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AN ANALYSIS OF THE SAMPLING PRINCIPLES
OF THE RCA COLOR TELEVISION SYSTEM

RADIO CORPORATION OF AMERICA
RCA LABORATORIES DIVISION

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RCA LABORATORIES DIVISION
PRINCETON, N. J.

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C. R. Tube Engineering

E. W. ENGSTROM
VICE PRESIDENT IN CHARGE OF RESEARCH

July 28, 1950.

Mr. T. J. Slowie, Secretary
Federal Communications Commission
Washington 25, D. C.

Re: Docket Nos. 8736, 8975, 9175, and 8976
Part II

Dear Sir:

On April 3-4, 1950, RCA submitted for the record in the above dockets material entitled, "An Analysis of the Sampling Principles of the RCA Color Television System," and this was given Exhibit No. 379. Three appendixes, which cover 2.4-megacycle sampling, reproduction of adjacent red and green areas, and reproduction of video frequencies higher than sampling frequencies used have been added to the information previously submitted and all of the material is being issued in bulletin form so as to give it wider distribution.

One hundred copies of this fourteenth* bulletin are filed herewith, and copies will be mailed to the persons and organizations on the list attached to Mr. Robert Zeller's letter of October 26, 1949.

Very truly yours,

E. W. Engstrom

E. W. Engstrom

*See attachment.

*Bulletins previously filed and distributed:

"A 15 by 20-Inch Projection Receiver for the RCA Color Television System" (letter dated October 20, 1949)

"Synchronization for Color Dot Interlace in the RCA Color Television System" (letter dated October 31, 1949)

"A Two-Color Direct-View Receiver for the RCA Color Television System" (letter dated November 9, 1949)

"An Experimental UHF Television Tuner" (letter dated December 12, 1949)

"A Three-Color Direct-View Receiver for the RCA Color Television System" (letter dated January 9, 1950)

"An Experimental Determination of the Sideband Distribution in the RCA Color Television System" (letter dated January 17, 1950)

"A Study of Co-Channel and Adjacent-Channel Interference of Television Signals, Part I" (letter dated January 17, 1950)

"A Study of Co-Channel and Adjacent-Channel Interference of Television Signals, Part II" (letter dated January 30, 1950)

"An Experimental UHF Television Converter" (letter dated January 30, 1950)

"Recent Developments in Color Synchronization in the RCA Color Television System" (letter dated February 8, 1950)

"Colorimetric Analysis of RCA Color Television System" (letter dated February 15, 1950)

"A Simplified Receiver for the RCA Color Television System" (letter dated February 28, 1950)

"General Description of Receivers for the RCA Color Television System which Employ the RCA Direct-View Tri-Color Kinescopes" (letter dated April 17, 1950)

An Analysis of the Sampling Principles of the RCA Color Television System

Radio Corporation of America

JULY 1950

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An Analysis of the Sampling Principles of the RCA Color Television System

Introduction

A qualitative description of the sampling procedure and the use of mixed highs, as well as the dot-interlacing method of increasing detail used in the RCA dot-sequential color television system, has already been given in, *A Six-Megacycle Compatible High-Definition Color Television System*, Radio Corporation of America, September 26, 1949. The reader is referred to that brochure for background material. The present bulletin will deal quantitatively with a number of aspects of the system, namely, the influence of sampling pulse width on color cross talk, the response of standard monochrome television receivers and color television receivers to sinusoidal variations and to step functions, the manner in which the method of mixed highs combines with the sampling procedure to produce high-frequency detail, and circuit methods of eliminating cross talk.

Cross-Talk as a Function of the Width of the Sampling Pulse

A block diagram of the RCA color television broadcasting station is shown in Fig. 1. The studio apparatus provides three electrical signals, one for each of the primary colors (green, red and blue). Each of these signals may contain frequency components out to at least 4 Mc, and in addition an average or d-c component.

For one signal routing of Fig. 1, each color signal passes through a low-pass filter which eliminates frequency components above a frequency f_A Mc. Where this bulletin deals with numerical values, f_A will be taken as 2.0 Mc. The green-channel signal coming out of its particular low-pass filter is designated as G_L on Fig. 1, indicating that at this point the signal contains the d-c component and a-c components with frequencies of f_A or less. The three low-frequency signals, G_L, R_L, and B_L are then sent into an electronic commutator or sampler.

For the second signal routing of Fig. 1, the three color signals from the camera are combined in electronic Adder No. 2 and then are passed through a band-pass filter. The output of this filter contains frequencies from f_A to f_B Mc, with contributions from each of the three color channels. For calculation purposes, f_B has been taken as 4.1 Mc. The signal at the output of the band-pass filter is designated as M_H, the mixed-high signal. The mixed high frequencies are fed to Adder No. 1 which is also receiving the signal from the electronic sampler.

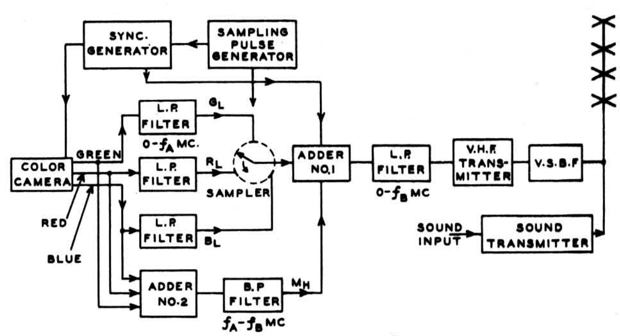


Fig. 1–Block diagram of the color television transmitter.

The frequency relationships relating to the RCA color television system are depicted in

Fig. 2, with the following numerical values chosen for purposes of illustrative calculation.

f_o= frequency of sampling pulse generator (3.8 Mc)*

f_A= upper limit of frequencies into the transmitter sampler and lower limit of mixed high frequencies (2.0 Mc)

f_B= maximum frequency component transmitted by the system (4.1 Mc). This upper limit may be determined by the receiver or transmitter cut-off characteristic, whichever is most restrictive.

f_B-f_o= upper limit of frequencies free from inherent color cross talk without circuit devices. (0.3 Mc)

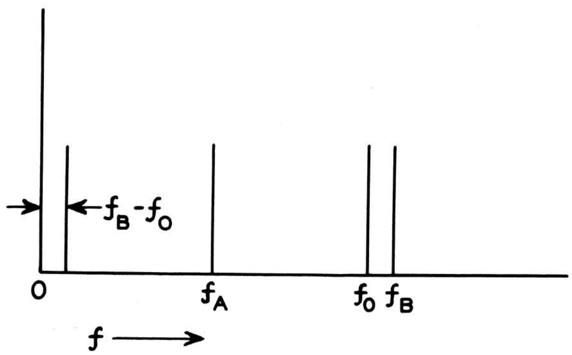


Fig. 2-Frequency relationships in the RCA color television system.

f_B=upper frequency limit of system.

f_o=frequency of sampling of individual colors.

f_A=maximum frequency of signals into the transmitter sampler. (Also lower frequency limit of mixed highs).

f_B-f_o=upper limit of frequencies free from inherent color cross talk without circuit devices.

Fig. 3 is a block diagram of one type of color television receiver. The output of the receiver sampler may go through separate video amplifiers to the picture reproducer, which may consist of three separate kinescopes, as indicated in, *A Three-Color Direct-View Receiver For The RCA Color Television System*, January 9, 1950, or the composite signal may go from the second detector through a single video amplifier to a point where the three kinescope grids are tied in parallel. The keying or sampling is accomplished by applying short negative pulses in sequence to the cathodes of the kinescopes, as described in, *A Simplified Receiver For The RCA Color Television System*, February 28, 1950.

*See statement in Conclusion concerning this frequency.

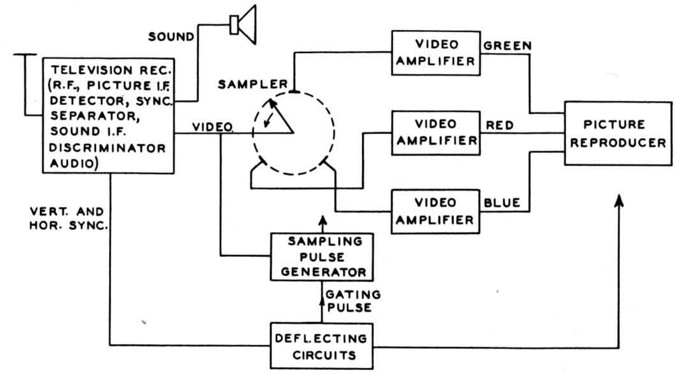


Fig. 3-Block diagram of one type of color television receiver.

The sampling procedure, at either the transmitter or the receiver, may be described in mathematical terms. Suppose that a signal G is applied to one grid of an electronic tube and that the tube has such characteristics that the output signal is always proportional to the signal G. In addition, a second grid is heavily biased except for regular periodic short intervals when this grid is driven to some prescribed positive value. The signal on this second grid thus acts as a gate on the signal G, and the output signal is proportional to signal G when the second grid is positive and the output signal is zero when the second grid is heavily biased.

The output signal may then be regarded as the product of the signal G and the gating signal. A representative gating signal is shown in Fig. 4. The period or time between successive gates is T, while the duration of a gate pulse is ΔT. The sampling frequency, $f_o=1/T$. The duty factor of the gate may be defined as $F=\Delta T/T$. Then, if the output is proportional to a signal G, the Fourier series for the gated product is

$$G(t)=G\cdot F\left[1+2\sum_{n=1}^{n=\infty} a_n \cos(n\omega_o t)\right] \quad (1)$$

where

$$a_n=\frac{\sin(n\pi F)}{n\pi F}$$

and

$$\omega_o=2\pi f_o$$

The input signal G may be varying as a function of time, but for this first consideration of cross talk, G will be constant, that is, a flat green area is scanned.

