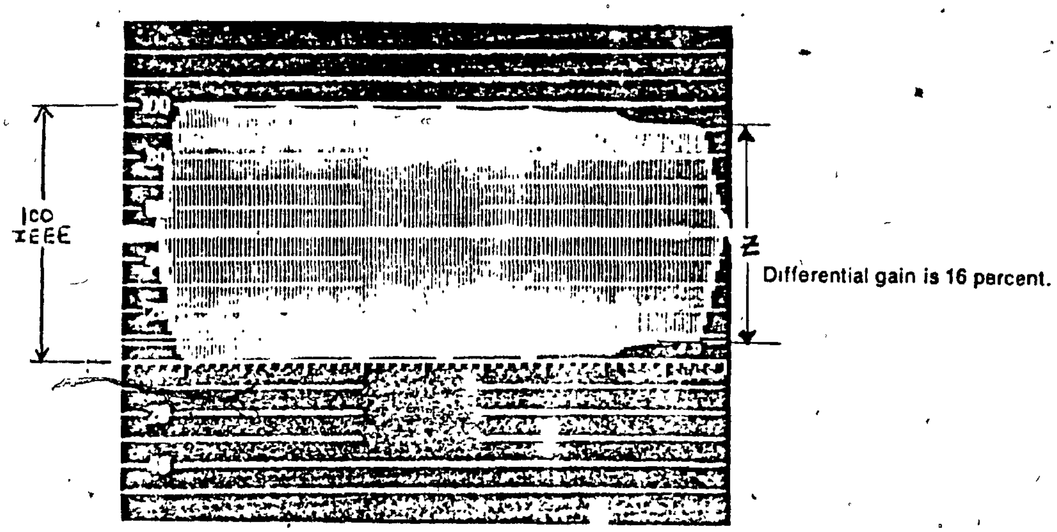


FIG. 3-2: EXAMPLE OF DIFFERENTIAL GAIN MEASUREMENT SIGNAL

Therefore:

$$\text{Differential gain} = (100-Z)\ \% = (100-84)\% = 16\%.$$

The differential gain shall not exceed[2] 15% at 10%, 50% and 90%. Average picture level (APL).

3.3 Differential Phase

The differential phase is the change in the phase of the sub-carrier at the receiving end as the luminance varies from blanking level to white level, the average picture level being maintained at 0 value.

The waveform normally used for this measurement is shown in Fig. 3-3 (10-rise modulated staircase). The test signal's amplitude and its sub-carrier phase at each step level must be accurately adjusted at the sending end prior to the commencement of the test. Similarly the waveform monitor and vectorscope at the receiving end should be properly calibrated.

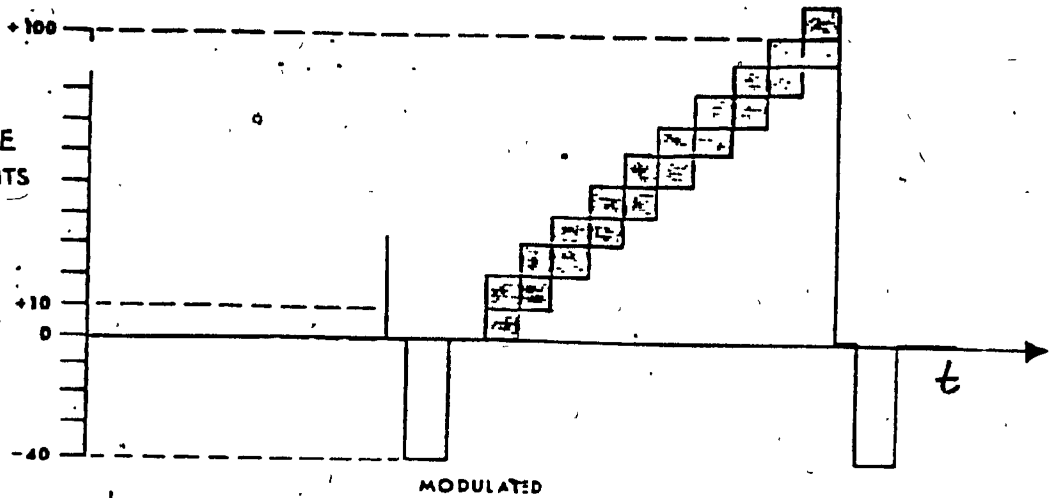


FIG. 3-3: 10-RISER MODULATED STAIRCASE

Following the above procedure, the test signal is fed to the equipment under test and the output through a high-pass filter to the vectorscope. The differential phase distortion is the measured peak-to-peak change in subcarrier phase at 50% Average Picture Level. The above measurement procedure should be repeated using the same test signal transmitted on every fifth television line with intermediate lines set at blanking level for a 10% APL and then at peak white level for a 90% APL value. An example of differential phase measurement is shown in Fig. 3-4.

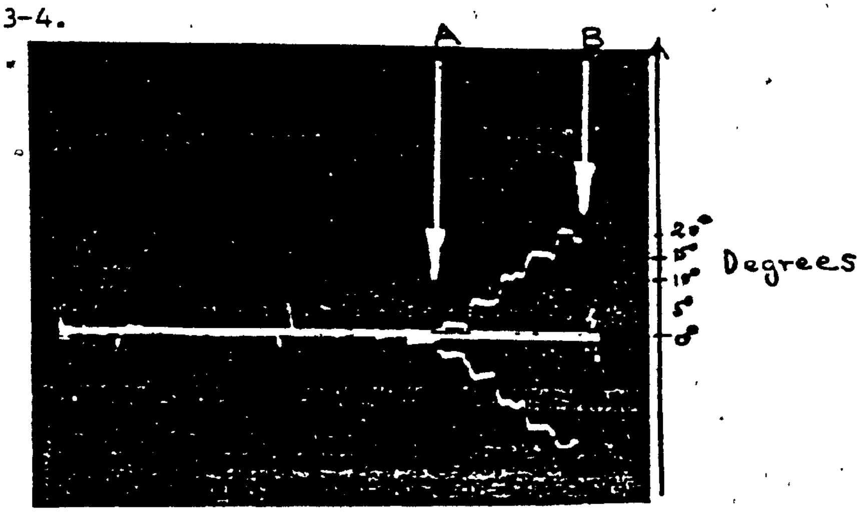


FIG. 3-4: DIFFERENTIAL PHASE MEASUREMENT

From Fig. 3.4 the differential phase is given by:

D.F. = (B-A) degrees = 20.0°

The differential phase shall not exceed[2] 5 degrees at 10%, 50% and 90% Average Picture Level.

3.4 Amplitude – Frequency Response

The video amplitude/frequency replay characteristics of the overall system are checked using a multiburst waveform. Details of the waveform proposed[1] for this test are shown in Fig. 3-5. This test signal

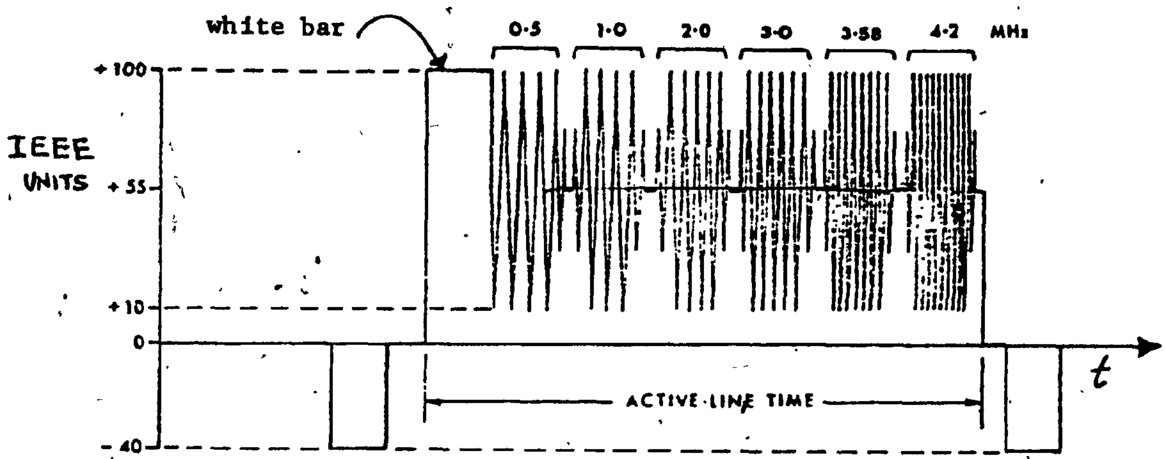


FIG. 3-5: MULTIBURST WAVEFORM

receives composite sync and blanking from local sync generator also consists of six bursts at different frequencies (0.5–4.2 MHZ). The open circuit voltage of the composite signal from a normal generator is two volts peak-to-peak. In terms of the 140 units IEEE scale the signal is composed of 40 units of sync, 7.5 units of setup and 92.5 units of bursts. The white bar of the signal is used for the mid-frequency band (15.75 KHz region). The vertical blanking component of the signal may be used for the low frequench band (60 Hz region).

The test signal's amplitude must be accurately adjusted at the sending end prior to the commencement of the test. Similarly, the waveform monitor at the receiving end should be properly calibrated. Following the above procedure, the amplitude of the white bar should be adjusted to exactly 100 IEEE units and then the peak-to-peak amplitude of each burst frequency should be measured and recorded. An example of amplitude/frequency distortion is shown in Fig. 3-6. In this example high frequency roll-off is shown. The burst amplitudes vary from 50 IEEE units in the 500 MHz burst to ·65 units in the 4.2 MHz burst.

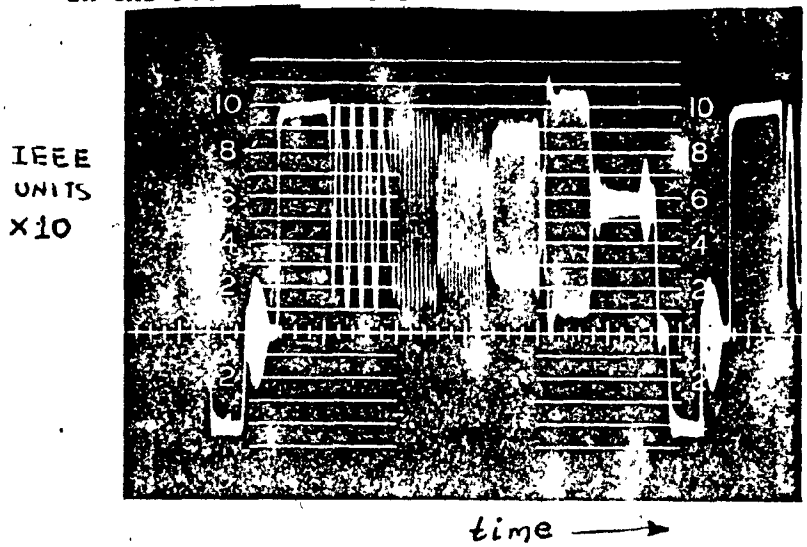


FIG. 3-6: MULTIBURST WAVEFORM AFTER THE TESTING DEVICE

All frequency burst amplitudes shall be 50 ± 5 IRE units.

3.5 2T Sin^2 Pulse K Factor

The 2T pulse has found wide acceptance as a test signal with which to measure the short-time waveform distortion that a typical TV picture will suffer when passing through a transmission system. For this measurement the pulse amplitude and shape must fall within limits which are determined by the K factor (this is a numerical value that represents the perceptibility of the subjective picture impairment).

The test is done using the sine squared 2T pulse test signal which is shown in Fig. 3-7.

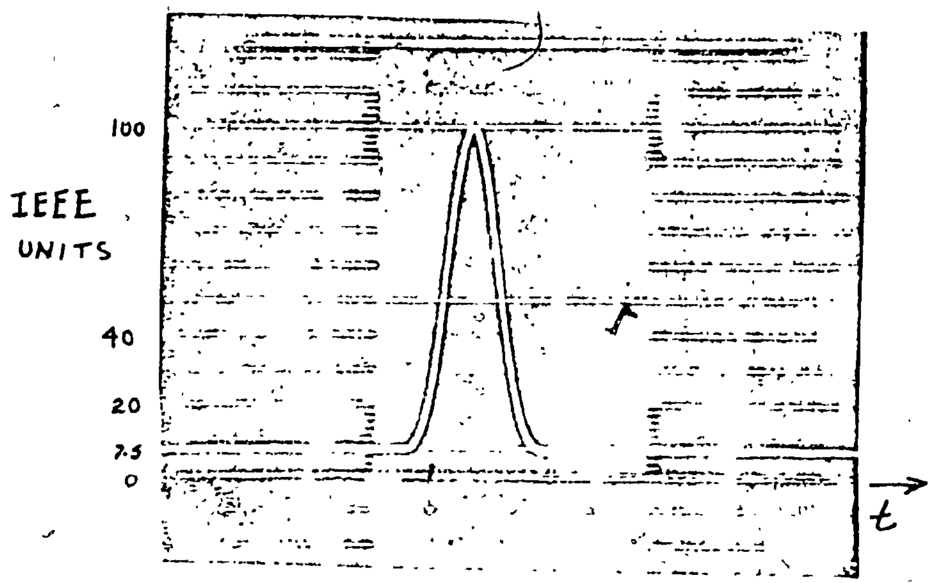


FIG. 3-7:- SINE SQUARED 2T PULSE

This test is very simple. It relies mainly on the use of special mask[3] for the CRO tube face, showing in outline the limits within which the sine squared 2T pulse should be contained when emerging from a link of given K rating. Fig. 3-8 shows such a mask for 2% and 4% limits. Other limits can, of course, be engraved if necessary.

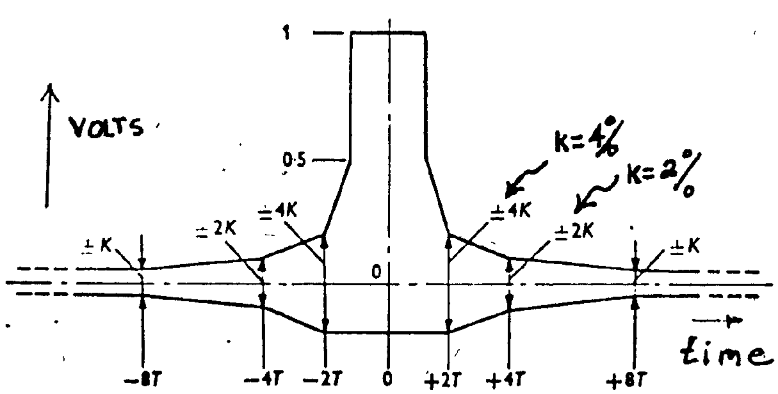


FIG. 3-8:- K RATING MASK FOR 2% & 4% LIMITS

In order to measure the K rating of a system the oscilloscope or waveform monitor must be adjusted so that:

- the sweep velocity corresponds with the time scale indicated.
- the black level of the signal trace coincides with the horizontal axis.
- the peak of the signal trace falls on the unity - amplitude line.
- the half-amplitude points of the response are symmetrically arranged about the vertical axis.