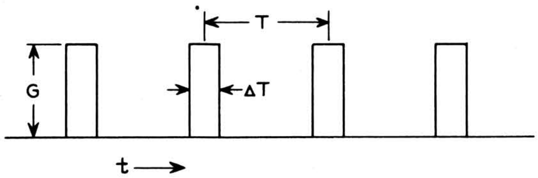


Fig. 4– Flat-top narrow sampling pulse.

$$G(t) = G \cdot F\left[1 + 2\sum_{n=1}^{n=\infty} a_n \cos(n\omega_o t)\right]$$

where F = duty factor = $\frac{\Delta T}{T}$

$$a_n = \frac{\sin(n\pi F)}{n\pi F}, \quad \omega_o = 2\pi f_o, \quad f_o = \frac{1}{T}$$

The Fourier coefficients of the gating pulse shown in Fig. 4 are displayed in Fig. 5 for n=1 and n=2, as a function of the duty factor F.

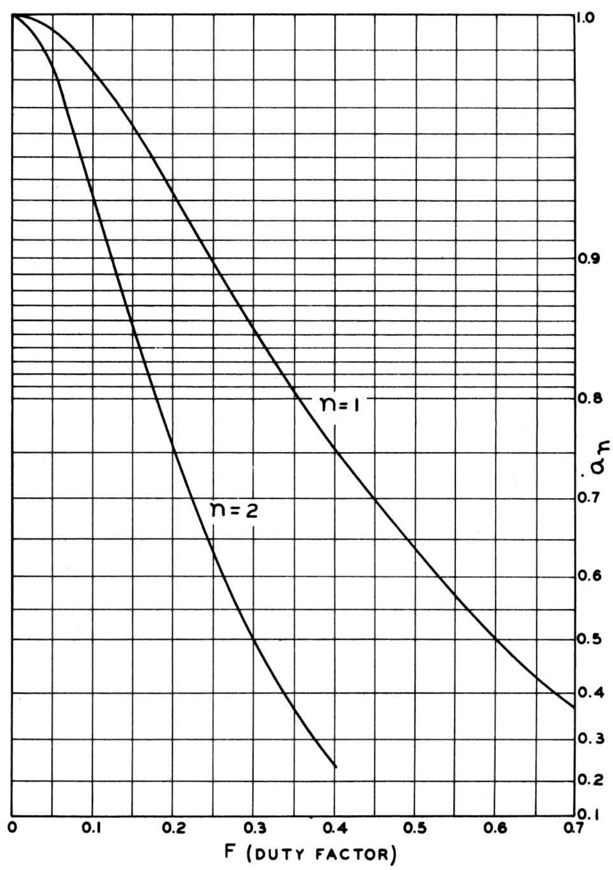


Fig. 5–Fourier coefficients of the sampling pulse of Fig. 4 as a function of duty factor.

Assume that the only signal from the color camera of Fig. 1 is for the moment a d-c signal from the green camera tube. After sampling at the transmitter, the signal at Adder No. 1 is

$$\frac{G}{3}\left[1 + 2\sum_{n=1}^{n=\infty} a_n \cos(n\omega_o t)\right] \tag{2}$$

Since the sampling frequency is 3.8 Mc and the upper pass limit of the transmitter is considered to be 4.1 Mc, only the fundamental term of the summation is retained. Then the signal out of the receiver second detector is

$$\frac{G}{3}\left[1 + 2a_1\cos(\omega_o t)\right] \tag{3}$$

The sampling of this signal at the receiver for a single color channel may be obtained by multiplying Eq. (3) by the Fourier series of Eq. (1), but assuming a phase displacement of θ degrees. (Green channel, $\theta = 0^\circ$; blue channel, $\theta = 120^\circ$; red channel, $\theta = 240^\circ$). Hence the signal at a particular color kinescope is

$$\frac{G}{9}\left[1 + 2a_1\cos(\omega_o t)\right]\left[1 + 2b_1\cos(\omega_o t + \theta) + 2b_2\cos(2\omega_o t + 2\theta) + \text{---}\right] = \frac{G}{9}\left[1 + 2a_1 b_1\cos\theta\right.$$
$$+ 2a_1\cos(\omega_o t) + 2b_1\cos(\omega_o t + \theta) + 2a_1 b_2\cos(\omega_o t + 2\theta)$$
$$+ 2a_1 b_1\cos(2\omega_o t + \theta) + 2b_2\cos(2\omega_o t + 2\theta) + 2a_1 b_3\cos$$
$$\left.(2\omega_o t + 3\theta) + \text{- - - -}\right] \tag{4}$$

In Eq. (4), b_n has been used for the Fourier coefficients at the receiver sampling, to avoid confusion with the a_n values used at the transmitter. Fig. 5 applies equally well to b_1 and b_2 as it did to a_1 and a_2.

The terms containing $2\omega_o t$ or greater may be dropped from Eq. (4), with the result

$$\frac{G}{9}\left[1 + 2a_1 b_1\cos\theta + 2a_1\cos(\omega_o t) + 2b_1\cos(\omega_o t + \theta) + 2a_1 b_2\cos(\omega_o t + 2\theta)\right] \tag{5}$$

The signal on the green kinescope is obtained by setting θ equal to zero in Eq. (5), thus

$$\frac{G}{9}\left[1 + 2a_1 b_1 + 2(a_1 + b_1 + a_1 b_2)\cos(\omega_o t)\right] \tag{6}$$

and the peak signal on the green kinescope is

$$PS_g = \frac{G}{9}\left[1 + 2(a_1 b_1 + a_1 + b_1 + a_1 b_2)\right] \tag{7}$$

By setting θ equal to 120 degrees or 240 degrees, and following through the proper manipulation, one may find the peak signal on the red or the blue kinescope. Since the peak signals on the blue and the red kinescopes due to cross talk are equal in magnitude and shifted in time, it is necessary to examine only one of these signals. Cross talk (CT) may be defined as the ratio of the peak signal on the red kinescope to the peak signal on the green kinescope. Then

$$CT=\frac{1-a_1b_1+2\sqrt{a_1^2+b_1^2+a_1^2b_2^2-a_1b_1-a_1^2b_2-a_1b_1b_2}}{1+2(a_1b_1+a_1+b_1+a_1b_2)} \qquad (8)$$

Three combinations of duty factor choices are interesting to examine.

Case I. Duty factor of sampling at transmitter equal to duty factor of sampling at the receiver. ($a_1=b_1$) (8) then becomes

$$CT=\frac{1-b_1^2+2b_1(1-b_2)}{1+2b_1(2+b_1+b_2)} \qquad (9)$$

The attendant cross talk is shown by the top curve of Fig. 6.

Case 2. Duty factor of sampling at transmitter very small.

($a_1=1$)

Eq. (8) then reduces to

$$CT=\frac{1-b_1+2\sqrt{1+b_1^2+b_2^2-b_1-b_2-b_1b_2}}{1+2(1+2b_1+b_2)} \qquad (10)$$

and the cross talk is shown by the middle curve of Fig. 6. It may be seen that for a large duty factor at the receiver, the reduction in cross talk achieved by a short duty factor at the transmitter is small.

Case 3. Duty factor of sampling at receiver very small.

($b_1=b_2=1$)

In this case, Eq. (8) reduces to the very simple form.

$$CT=\frac{1-a_1}{1+2a_1} \qquad (11)$$

This cross talk condition is shown by the lower curve in Fig. 6.

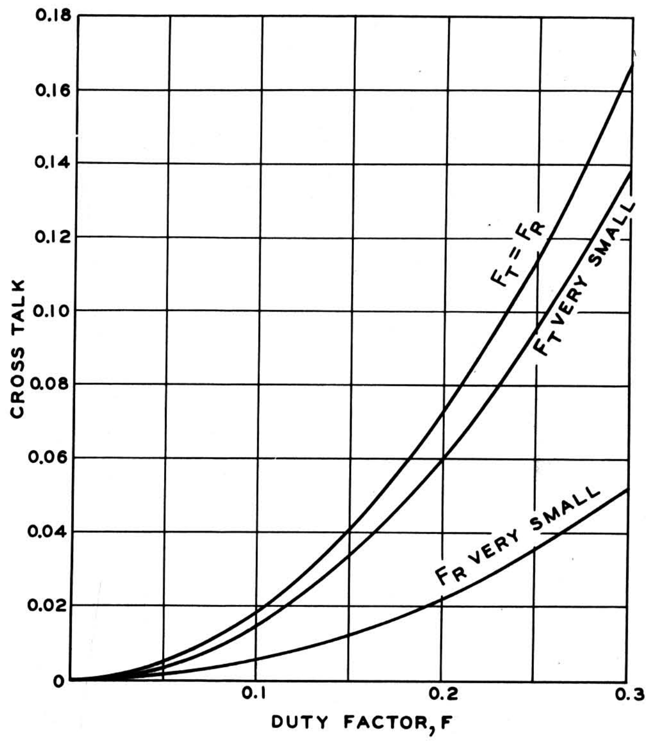


Fig. 6—Cross talk as a function of the duty factor of sampling.

Upper curve - duty factor of sampling at transmitter equal to duty factor of sampling at receiver.

Middle curve - duty factor of sampling at transmitter very small.

Lower curve - duty factor of sampling at receiver very small.

The analysis displayed in Fig. 6 shows the importance of maintaining a short duty factor at the receiver sampler. Since it is possible to maintain the effect of a short duty cycle at the transmitter sampler, both by gating control and circuit adjustment, it would appear that the middle curve of Fig. 6 would be applicable for the actual receiver conditions. It may be seen that when the duty factor at the receiver is maintained at less than 0.15, the cross talk signal remains at least 30 to 1 down from the desired signal.