Once then (using at first an expanded time scale) place the test signal within the outline for the 2T sine squared pulse in a manner explained further on and note the K-rating limit that it falls within. Fig. 3-9 shows the K-ratings of two different tests.

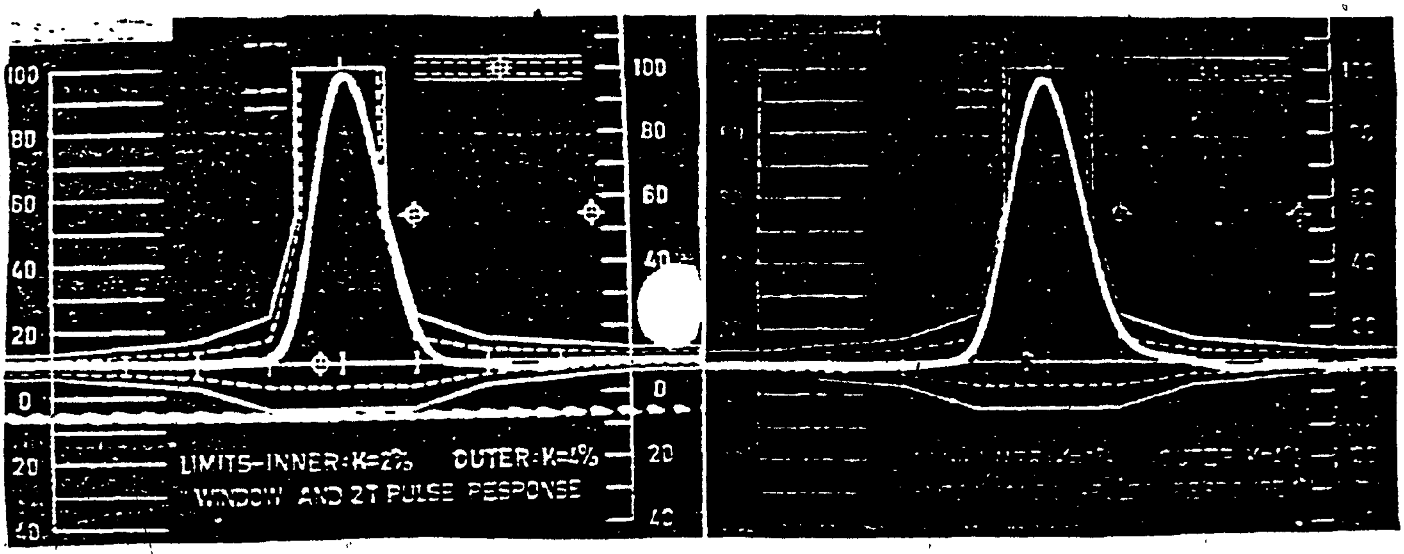


FIG. 3-9: K-RATING OF THE FIRST WAVEFORM IS K=2% AND 3% FOR THE SECOND

The choice of sine-squared pulse is ideal for this type of test as the spectrum of the pulse does not extend beyond a frequency equal to the reciprocal of the half-amplitude duration. Thus the 2T pulse (0.125 μsec) for the 525 line system has a band width of 4.2 MHz.

In many instances a K factor graticule is not available or sometimes waveform photographs are presented without a graticule and it is therefore desirable to determine the K factor from straight forward time and/or amplitude measurements[4].

For the K factor of the 2T pulse shape Fig. 3-10 lists the formulas in their general form applicable to any TV system.

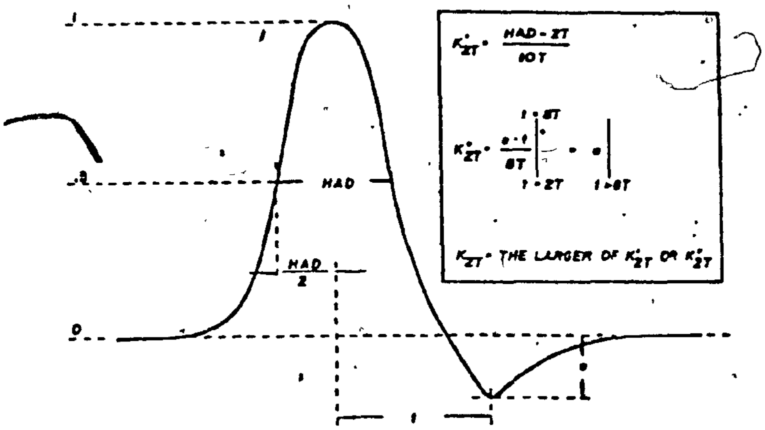


FIG. 3-10: ILLUSTRATION OF PULSE SHAPE DISTORTION K_{2T}

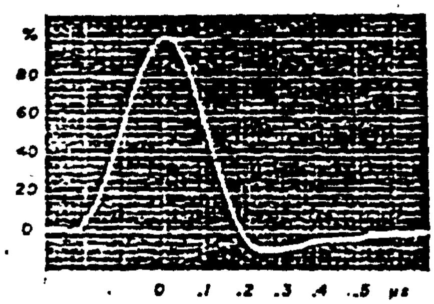
The first factor has to do with the pulse half-amplitude duration (H.A.D.) which is .25 µsec in most test measurements and therefore, K_{2T} = 0. The other subfactors have to do with the pulse skirt, which may have the shape of overshoot, smear, or ringing:

$$K_{2T} = a.t. \Big|_{t\,=\,.25}^{t\,=\,1} \qquad = a \qquad t > 1$$

where a and t are the amplitude (in %) and time (in µsec) coordinates of any given point on the waveform within the stated time interval.

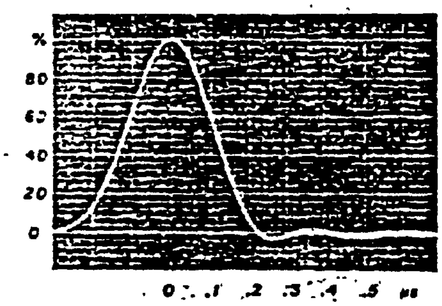
Fig. 3-11 shows the three types of distortions. Fig. 3.11 (a) shows overshoot with K_{2T} = a.t. = 10 * 0.26 = 2.6%; Fig. 3.11 (b) shows ringing with K_{2T} = 3 * 0.26 = .8%, and finally Fig. 3.11 (c) shows smearing with K_{2T} = 9 * 0.25 = 2.3%.

e (%)	t (µs)	K (%)
10	.26	2.6



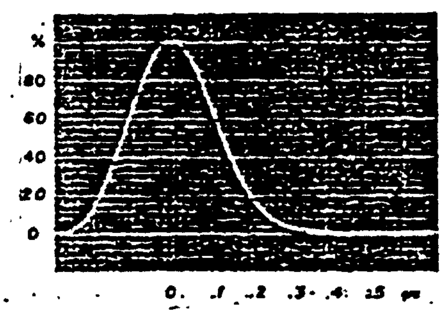
(a)

e (%)	t (µs)	K (%)
3	.26	.8
1.5	.38	.6



(b)

e (%)	t (µs)	K (%)
9	.25	2.3



(c)

FIG. 3-11: a) OVERSHOOT DISTORTION
b) RINGING DISTORTION
c) SMEARING DISTORTION

3.6 Chrominance-to-Luminance Ratio and Group Delay

To measure the chrominance-to-luminance ratio and group delay in a TV system the modulated sine-squared is used as a test signal. This signal is shown in Fig. 3-12.