For the remainder of the analysis in this bulletin, it will be assumed that the lessons pointed out by Fig. 6 will be well learned. Hence, $a_1=b_1=b_2=1$ will be used in the following analysis. To do otherwise would cloud the results in unnecessary rigor and would add little to the knowledge gained.

The Sampling Procedure Applied to Large Color Areas with a Sinusoidal Variation of the Color

a. A large green area with no variation

The green signal from the camera is assumed to be constant in magnitude, of value G. Fig. 7(a) shows this fixed value, where G has been set equal to unity. Under the new assumptions, ($a_1 = b_1 = b_2 = 1$) the signal to the transmitter modulator is given by Eq. (3) as

$$\frac{G}{3}[1 \pm 2\cos(\omega_0 t)] \quad (12)$$

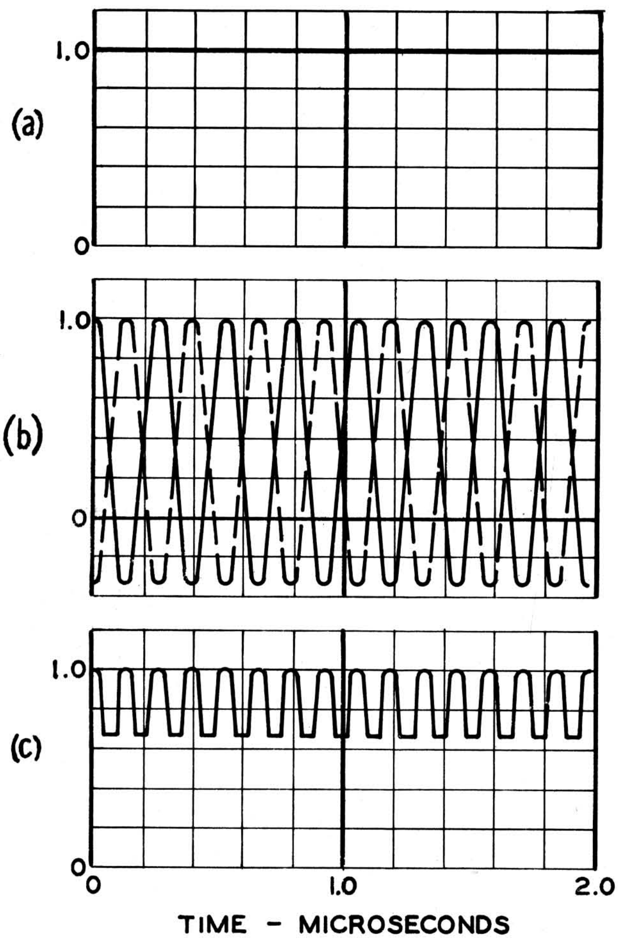


Fig. 7- (a) Constant signal out of green camera tube.

(b) Signal to transmitter modulator. Also the signal on the kinescope grid of a conventional black-and-white receiver, as well as the signal on the green kinescope grid of a color receiver.

(c) Combined light intensity of two successive scans of the same line on a conventional black-and-white receiver, and the combined light intensity of two successive scans of the same line on a color television receiver.

where the plus sign applies for the first scan of the particular line and the minus sign applies to the second scan of the same line. This shift of the sampling by one-half of the sampling cycle is accomplished by the methods described in, *Recent Developments In Color Synchronization In The RCA Color. Television System*, February 8, 1950. The plot of Eq. (12) for the two scans of the same line is shown in Fig. 7(b).

The signal from the second detector or on the kinescope grid of a conventional black-and-white television receiver will also be given by Eq. (12). Hence the solid line of Fig. 7(b) may be regarded as the voltage applied to the kinescope grid of a black-and-white receiver during the first scan of a particular line, while the broken line is the corresponding voltage during the second scan of the same line.

Assuming that the kinescope actually cuts off with negative applied signal, and neglecting the non-linearity of the input control-voltage vs. light-output characteristic of the kinescope, the solid line above the axis may be regarded as the effective light intensity along one line scan, while the portion of the dotted line above the axis may be regarded as the effective light intensity along the same line in the next scan. Since the second scan of the same line occurs only one-thirtieth of one second after the first scan of the same line, Talbot's law indicates that the light intensities may be added as far as the effect upon the eye is concerned. Fig. 7(c) was constructed from the positive values of Fig. 7(b) and may be regarded as the response on a conventional black-and-white receiver.

Turning now to the color receiver of Fig. 3, the signal on the green kinescope may be obtained directly from Eq. (6) by letting $a_1 = b_1 = b_2 = 1$. Then Eq. (6) becomes Eq. (12) and Fig. 7(b) may now be regarded as the voltage on the green kinescope grid during the first and second scans of the same line, while Fig. 7(c) depicts the light intensity distribution on one line of the green kinescope due to two successive scans of the line.

The signal on the grid of the red kinescope is determined by setting θ equal to 240 degrees in Eq. (5), and for the assumed condition of narrow sampling which sets $a_1 = b_1 = b_2 = 1$, the result is identically zero. Similarly, by setting θ equal to 120 degrees, the signal on the grid of the blue kinescope is found to be zero. Hence, with narrow sampling of a d-c signal which represents a flat field of a single color, there is no cross talk into the other two color channels.

b. $G+g \cdot \sin(\omega t)$ where $0<f<f_B-f_o$

In this particular case, the green area is slowly varying so that the electrical signal is made up of a d-c component and an a-c component of frequency f where $0<f<f_B-f_o$. This frequency region may be noted on Fig. 2. For purposes of illustration, f_B has been chosen equal to 4.1 Mc and f_o equal to 3.8 Mc, hence the frequency of variation dealt with in this section must be less than 0.3 Mc.

The signal out of the green camera tube is $G+g.\sin(\omega t)$ where ω is 2πf. This signal is sampled at the transmitter sampler in the fashion of Eq. (3) so the signal at Adder No. 1 is

$$[G+g\cdot\sin(\omega t)]\cdot\frac{1}{3}\cdot[1+2\cos(\omega_o t)] \qquad (13)$$

Eq. (13) could be expanded to develop the sidebands generated by the product $\sin(\omega t)\cdot\cos(\omega_o t)$. It would be found that the sidebands have frequencies f_o+f and f_o-f, both of which would tass through the filter and the transmitting system. Accordingly, there is no need to make the expansion for this case.

Eq. (13) also represents the signal on the kinescope grid of a conventional black-and-white television receiver. Reversing the sign in the second bracket expression yields the equation for the second scanning of the same line.

When G=1 and $g=\frac{1}{2}$, the signal out of the green camera tube is $G+g\cdot\sin(\omega t) = 1+\frac{1}{2}\sin(\omega t)$. The frequency has been taken as 0.2 Mc. Fig. 8(a) shows the signal out of the green camera tube for this condition.

Fig. 8(b) shows a plot of Eq. (13) for this same condition and may be regarded as the voltage on the kinescope of a conventional black-and-white receiver for two successive scans of the same line. Fig. 8(c) shows a summation which depicts the effective light intensity on the same line of the black-and-white receiver tube.

Eq. (13) is also the signal out of the second detector of the color receiver into the sampler. The sampling of this signal at the receiver for a single color channel may be obtained by multiplying Eq. (13) by the Fourier series of Eq. (1), but assuming a phase displacement of θ degrees. Of course, a short sampling is assumed so that the Fourier coefficients are unity. Hence the signal at a particular color kinescope is

$$\frac{1}{9}\Big[G+g\cdot\sin(\omega t)\Big]\Big[1+2\cos(\omega_o t)\Big]\Big[1+2\cos(\omega_o t+\theta)+2\cos(2\omega_o t+2\theta) + - - -\Big]=\frac{1}{9}\Big[G+g\cdot\sin(\omega t)\Big]\Big[1+2\cos\theta$$
$$+\ 2\cos(\omega_o t)\ +\ 2\cos(\omega_o t+\theta)\ +\ 2\cos(\omega_o t+2\theta)$$
$$+\ 2\cos(2\omega_o t+\theta)\ +\ 2\cos(2\omega_o t+2\theta)\ +\ 2\cos(2\omega_o t+3\theta)$$
$$+\ 2\cos(3\omega_o t+2\theta)\ +\ 2\cos(3\omega_o t+3\theta)\ +\ 2\cos(3\omega_o t+4\theta)$$
$$+ - - -\Big] \qquad (14)$$

Now to find the signal on the green kinescope grid, simply let θ equal zero in Eq. (14), which reduces to

$$\Big[G+g\cdot\sin(\omega t)\Big]\cdot\frac{1}{3}\cdot\Big[1+2\cos(\omega_o t)\Big] \qquad (15)$$

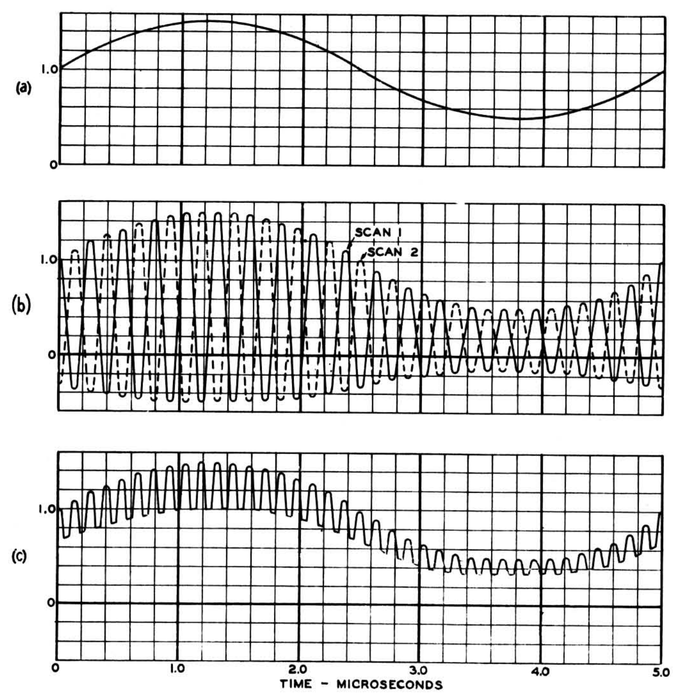


Fig. 8- (a) Signal out of green camera tube; f=0.2 Mc $G+g\cdot\sin(\omega t) = 1+\frac{1}{2}\sin\omega t$.

(b) Signal to transmitter modulator. Also the signal on the kinescope grid of a conventional black-and-white receiver, as well as the signal on the green kinescope grid of a color television receiver.

(c) Combined light intensity of two successive scans of the same line on a conventional black-and-white receiver, and the combined light intensity of two successive scans of the same line on a color television receiver.

Since Eq. (15) is identical with Eq. (13), it is seen that Fig. 8(b) may be regarded as the voltage applied to the kinescope of the green tube in the color receiver for two successive scans of the same line, and Fig. 8(c) may be regarded as the equivalent light intensity variation for two scans of the same line.

To find the signal on the grid of the blue kinescope, set θ equal to 120 degrees in Eq. (14) and it will be seen that the second bracketed expression goes to zero. If θ is then set equal to 240 degrees, an identical result is found, indicating no signal on the red tube.

Hence, when the frequency of variation is less that $f_B - f_o$, there is no cross talk and the single-color field is reproduced correctly in magnitude and position by the sampling procedure.

c. $G + g \cdot \sin(\omega t)$ *where* $f_B - f_o < f < f_A$

In this case, the green area is varying so that the electrical signal is made up of a d-c component and an a-c component of frequency f where $f_B - f_o < f < f_A$. This frequency region may be noted on Fig. 2, and for illustrative purposes lies between 0.3 Mc and 2.0 Mc.

The signal out of the green camera tube is $G + g \cdot \sin(\omega t)$. For purposes of illustration, f has been chosen to be 1.6 Mc, G=1 and $g = \frac{1}{2}$. Fig. 9(a) shows this signal, $1 + \frac{1}{2}\sin(\omega t)$.

The signal from the green camera tube is sampled so that the signal at Adder No. 1 in Fig. 1 is

$$\left[G + g \cdot \sin(\omega t)\right] \cdot \frac{1}{3}\left[1 + 2\cos(\omega_o t)\right]$$
$$= \frac{G}{3}\left[1 + 2\cos(\omega_o t)\right] + \frac{g}{3}\sin(\omega t) - \frac{g}{3}\sin(\omega_o - \omega)t$$
$$t + \frac{g}{3}\sin(\omega_o + \omega)t \qquad (16)$$

Since $f > f_B - f_o$, $f_o + f > f_B$ and the last term in Eq. (16) is lost in going through the final filter before the transmitter in Fig. 1. (This filter is not necessarily a physical reality, but serves the purpose of specifying the upper limit of frequencies that may be transmitted. It is likely that the upper frequency restriction will be imposed by the receiver rather than the transmitter.) Hence the signal at the modulator is

$$\frac{G}{3}\left[1 + 2\cos(\omega_o t)\right] + \frac{g}{3}\sin(\omega t) - \frac{g}{3}\sin(\omega_o - \omega)t \qquad (17)$$

Inspection of Eq. (17) shows that the loss of one of the terms with a coefficient $\frac{g}{3}$ has made it impossible for Eq. (17) to reproduce the desired variation in correct amplitude. This condition may be corrected by altering the response characteristics of the low-pass filters preceding the sampler in the transmitter of Fig. 1. The filters should have a response in the region $f_B - f_o < f < f_A$ which is 1.5 times the gain in the region $0 < f < f_B - f_o$. Under this new condition, Eq. (17) becomes

$$\frac{G}{3}\left[1 + 2\cos(\omega_o t)\right] + \frac{g}{2}\sin(\omega t) - \frac{g}{2}\sin(\omega_o - \omega)t \qquad (18)$$

the condition where G=1 and $g = \frac{1}{2}$, computed from Eq. (18), is shown in Fig. 9(b) for two successive line scans. These curves apply to the modulator signal in the transmitter and to the signal on the kinescope grid of a black-and-white receiver. Fig. 9(c) shows the effective light intensity due to two scans of the same line on a black-and-white receiver.

Eq. (18) may also be regarded as the signal into the sampler of the color receiver of Fig. 3. The previously-used expedient of multiplying by the generalized sampling function may now be resorted to just as was done in obtaining Eq. (14). The result of sampling Eq. (18) is

$$\frac{G}{9}\left[1 + 2\cos(\omega_o t)\right]\left[1 + 2\cos(\omega_o t + \theta) + 2\cos(2\omega_o t + 2\theta) + \cdots\right.$$
$$+ \frac{1}{3}\left[\frac{g}{2}\sin(\omega t) - \frac{g}{2}\sin(\omega_o - \omega)t\right]\left[1 + 2\cos(\omega_o t + \theta)\right.$$
$$\left. + 2\cos(2\omega_o t + 2\theta) + \cdots\right]$$
$$= \frac{G}{9}\left[1 + 2\cos(\omega_o t)\right]\left[1 + 2\cos(\omega_o t + \theta) + 2\cos(2\omega_o t + 2\theta) + \cdots\right]$$
$$+ \frac{g}{6}[\sin(\omega t) + \sin(\omega t + \theta)$$
$$+ \sin([\omega_o + \omega]t + \theta) + \sin([\omega_o + \omega]t + 2\theta)$$
$$- \sin([\omega_o - \omega]t + \theta) - \sin(\omega_o - \omega)t + \cdots] \qquad (19)$$

Now to find the signal on the green kinescope, let θ=0 degrees in Eq. (19) and find

$$\frac{1}{3}\left[G + g \cdot \sin(\omega t)\right]\left[1 + 2\cos(\omega_o t)\right] \qquad (20)$$

The condition where G=1 and $g = \frac{1}{2}$, computed from Eq. (20), is shown in Fig. 9(d) and depicts the voltage on the grid of the green kinescope for two successive line scans. Fig. 9(e) shows the effective light intensity due to two scans of the same line on the green kinescope.

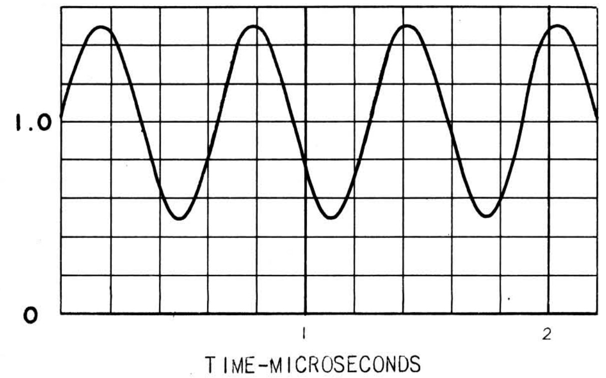


Fig. 9(a) – Signal out of green camera tube; f=1.6 Mc, $G+g\cdot\sin(\omega t) = 1+\frac{1}{2}\sin(\omega t)$

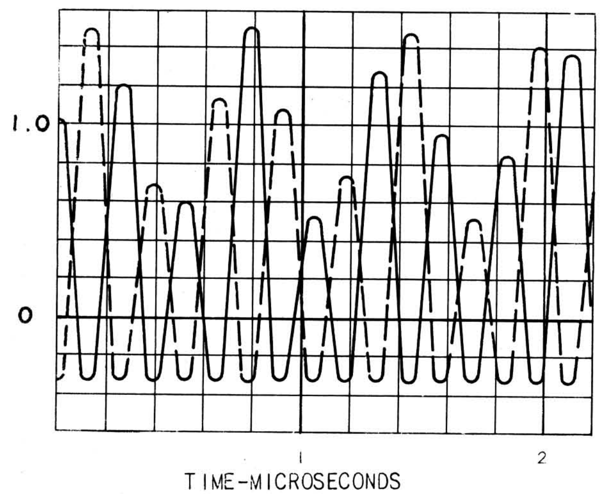


Fig. 9(b) – Signal to transmitter modulator. Also the signal on the kinescope grid of a conventional black-and-white receiver.

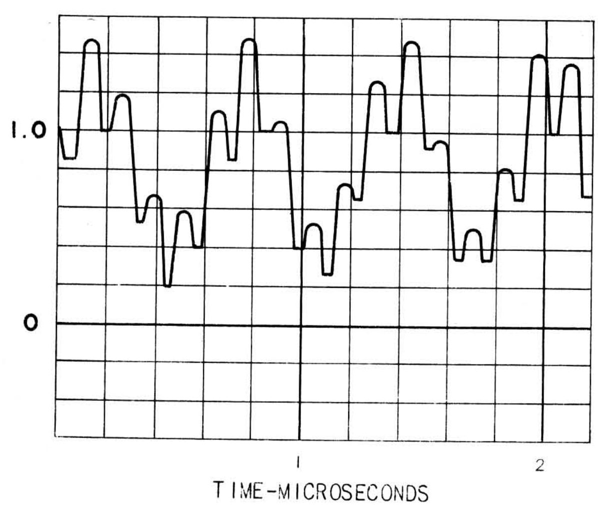


Fig. 9(c) – Combined light intensity of two successive scans of the same line on a black-and-white receiver.

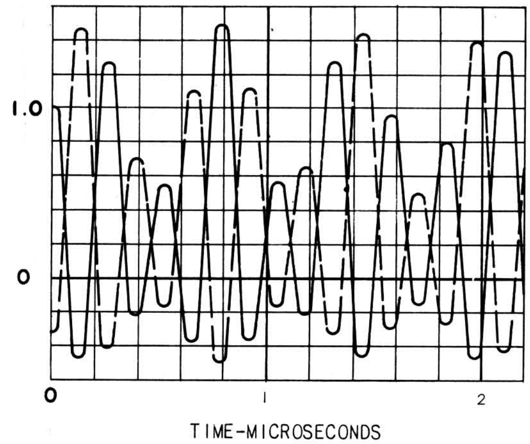


Fig. 9(d) – Signal on the green kinescope grid of a color television receiver.