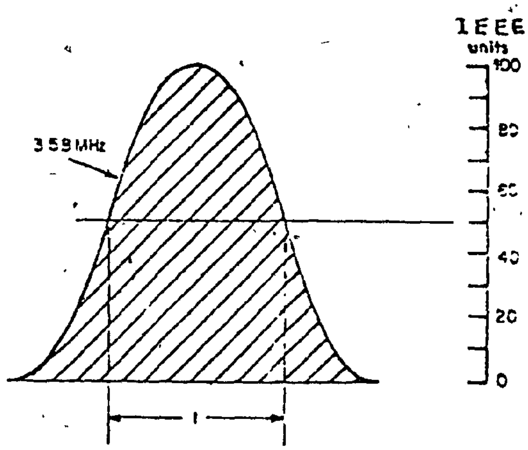


FIG. 3-12: MODULATED SINE-SQUARE SIGNAL

Upon entering this signal into the device under test, the device may exhibit four different kinds of distortions. They might appear at the output of the system as shown in Fig. 3-13.

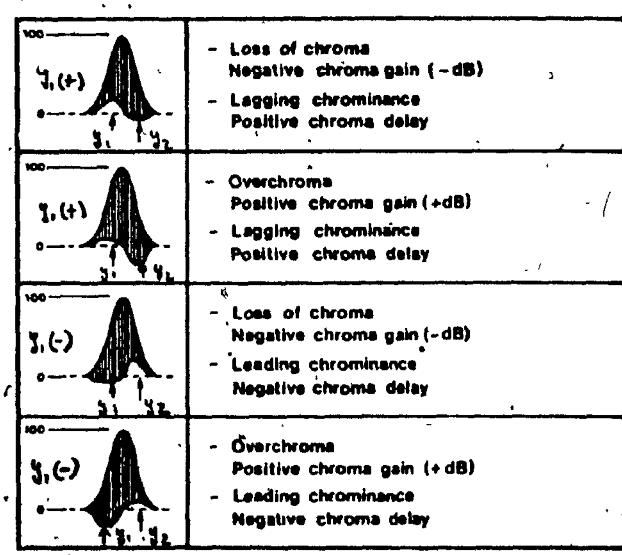


FIG. 3-13: CHROMA/LUMINANCE DISTORTIONS

The chrominance-to-luminance have been derived by Dr. Siocos and may be conveniently expressed in the following form:

$$\frac{C}{L} = \frac{1 - (y_1 + y_2 + Y_1Y_2)}{1 + (y_1 + y_2 - y_1y_2)}$$

and the chrominance-to-luminance group delay as:

$$t_{c/l} = \frac{nT}{n} \cos^{-1} \quad 1 + \frac{8y_1y_2}{1 - (y_1 + y_2 + y_1y_2) \quad 1 + (y_1 + y_2 - y_1y_2)}$$

where y_1 and y_2 are the two peaks of the distorted pulse baseline. They are normalized by dividing by the output pulse height. Note that y_1 and y_2 are algebraic and of opposite signs to one another. By convention y_1 is the earlier peak. T is 125 μsec and n is constant for color television equal to 20.

When either y_1 or y_2 is 0, $t_{c/l} = 0$. When distortion is very small y_1y_2 can be neglected, and therefore

$$A = \frac{C}{L} = \frac{1 - (y_1 + y_2)}{1 + (y_1 + y_2)}$$

and

$$t_{c/l} = \sqrt{\frac{4nT}{\Pi} (-y_1y_2)}$$

These are the well-known formulas for the calculation of $\frac{C}{L}$ and $t_{c/l}$.

Fig. 3-14 gives two graphs[3] which can be used to obtain $t_{c/l}$ and $\frac{C}{L}$ in db's for any given values of y_1 and y_2.