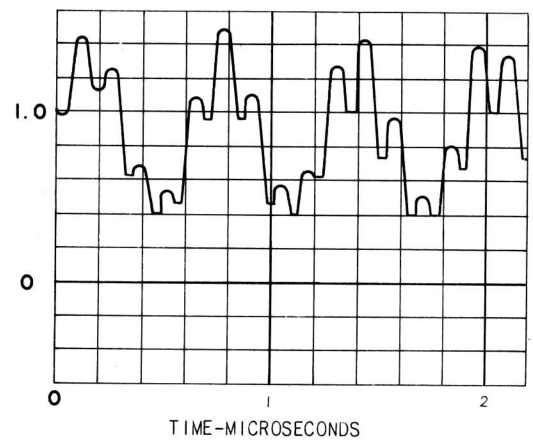


Fig. 9(e) – Combined light intensity of two successive scans of the same line on the green kinescope of a color television receiver.

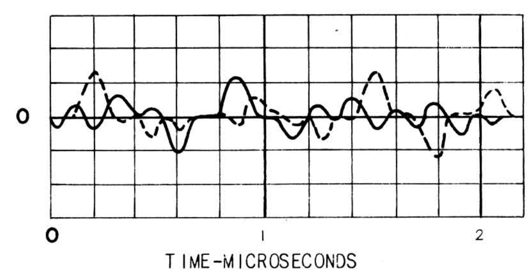


Fig. 9(f) – Cross talk voltage on red kinescope grid.

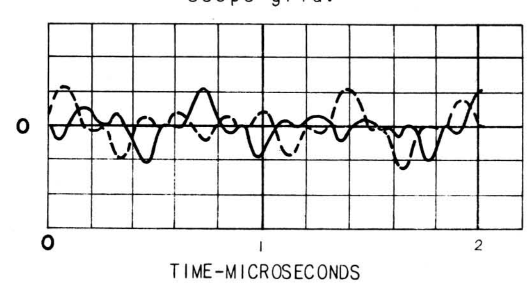


Fig. 9(g) – Cross talk voltage on blue kinescope grid.

The signal on the grid of the red kinescope (due to color cross talk) is found by setting $\theta = 240$ degrees in Eq. (19), with the result

$$\frac{g}{6}\sin(\omega t-60^\circ)\left[1+2\cos(\omega_o t-120^\circ)\right] \text{ (on red kinescope)} \quad (21)$$

and setting $\theta = 120$ degrees gives

$$\frac{g}{6}\sin(\omega t+60^\circ)\left[1+2\cos(\omega_o t+120^\circ)\right] \text{ (on blue kinescope)} \quad (22)$$

The voltage on the grid of the red kinescope due to the erroneous sampling of the green signal is shown in Fig. 9(f) as computed from Eq. (21), while Fig. 9(g) shows the signal on the grid of the blue kinescope.

These equations show that cross talk up to 50 per cent is possible in the region where the frequency is greater than $f_B - f_o$ and less than f_A, or in the example, when the frequency lies between 0.3 Mc and 2.0 Mc.

At first glance, this degree of cross talk might seem intolerable. In the case shown in Fig. 9, it is likely that non-linearity of the light-output vs grid-voltage characteristic of the kinescopes would make the cross talk of negligible importance. In the converse case, if the average intensity of the red tube were high, the erroneous voltage of Fig. 9(f) might be enhanced to a point where cross talk produced undesirable effects. While this cross talk has not appeared to be a serious problem in the RCA Color Television System, means for eliminating the effect will be described later.

d. $G+g\cdot\sin(\omega t)$ where $f_A<f<f_B$

In this case, the green area is varying so that the electrical signal is made up of a d-c component and an a-c component of frequency f where $f_A<f<f_B$. This frequency region may be noted on Fig. 2, and for illustrative purposes lies between 2.0 and 4.1 Mc.

The signal from the green camera tube is $G+g\cdot\sin(\omega t)$. For purposes of illustration, f has been chosen as 3.4 Mc, G=1 and $g=\frac{1}{2}$. Fig. 10(a) shows this signal $1+\frac{1}{2}\sin(\omega t)$.

The d-c signal G goes through the transmitter sampler, but since the a-c term is of a frequency lying in the region committed to "mixed-highs," this latter signal goes through Adder No. 2 and the appropriate band-pass filter into Adder No. 1 of Fig. 1. Hence the signal into the transmitter modulator is

$$\frac{G}{3}\left[1+2\cos(\omega_o t)\right] + g\cdot\sin(\omega t) \quad (23)$$

Eq. (23) also applies to the voltage on the kinescope grid of a black-and-white receiver. The background term is sampled while the mixed-high signal, unsampled, is superimposed to supply fine detail.

The signal out of the second detector of a color receiver also has the form of Eq. (23). Sampling in the receiver results in a signal on the grid of the green kinescope of the form

$$\frac{1}{3}\left[G+g\cdot\sin(\omega t)\right]\left[1+2\cos(\omega_o t)\right] \quad (24)$$

A plot of this equation is shown by Fig. 10(b), while Fig. 10(c) shows the combined light intensity on a single line of the green tube for two successive scans of the same line. This latter plot shows the effect of the beat between the high-frequency component and the sampling frequency, so that Fig. 10(c) is not a very faithful reproduction of Fig. 10(a).

The output of the red sampler, (the voltage on the grid of the red kinescope) is

$$\frac{g}{3}\sin(\omega t)\left[1+2\cos(\omega_o t-120^\circ)\right] \quad (25)$$

while the voltage on the grid of the blue kinescope is

$$\frac{g}{3}\sin(\omega t)\left[1+2\cos(\omega_o t+120^\circ)\right] \quad (26)$$

The voltage on the red kinescope is shown in Fig. 10(d), while the voltage on the blue kinescope is given by Fig. 10(e).

It is obvious that the high-frequency signal mixing in this region is one hundred per cent, since the philosophy of the principle of "mixed-highs" has already been accepted, the high-frequency components of the three camera tubes have been deliberately combined at the transmitter so that these signals have completely lost color identity. Because of the inability of the eye to see color in the fine detail, it is possible to combine the positive values of Figs. 10(d) and 10(e) with Fig. 10(c) with the result shown in Fig. 10(f), which is a more satisfactory representation of Fig. 10(a). However, it is well known that the resolution of the eye is very poor in blue, so it seems more fair to combine only Fig. 10(d) with Fig. 10(c), with Fig. 10(g) resulting. The

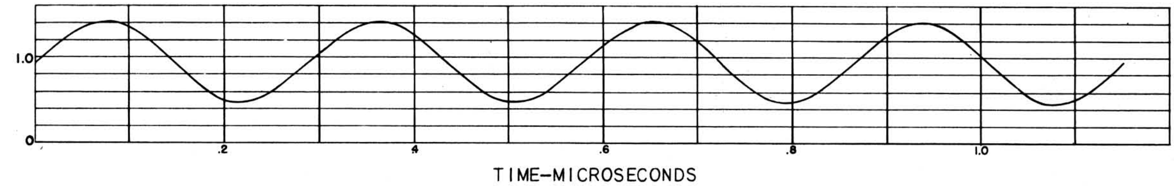


Fig. 10(a) - Signal out of green camera tube; f=3.4 Mc, $G+g.\sin(\omega t) = 1+\frac{1}{2}\sin(\omega t)$

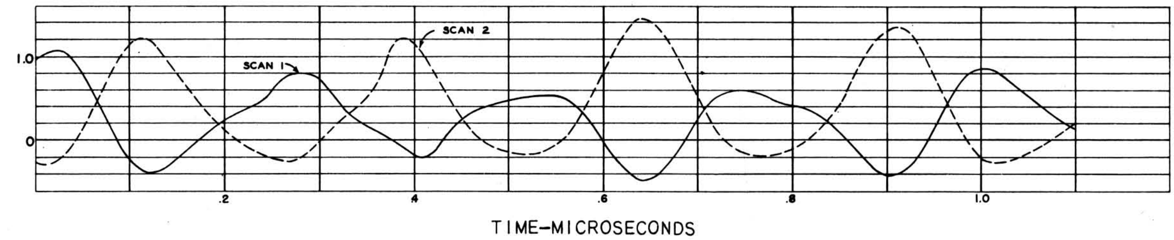


Fig. 10(b) - Signal on the green kinescope grid of a color television receiver.

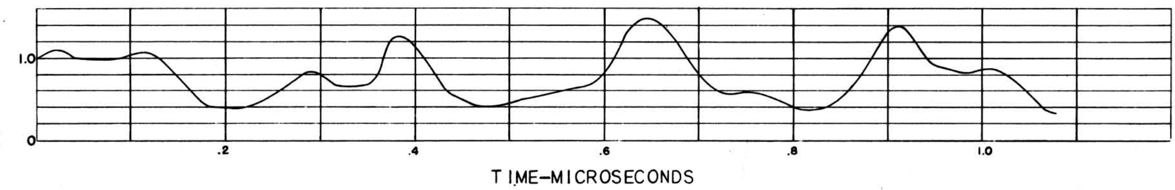


Fig. 10(c) - Combined light intensity of two successive scans of the same line on the green kinescope of a color television receiver.