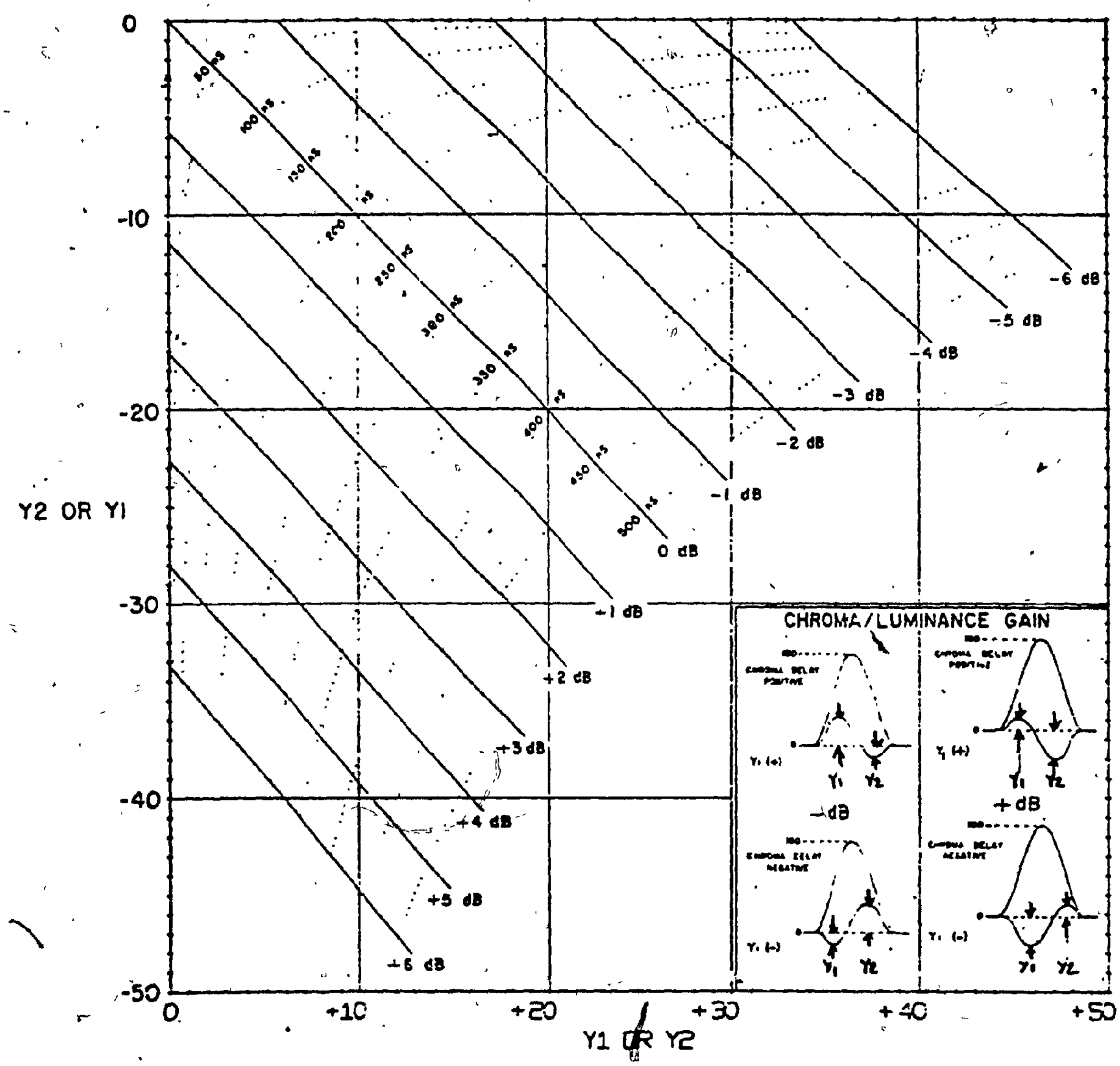


FIG. 3-14: GRAPHS FOR OBTAINING $t_{c/l}$ AND $\frac{C}{L}$

3.7 Signal-To-Noise Ratio

In a television system the lowest levels that can be allowed at antenna output terminals at repeater inputs, or at the customer's set, without producing snowy pictures, depend on thermal noise. Any resistor or source with an internal resistance generates a thermal noise signal. In the case of a resistor this noise is due to the random motion of electrons and its magnitude can be calculated.

If a sensitive high impedance voltmeter (which generates no noise itself) is connected across a 75Ω resistor (or resistive source), as in Fig. 3-15, it will measure

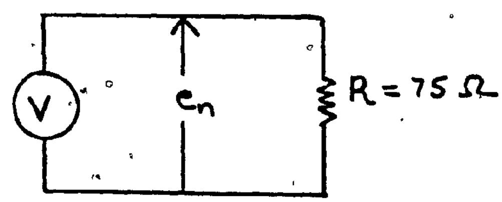


FIG. 3-15

an open circuit noise voltage

$$e_n = \sqrt{4RBK}$$

where e_n is the RMS noise voltage

R is the resistance in ohms

B is the bandwidth of the voltmeter in MHz

K is the constant approximately equal to 40×10^{-16} at room temperature (68°F).

Therefore,

$$e_n = \sqrt{4 \times 75 \times 4.2 \times 40 \times 10^{-16}}$$

$$= \sqrt{900 \times 10^{-15}} = 224.5 \times 10^{-8} V$$

$$= 2.24 \mu V \text{ R.M.S.}$$

If this source were connected to a 75 ohm load (which had no noise in itself), as in Fig. 3-16

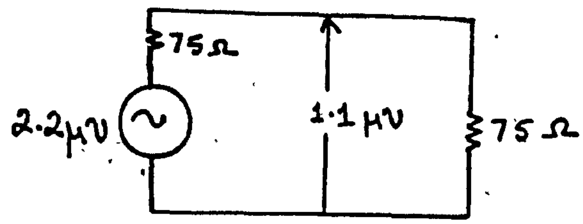


FIG. 3-16

it would deliver half this voltage to the load. Thus the noise input into 75 ohms is 1.1μV RMS or -59 dBμV. This is the basic noise level, the minimum that will exist in any part of a 75 ohm system.

In order to avoid snowy pictures, the signal, at any point in a system must be sufficiently strong to override the noise. This relationship is expressed by the "signal-to-noise ratio", which is the difference between the signal level and the noise level, both measured in dB at the same point in the system. For comparison, consider the results of series of tests conducted by the Television Allocations Study Organization (TASO) and published in their report to the F.C.C. in 1959. Their ratings, corrected for a 4 MHz bandwidth instead of 6 MHz they used, are shown below:

Taso Picture Rating	S/N Ratio
1. Excellent (no perceptible snow)	45dB
2. Fine (snow just perceptible)	35dB
3. Passable (snow definitely perceptible, but not objectionable)	29dB
4. Marginal (snow somewhat objectionable)	25dB

The signal-to-noise ratio measurements are made by using the following procedure:

1) Using the test setup shown in Fig. 3-17, feed a standard unmodulated staircase signal to the terminated input of the equipment under test.

2) Obtain a single line display of the staircase waveform

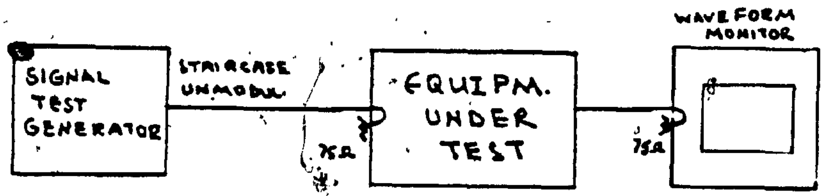


FIG. 3-17: SIGNAL TO NOISE RATIO MEASUREMENT SET UP

using delay sweep facilities of the oscilloscope and ensure that it exactly fills the 0 to 100 portion of the IEEE scale.

3) Set the horizontal gain and centering such that the top of the first step is displayed centrally and is two to three centimeters long.

4) Increase the scope vertical gain by 10 and on the first step measure:

   i) The peak-to-peak continuous random noise, and express this figure as a percentage of the signal (now represented by 100 IEEE units) and convert this figure in dB. Because continuous random noise is expressed as a peak-to-peak signal to an RMS noise ratio, a factor of 15dB should be added to the calculated figure.

Fig. 3-18 shows the staircase signal with continuous random noise:

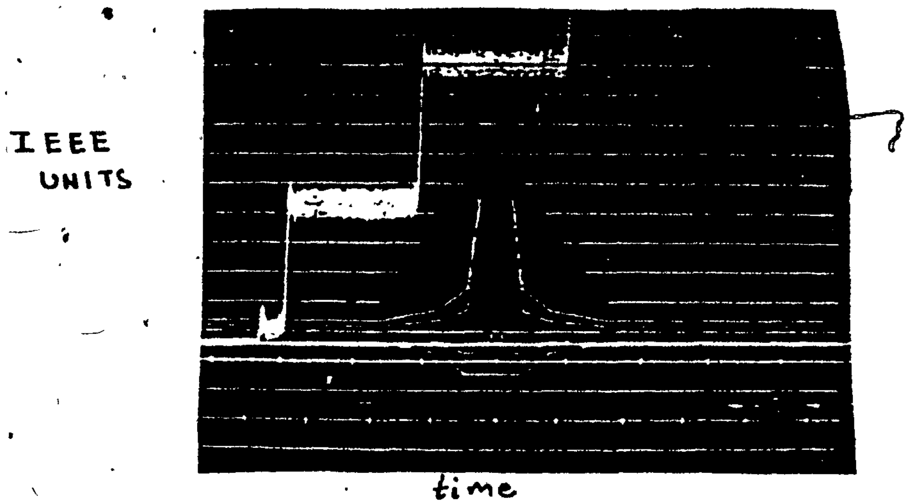


FIG. 3-18: STAIRCASE WITH CONTINUOUS RANDOM NOISE

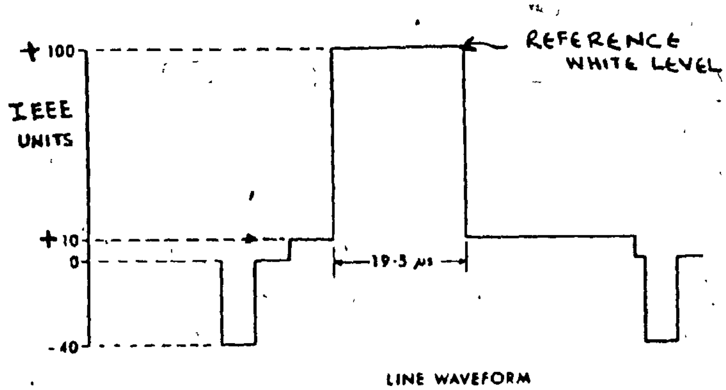
The peak-to-peak value of the noise is approximately 8%. Then using the graphs of Fig. 3-20 the 8% noise is converted into 42dB's. By adding 15dB to this figure, 57dB is the measured continuous random noise. In the case where the IRE graticule is not available and an oscilloscope is used to get the S/N ratio, the peak-to-peak noise is measured in volts and then converted in dB.

ii) Periodic noise observed at line rate estimated on a peak-to-peak basis and expressed as a percentage of the original signal amplitude.

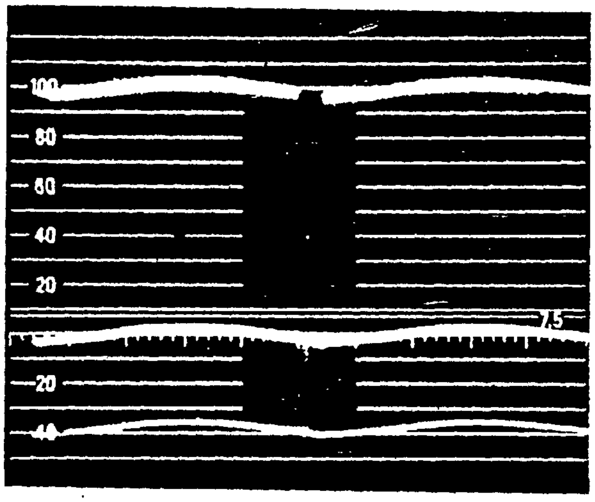
The window test signal shown in Fig. 3-19 (a) is used when measuring periodic noise. The test signal's amplitude must be accurately adjusted to 100IRE units at the sending end prior to the commencement of the test.

Fig. 3-19 (b) shows super-imposed periodic noise on the window signal:

$$\text{Signal-to-Periodic Noise (dB)} = 20 \log_{10} \frac{\text{100 IRE Units}}{\text{peak-to-peak amplitude of periodic noise}}$$



(a)



(b)

FIG. 3-19

a) WINDOW TEST SIGNAL

b) SUPERIMPOSED PERIODIC NOISE ON THE WINDOW SIGNAL

iii) Transients at both line and field rates are observed and expressed as a percentage of the original signal amplitude, converted to dB.

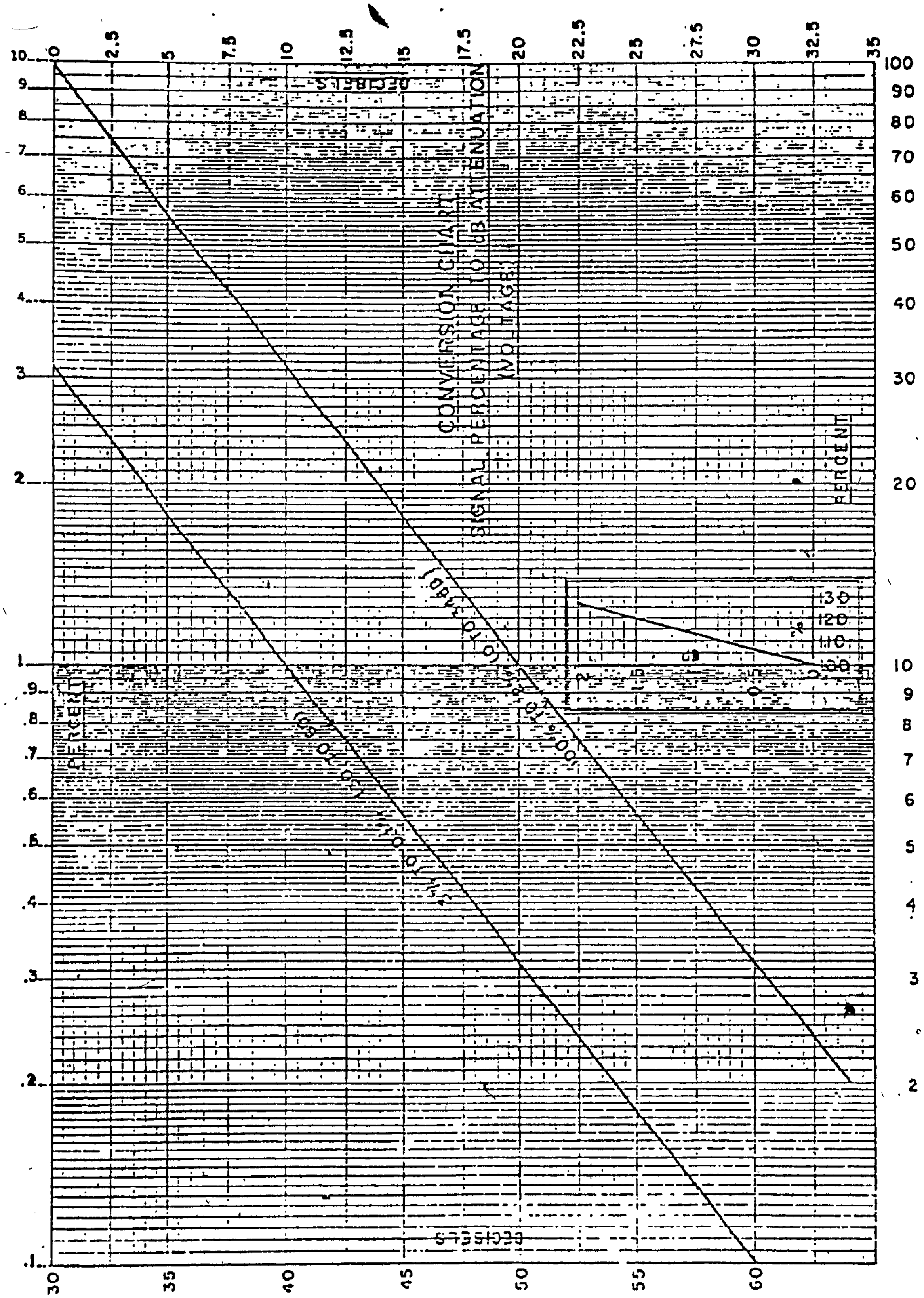


FIG. 3-20: CONVERSION GRAPH FROM PERCENTAGE TO DECIBELS UNITS

3.8 Return Loss

Television signals in broadcast studios and network facilities are generally distributed by unbalanced 75Ω transmission lines. The lines are operated on a matched impedance basis to permit uniform wide-band transmission. An impedance mismatch will cause improper signal level. It will also generate a reflection which may appear in the output signal as an echo. If the mismatch varies with frequency, signal distortion will occur in the form of an incorrect amplitude frequency characteristic. To solve the problem of impedance error in video systems a parameter called 'return loss' has been introduced. This parameter permits measuring and specifying the impedance error of both cables, bridging and terminating devices. The return loss technique does not directly measure either the resistive or reactive components of an impedance. Instead, it measures the reflection produced when a termination is in error or when an impedance discontinuity occurs.