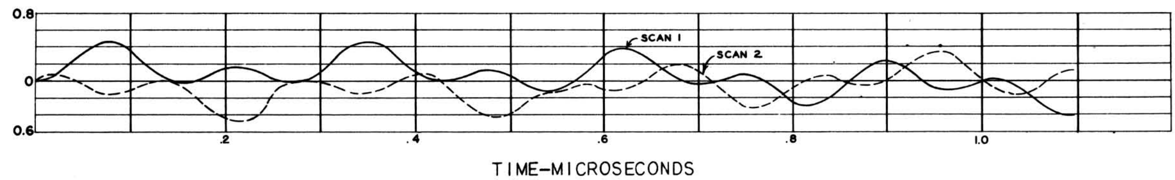


Fig. 10(d) - Voltage on the red kinescope grid.

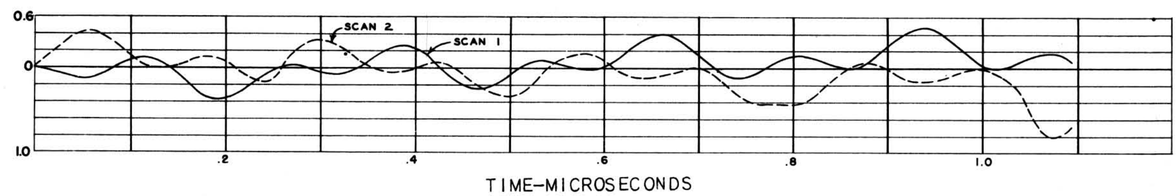


Fig. 10(e) - Voltage on the blue kinescope grid.

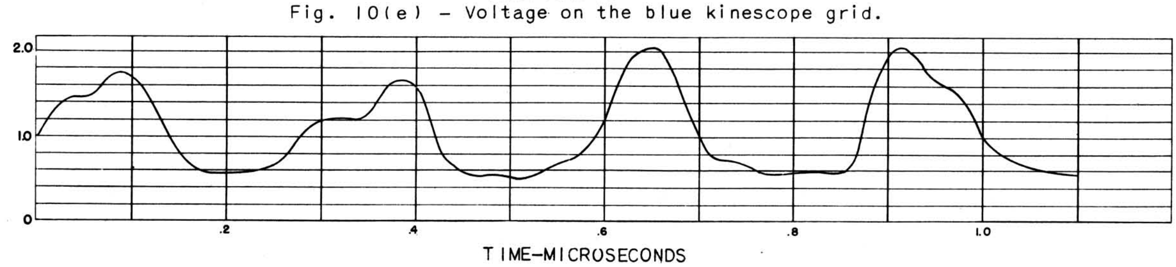


Fig. 10(f) - Combined light intensity of two successive scans of the same line, obtained by adding light intensities of the green, red and blue tubes.

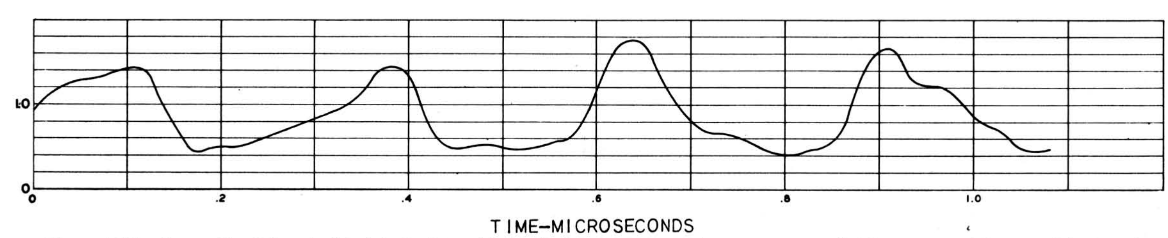


Fig. 10(g) - Combined light intensity of two successive scans of the same line, obtained by adding light intensities of the green and red tubes.

improvement in reproduction of Fig. 10(a) by Fig. 10(g) is striking, particularly when it is recalled that the rate of the variations in Fig. 10(a) is at a high frequency, and that the differences between Fig. 10(a) and Fig. 10(g) represent still higher frequency components, which are beyond the limits of ordinary resolution.

The Sampling Procedure Applied to Step Functions of Light Intensity

a. Response of conventional black-and-white television receivers

In the preceding pages, attention has been given to a color intensity change which produces an electrical signal consisting of a d-c term and a single a-c component. Such an analysis serves to demonstrate the detailed mechanism of the system. However, it is not a condition often encountered in producing an actual television image. Generally, it is more interesting to examine the action of the system near edges of objects in order to determine rise time, overshoot, and color cross talk.

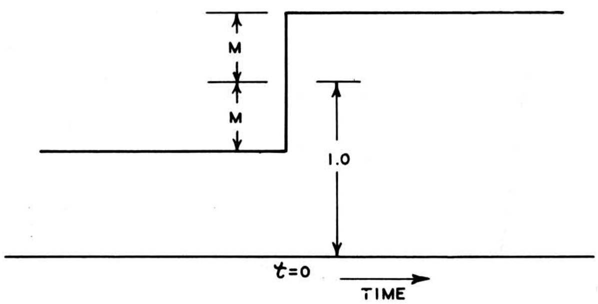


Fig. 11- Idealized step function of voltage which has a value of 1-M for time less than zero and a value of 1+M for time greater than zero.

For purpose of analysis, let us assume that the voltage coming from the green camera tube has the form shown in Fig. 11, where the voltage has the value 1-M for all values of time less than zero, and has the value of 1+M for all times greater than zero. The function of Fig. 11 may be produced exactly only when the associated circuits have unlimited frequency response. For this idealized condition, the signal from the green camera tube is given by the following Fourier Integral.

Green camera signal=

$$1+\frac{2M}{\pi}\int_{\beta=0}^{\beta=\infty} d\beta \int_{\omega=0}^{\omega=\infty} \sin(\omega\beta)\sin(\omega t)\cdot d\omega \qquad (27)$$

where β = an integration variable

$\omega = 2\pi f$

f = a frequency component lying between zero and infinity

t = the instant of time at which the signal is to be evaluated.

Now, assume that a circuit is imposed which has unity gain for all frequencies below f_B and zero response for all frequencies above f_B, and with no appreciable phase shift. Then Eq. (27) becomes

$$\text{G.C.S.} = 1+\frac{2M}{\pi}\int_{\beta=0}^{\beta=\infty} d\beta \int_{\omega=0}^{\omega=2\pi f_B} \sin(\omega\beta)\sin(\omega t)\cdot d\omega$$

$$= 1+\frac{2M}{\pi}\cdot \mathrm{Si}(2\pi f_B t) \qquad (28)$$

where $\mathrm{Si}(x)$ = Integral sine of $x = \int_0^x \frac{\sin u}{u}\cdot du$, a well known and tabulated function.

Fig. 12 shows a plot of Eq. (28) with $M = \frac{1}{2}$ and with the upper frequency limit f_B equal to 4.1 Mc. It should be noted that Fig.12 and not Fig. 11 should be used in judging the response when other circuit factors have been added.

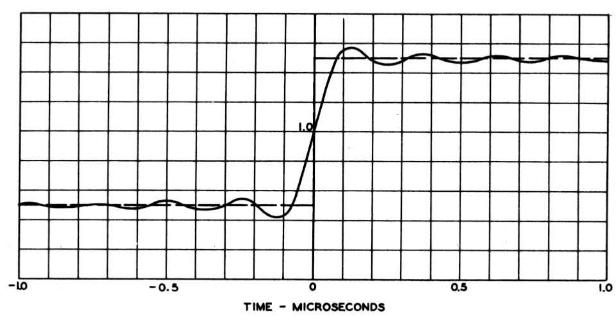


Fig. 12- Response to the step function of Fig. 11 ($M=\frac{1}{2}$) for a circuit which has unity gain for all frequencies below 4.1 Mc, zero response above 4.1 Mc, and linear phase shift.

To find the signal at the transmitter modulator, use may be made of previously developed material to operate upon the term $\sin(\omega t)$ in Eq. (28). Three frequency regions must be considered.

First, when $0<f<f_B-f_o$, Eq. (13) teaches that $\sin(\omega t)$ becomes $\frac{\sin(\omega t)}{3}[1+2\cos(\omega_o t)]$ at the transmitter modulator.

Secondly, when $f_B-f_o<f<f_A$, Eq. (18) shows that $\sin(\omega t)$ becomes $\frac{1}{2}\sin(\omega t) - \frac{1}{2}\sin(\omega_o-\omega)t$ at the transmitter modulator.

Then also in the region where $f_A<f<f_B$, Eq. (23) shows that $\sin(\omega t)$ is unchanged.

Eq. (12) tells that the unit value in Eqs. (27) and (28) become simply $\frac{1}{3}[1+2\cos(\omega_o t)]$.

When these operations are performed on Eq. (27), the signal into the transmitter modulator is

$$\text{T.M.S.} = \frac{1}{3}[1+2\cos(\omega_o t)]$$

$$+\frac{2M}{3\pi}\left[1+2\cos(\omega_o t)\right]\int_{\beta=0}^{\beta=\infty} d\beta \int_{\omega=0}^{\omega=2\pi(f_B-f_o)} \sin(\omega\beta)\ \sin(\omega t)d\omega$$

$$+\frac{M}{\pi}\int_{\beta=0}^{\beta=\infty} d\beta \int_{\omega=2\pi(f_B-f_o)}^{\omega=2\pi f_A} \sin(\omega\beta)\sin(\omega t)d\omega$$

$$-\frac{M}{\pi}\int_{\beta=0}^{\beta=\infty} d\beta \int_{\omega=2\pi(f_B-f_o)}^{\omega=2\pi f_A} \sin(\omega\beta)\sin(\omega_o-\omega)t\cdot d\omega$$

$$+\frac{2M}{\pi}\int_{\beta=0}^{\beta=\infty} d\beta \int_{\omega=2\pi f_A}^{\omega=2\pi f_B} \sin(\omega\beta)\sin(\omega t)d\omega \qquad (29)$$

Integration and combination of terms yields

$$\text{T.M.S.} = \frac{1}{3}\left\{1\pm 2\cos(\omega_o t)\right\}\left\{1+\frac{2M}{\pi}\text{Si}\left[2\pi(f_B-f_o)t\right]\right\}$$

$$+\frac{M}{\pi}\left\{2\text{Si}(2\pi f_B t) - \text{Si}(2\pi f_A t) - \text{Si}\ 2\pi(f_B-f_o)t\right\}$$

$$\pm\frac{M}{\pi}\cos(\omega_o t)\left\{\text{Si}(2\pi f_A t) - \text{Si}\left[2\pi(f_B-f_o)t\right]\right\}$$

$$\pm\frac{M}{\pi}\sin(\omega_o t)\left\{\text{Ci}[2\pi(f_B-f_o)t] - \text{Ci}(2\pi f_A t)\right\} \qquad (30)$$

where $\text{Ci}(x)$ = Integral cosine of $x = -\int_x^\infty \frac{\cos u}{u}du$. Where the $\pm$ signs appear in Eq. (30), the plus sign applies to the first scan of the line and the minus sign applies to the second scan of the same line.

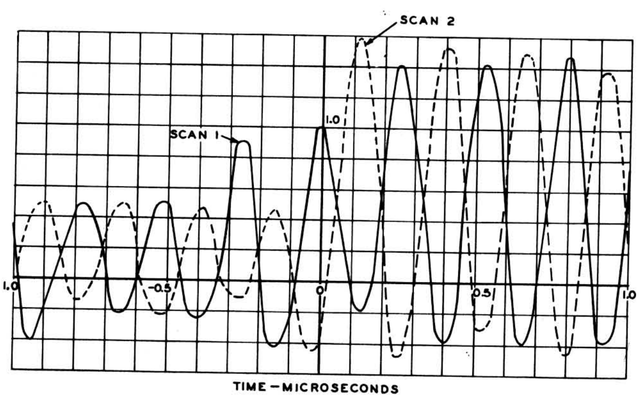


Fig. 13- Transmitter modulator signal, for two successive scans of the same line. Also the signal on the kinescope grid of a conventional black-and-white receiver.

It should be noted that Eq. (30) is also the voltage appearing on the kinescope grid in a black-and-white receiver. Fig. 13 is a plot of Eq. (30) for the following conditions:

$$M = \tfrac{1}{2}$$
$$f_B = 4.1 \text{ Mc.}$$
$$f_o = 3.8 \text{ Mc.}$$
$$f_A = 2.0 \text{ Mc.}$$
$$f_B - f_o = 0.3 \text{ Mc.}$$

and may be considered as the transmitter modulator signal for two successive scans of the same line, as well as the signal on the kinescope grid of a conventional black-and-white receiver. Fig. 14 shows the combined light intensity of two successive scans of the same line on a black-and-white receiver. This latter figure, constructed graphically from Fig. 13, shows close agreement with Fig. 12.

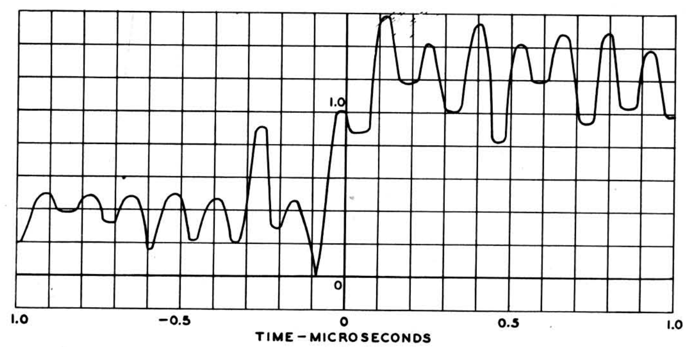


Fig. 14- Combined light intensity of two successive scans of the same line on a black-and-white receiver.

b. Response of a color television receiver

To find the signal on the kinescopes of a color television receiver, the operating procedure on the $\sin(\omega t)$ term of Eq. (27) is determined by referring to Eqs. (15), (20), and (24). These equations show that $\sin(\omega t)$ is converted to $\frac{\sin(\omega t)}{3}[1+2\cos(\omega_o t)]$ in all frequency regions up to f_B so the signal on the green kinescope is simply

$$\text{G.K.S.} = \frac{1}{3}\left[1\pm 2\cos(\omega_o t)\right]\left[1+\frac{2M}{\pi}\ \text{Si}(2\pi f_B t)\right] \qquad (31)$$

where the $\pm$ signs apply to the first and second scans of the same line.

Comparison of Eqs. (28) and (31) shows that the signal on the green kinescope is a perfect reproduction of the green camera signal multiplied by the sampling function. Fig. 15 shows a plot of Eq. (31), the signal on the green kinescope grid of a color television receiver, for the same frequency restrictions used in the previous calculations, while Fig.16 shows the combined light intensity of two successive scans of the same line on the green kinescope of a color television receiver.

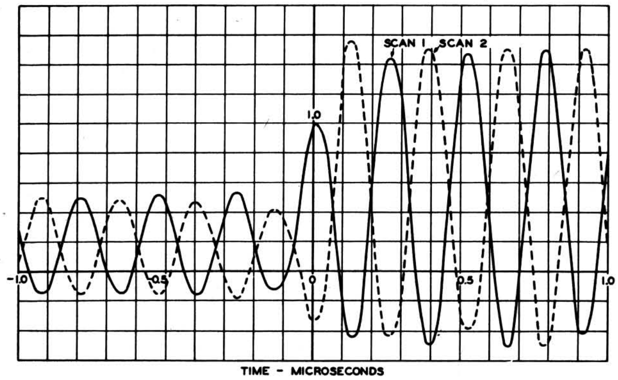


Fig. 15– Signal on the green kinescope grid of a color television receiver.

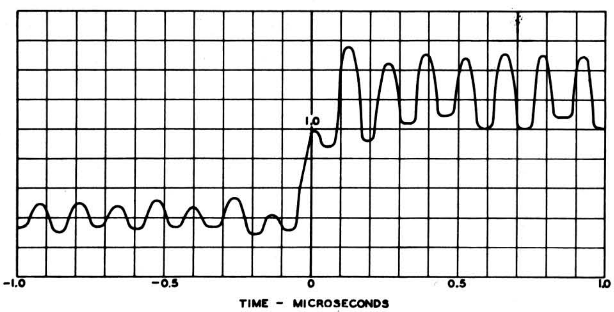


Fig. 16– Combined light intensity of two successive scans of the same line on the green kinescope of a color television receiver.

The cross talk may be deduced by using Eqs. (21) and (25) for the red tube cross talk and Eqs. (22) and (26) for the blue tube cross talk in conjunction with Eq. (27). Then the red kinescope signal is

$$R.K.S. = \frac{2M}{\pi}\left\{1 \pm 2\cos(\omega_o t - 120^\circ)\right\}\left\{\frac{1}{3}Si(2\pi f_B t) - \frac{1}{4}Si(2\pi f_A t) - \frac{1}{12}Si\left[2\pi(f_B - f_o)t\right] + \frac{\sqrt{3}}{12}Ci\left[2\pi(f_B - f_o)t\right] - \frac{\sqrt{3}}{12}Ci(2\pi f_A t)\right\} \quad (32)$$

and the blue kinescope signal is

$$B.K.S. = \frac{2M}{\pi}\; 1 \pm 2\cos(\omega_o t + 120^\circ)\; \frac{1}{3}Si(2\pi f_B t) - \frac{1}{4}Si(2\pi f_A t) - \frac{1}{12}Si\left[2\pi(f_B - f_o)t\right] - \frac{\sqrt{3}}{12}Ci\left[2\pi(f_B - f_o)t\right] + \frac{\sqrt{3}}{12}Ci(2\pi f_A t) \quad (33)$$

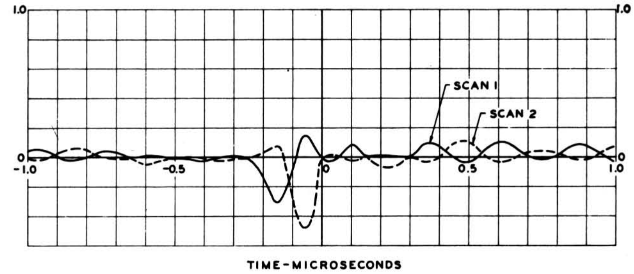


Fig. 17– Cross talk voltage on the red kinescope grid for two successive scans of the same line.

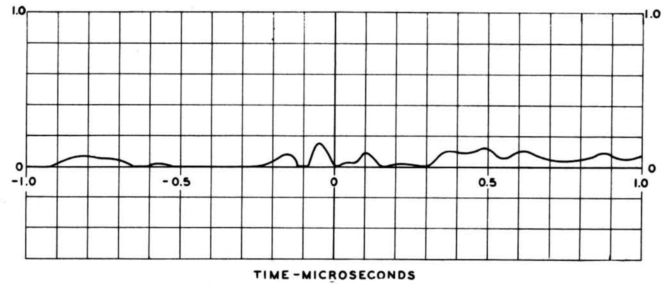


Fig. 18– Combined light intensity of two successive line scans of the same line on the red kinescope.

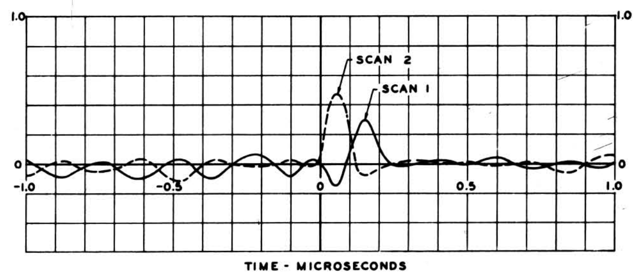


Fig. 19– Cross talk voltage on the blue kinescope grid for two successive line scans of the same line on the blue kinescope.