The reflection coefficient of a transmission system is given by:

$$r = \frac{\text{Reflected Voltage}}{\text{Incident Voltage}} = \frac{Er}{Ei} \qquad \ldots .(3.1)$$

Since reflections arise as a consequence of impedance mismatch, it is natural to expect that the reflection coefficient can be expressed in terms of transmission line characteristic impedance Zo and the terminating impedance Zx. In these terms:

$$r = \frac{Zx - Zo}{Zx + Zo} \qquad \ldots .(3.2)$$

By inspection of Eg (2), it is evident that when the terminating impedance Zx is larger than the cable characteristic impedance Zo, the reflection coefficient is a positive number. In the limiting case of an open circuit termination, the reflection is +1. The physical interpretation of this is that all incident signals are reflected without polarity inversion. When the termination is matched to the line, Zx = Zo, the reflection coefficient is zero.

By definition, return loss is given by:

$$RL = 20 \log \left|\frac{Ei}{Er}\right| = 20 \log \left| r \right|$$

$$= 20 \log \left|\frac{Zx + Zo}{Zx - Zo}\right|$$

An open and short circuit mismatch both produce a return loss of 0dB, while a perfect impedance match results in a return loss of ∞ dB. Return loss is determined by measuring the incident and reflected signal magnitudes using a return loss - bridge. One version of return loss bridge which was developed at the CBS Television Network is shown in Fig. 3-21.

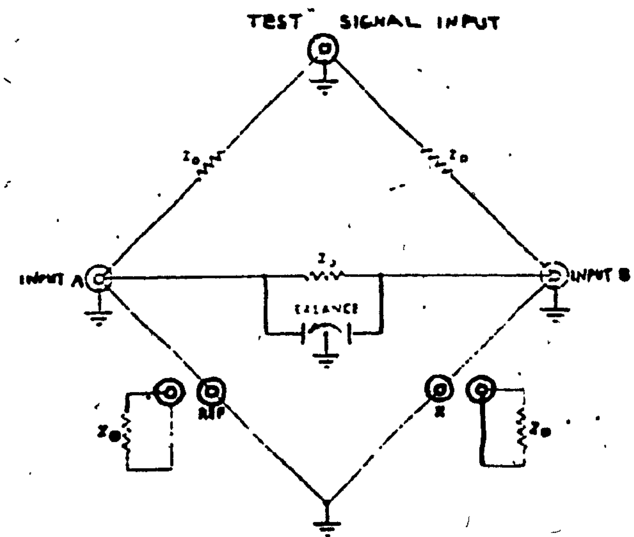


FIG. 3-21: CBS RETURN LOSS BRIDGE

The CBS bridge does not use a transformer. Instead it takes advantage of modern oscilloscope design and uses a wide band differential pre-amplifier as a balanced error detector. Return loss is measured directly by reading the magnitudes of the incident and reflected signals on the oscilloscope screen. The CBS bridge is designed to move return loss measurements with respect to 75Ω, since that is the standard impedance for television signal distribution by broadcasters.

The connections for calibration and use of return loss bridge are shown in Fig. 3-22. A bridge arm is extended to the unknown impedance which is to be measured via a short cable which thus eliminates the necessity of bringing the device to be evaluated up to the bridge terminals.

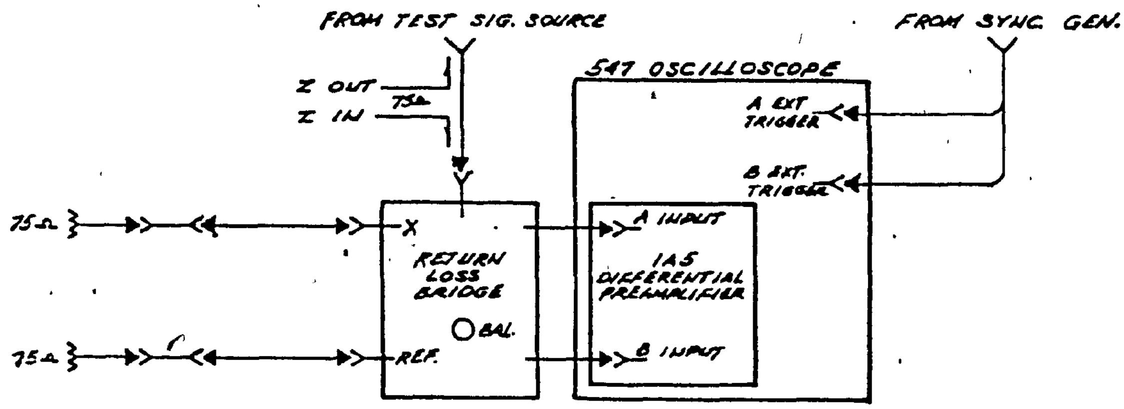


FIG. 3-22: CONNECTIONS FOR CALIBRATION AND USE OF RETURN LOSS BRIDGE

The cable is initially terminated by the precision bridge arm. The presence of one extension cable will not permit the bridge to be balanced. This situation is avoided by inserting an identical cable between the REF terminal and the removable bridge arm. The extension cables should generally be no longer than necessary to reach the device to be tested. If the device can be brought directly to the bridge connection (as would be the case in measuring cable re urn loss) the extension cables may be dispensed with.

The multiburst test signal is used for calibration and in the application of the bridge. With the equipment connected as shown in Fig. 3-22, the termination from the extension cable on the X connector on the bridge is removed. The oscilloscope is set to 10 μs/cm horizontal sweep, and 50 mV/cm vertical sensitivity and is triggered by the external horizontal drive signal. The displayed signal will have a peak-to-peak amplitude of 250 mV. This 250 mV is 1/8 of the test generator. This burst level is the incident signal. The X cable is re-terminated and the preamplifier vertical sensitivity is increased to 1 mV/cm. A horizontal trace with some high frequency bursts, such as that shown in Fig. 3-23 will usually be observed. The balance control is adjusted to minimize the burst. To implement the bridge it is necessary to remove

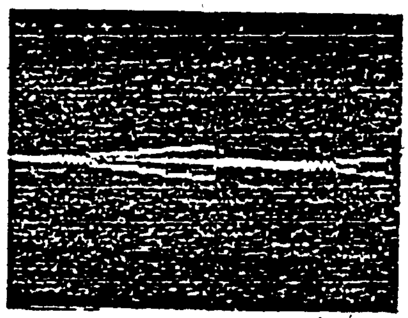


FIG. 3-23: REFLECTION OF MULTIBURST SIGNAL FOR 5-pF SHUNTING 75.0-Ω TERMINATION: HORIZONTAL, 10 μs/cm; VERTICAL, 1 mV/cm

the X cable termination and connect the extension cable to the device under test. In the case of bridging device, the removable X termination should be used to terminate the device. The deflection on the scope is the reflected signal. The return loss is calculated from the ratio of this measurement with the termination disconnected as described above during calibration. An example of this procedure is shown in Fig. 3-24. In this case, the return loss caused by a termination of 74.3 was measured. The reflection amplitude was 0.8 mV. Therefore,

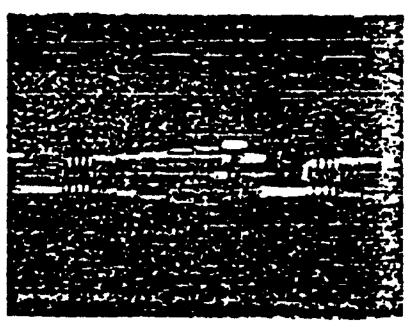


FIG. 3-24: REFLECTION OF MULTIBURST SIGNAL FOR 5-pF SHUNTING 74.3-Ω TERMINATION: HORIZONTAL, 10 μs/cm; VERTICAL, 1 mV/cm

the return loss is given by:

$$RL = 20 \log_{10} \left| \frac{Ei}{Er} \right| = 20 \log \left| \frac{165}{8} \right| = 46dB$$

The return loss bridge is not restricted to measuring termination errors. One important amplication is in the evaluation of transmission lines. A review of specifications from different sources for amplifier input return loss gives a range of values from as low as 26dB to as high as 54dB. Return loss of frequently used video cables has been found to range between 28dB and 38dB per one hundred feet. Finally, an acceptable value of return loss depends on system performance specification, the system complexity and the usual economic considerations.

In the case where the return loss bridge is not available, the video sweep method is used to evaluate termination conditions. The test set up shown in Fig. 3-25 is implemented.

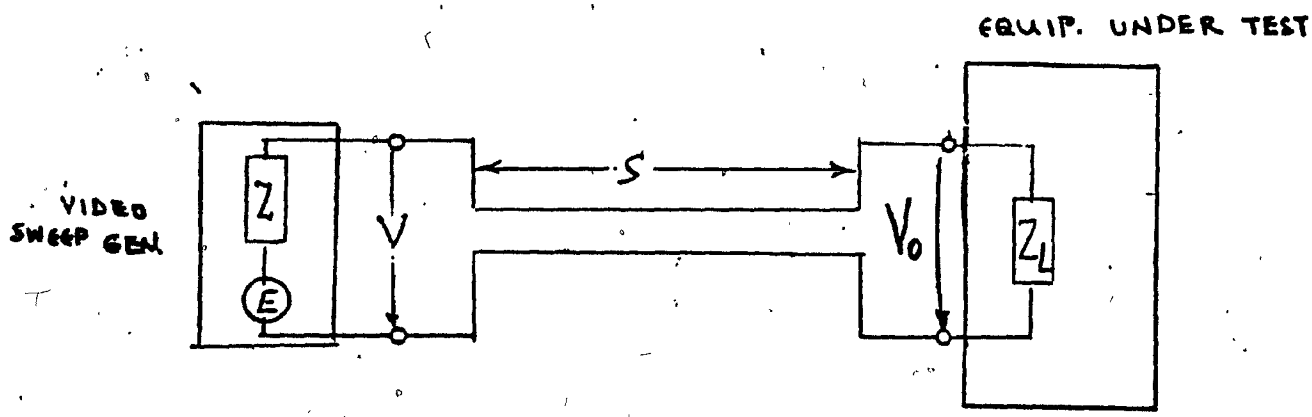


Fig. 3-25 RETURN LOSS MEASURMENT SET UP

In a resonant line fed by a video sweep signal, the waveform observed near the sending end will exhibit a certain number of minima and maxima occuring at regular frequency intervals. A minimum occurs when incident and reflected waves are in antiphase and a maximum occurs when they are in phase. It follows that at frequencies where a minimum occurs, the line is a whole number of half wavelengths long, and that at frequencies where a maximum occurs, the line is an odd number of quarter wavelengths long.

Fig. 3-26 illustrates a double exposure picture showing Vo as the inner trace, and V as the outer trace. The unknown load was 75Ω I/P resistance amplifier.

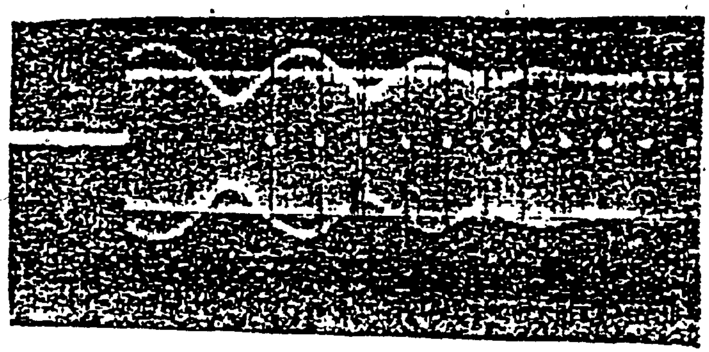


Fig. 3-26: A DOUBLE EXPOSURE PICTURE SHOWING Vo AS THE INNER TRACE, AND V AS THE OUTER TRACE.

Stipulating that the generator impedance is equal to the characteristic of the line ($Z = Z_o$) we have

$$\text{at a minimum} \quad \left|\frac{V - Vo}{Vo}\right| = \left|\frac{Z_L - Z}{Z_L + Z}\right| = \left|p\right| \qquad (1)$$

and

$$\text{at a maximum} \quad \left|\frac{V - Vo}{Vo}\right| = \left|\frac{Z - Z_L}{Z_L + Z}\right| = \left|p\right| \qquad (2)$$

Using then equations (1) and (2) and looking at the photograph taken, the reflection coefficient magnitude can be evaluated by forming $\frac{V-Vo}{Vo}$. The results for Fig. 3-26 are shown in Table 1.

TABLE 1

Frequency	Reflection Coefficient (Magnitude)	V
2.15 Mc/s	5%	min.
3.60	10-1/2	max.
5.05	13-1/2	min.
6.50	21	max.
7.95	24	min.
9.40	31-1/2	max.
10.85	36-1/2	min.
12.30	41	max.

CONCLUSIONS

The paper just described included three basic sections, namely, the development of Color Television Signal, Test Equipment and Test Procedures.

The NTSC Color Television Signal was the first system to be used in broadcasting with considerable success. Subsequent systems developed in Europe, such as the PAL and SECAM system, which were put into service at a later date, possessed considerable advantages over the NTSC in the methods of signal generation, transmission, as well as in susceptibility to signal degradation. However, the advancement of integrated circuits and digital techniques brought immense improvements to the NTSC system, e.g. much closer tolerances, high stability and excellent reproduction.

The above improvements in quality could not have reached this high standard had it not been for the parallel improvement in Television Test equipment, as well as the testing techniques. VITs (Vertical Interval Tests) are widely used, which permit an 'on line' and continuous testing of the television signal. Electronic storage devices enable technical personnel to closely examine and rectify every aspect of the television chain.

The evolvement of standard test procedures, an ongoing continuous process in their development and improvement, has enabled testing of system to be executed in thorough, systematic, and more important, in a repeatable manner.

A field of high technological advancement as it is, television did not stay immune to the influence of automation systems and computers. Television production centres are being constantly automated, relieving able people from the repetitive aspects of broadcasting and availing themselves of other more rewarding and interesting tasks.

And what does the future hold for television viewers?
Well, just as 'stereo' sound followed monaural, and three-dimensional films followed two dimensional ones, it is hard to believe that 'stereo television' is not around the corner.

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