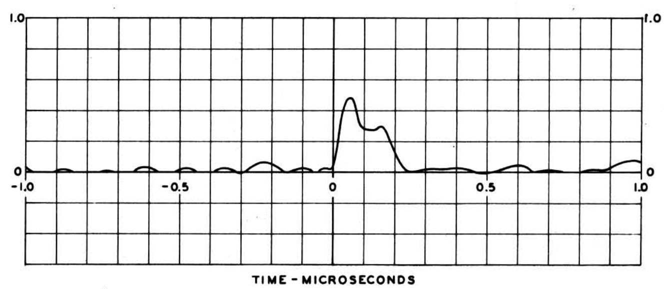


Fig. 20– Combined light intensity of two successive line scans of the same line on the blue kinescope.

Fig. 17 shows the cross-talk voltage on the red kinescope grid for two successive scans of the same line, while Fig. 18 displays the combined light intensity of two successive line scans of the same line on the red kinescope.

Fig. 19 and Fig. 20 show corresponding effects for the blue kinescope.

Cross-Talk Elimination between the Green and the Red Channels when $f_B - f_o < f < f_A$

It was observed in Section *III*, where the frequency of the signal component lies between $f_B - f_o$ and f_A, that the color cross-talk terms may be up to 50 per cent of the desired terms. While it has not yet been clearly established that it is necessary to reduce or eliminate this cross talk, rather simple circuit expedients are possible to completely eliminate the cross talk. It should be remembered that the response in the mixed-high region has not been considered to be cross talk, since the crossing of signals in this region has been regarded as entirely legitimate.

a. Simple modification of the transmitter sampler

As a first step in describing a number of possibilities, a simple modification of the transmitter sampler may first be considered. Fig. 21 shows the part of Fig. 1 which has been changed somewhat. The mixed-high circuits have been unchanged but are not shown. The low-pass filters in the red and the green channels as before pass frequencies up to f_A, but now have unity gain up to $f_B - f_o$ and have a gain of 2.0 from this frequency up to f_A. The low-pass filter in the blue channel may cut off at $f_B - f_o$, since the eye is very poor in resolving power in the blue.

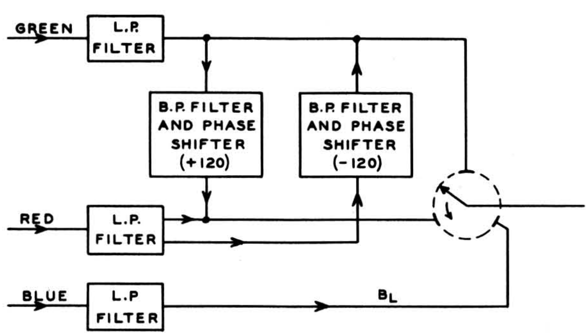


Fig. 21- Circuit modifications at the transmitter to eliminate cross talk between the red and green channels.

A band-pass filter and phase shifter connect the output of the low-pass filter in the green channel to the input of the red sampler. This channel passes frequencies between $f_B - f_o$ and f_A, the region where it is desired to eliminate cross talk. The signal from the green channel to the red sampler position is made one-half of the signal going to the green sampler position. In addition, all the frequency components are advanced 120 degrees in phase in passing through the circuit. This latter condition is quite easily brought about by a double modulating and filtering process. The corresponding element going from the red channel to the green sampling position has the same characteristics except that the phase of the components is retarded by 120 degrees.

With the signal $g \cdot \sin(\omega t)$ coming from the green camera, the signal going into the green sampler position at the transmitter is $2g \cdot \sin(\omega t)$. This signal is sampled by the function $\frac{1}{3}[1+2\cos(\omega_o t)]$ and becomes $\frac{2g}{3}\sin(\omega t) - \frac{2g}{3}\sin(\omega_o-\omega)t$. The signal into the red sampler (from the green channel through the phase shifter) is $g.\sin(\omega t+120^\circ)$. This signal is sampled by the function $\frac{1}{3}[1+2\cos(\omega_o t-120^\circ)]$ yielding a signal out of the red sampler of $\frac{g}{3}\sin(\omega t+120^\circ) - \frac{g}{3}\sin[(\omega_o-\omega)t-240^\circ]$. The total signal into the modulator is

$$\frac{g}{\sqrt{3}}\left\{\sin(\omega t+30^\circ) - \sin\left[(\omega_o-\omega)t+30^\circ\right]\right\} \qquad (34)$$

When Eq. (34) is sampled at the color receiver by the green sampler, using the sampling function

$$\frac{1}{3}\left[1+2\cos(\omega_o t) + 2\cos(2\omega_o t) + \text{---}\right]$$

the signal on the green kinescope grid becomes

$$\frac{g \cdot \sin(\omega t)}{3}\left[1+2\cos(\omega_o t)\right]$$

However, when Eq. (34) is sampled by the red sampler at the receiver, using the sampling function

$$\frac{1}{3}\left[1 + 2\cos(\omega_o t-120^\circ) + 2\cos(\omega_o t-240^\circ) + \text{---}\right]$$

the signal on the red kinescope grid becomes identically zero.

Thus, a method of completely eliminating the cross talk between the red and the green channels in the frequency region above $f_B - f_o$ and below f_A has been displayed.

b. Addition of a low-pass filter to the color receiver

The additions of Fig. 21 may be added to the transmitter without any changes in the receiver of Fig. 3. If color receivers of this type were in operation in the field, the changes in the transmitter shown in Fig. 21 could be made without altering a single receiver. The immediate effect would be an elimination of cross talk in the region in question between the green and red channels. The cross talk of red and green into the blue channel would be unchanged, but because of the high-frequency nature would probably be of no consequence. Cross talk of the blue into red or green would be eliminated by restricting the components of the blue signal to frequencies less than f_B-f_o by means of the low-pass filter in the blue channel preceding the transmitter sampler.

As another experiment to investigate the matter of reduction of cross talk, a low-pass filter could be inserted in the video amplifier circuit leading to the blue kinescope in Fig. 3. This filter would also remove the f_o sampling component in the blue channel.

Before proceeding with an examination of other circuit details, it may prove interesting to see what has happened to the step function response for the receiver and transmitter condition described in this section.

The desired response of the signal at the green kinescope has remained unchanged and is given by Eq. (31) and by Figs. 15 and 16. The cross-talk conditions have changed, however. For instance, in the red channel, the only signal-mixing components are those that have been placed there deliberately by the use of mixed highs. The signal on the red kinescope grid due to the step function in the green channel is

$$R.K.S. = \frac{2M}{3\pi}\left[1 \pm 2\cos(\omega_o t-120^\circ)\right]\left[Si(2\pi f_B t) - Si(2\pi f_A t)\right] \qquad (35)$$

Fig. 22 shows the signal corresponding to Eq. (35) for two scans of the same line, with $M=\frac{1}{2}$, $f_B=4.1$ Mc, $f_A=2.0$ Mc, and $f_o=3.8$ Mc. Fig. 23 shows the combined light intensities on the red tube for two scans of the same line, and Fig. 24 has been constructed by adding Fig. 23 to Fig. 16, since the contribution from the red tube came entirely from the use of the mixed-highs.

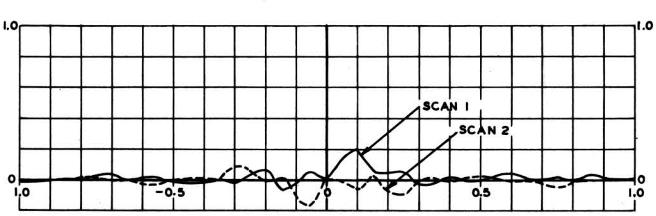


Fig. 22- Signal on grid of red kinescope due to step function in the green channel and the use of mixed highs.

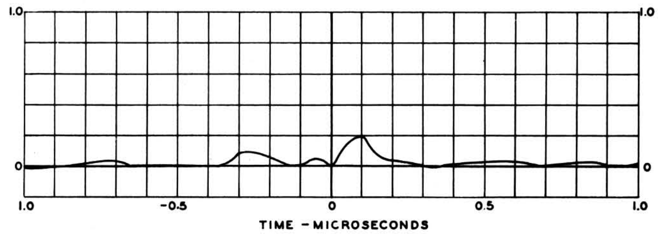


Fig. 23- Combined light intensities on the red tube.

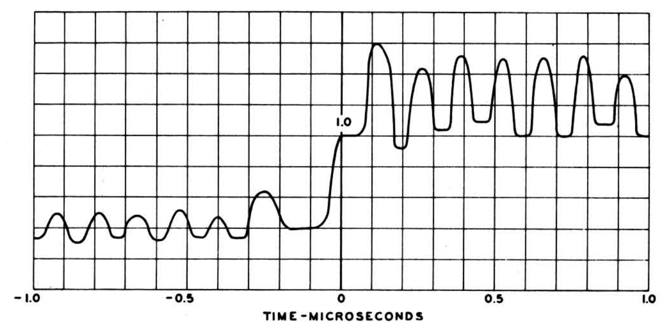


Fig. 24- Combined light intensities from red and green kinescopes.

c. Increased resolution in the blue channel

In the previous example, a method of eliminating cross talk between the red and green channels has been displayed, but the resolution in the blue channel to f_B-f_o (0.3 Mc in the numerical example.) has been restricted. If it should prove desirable to follow the above path of exploration and it became evident that greater resolution were desired in the blue channel, the resolution could be doubled by a simple sampling or interrupting method with dot interlacing. By this method, the resolution could be increased to $2(f_B-f_o)$, or 0.6 Mc in the example.

Suppose that a sampler with a very broad pulse but sampling at a rate of twice the frequency f_B-f_o is incorporated in the blue channel and this sampler is followed by a low-pass filter which cuts off at one half the sampling frequency. Also a simple dot interlace is introduced. Let f_s be the sampling frequency. Then suppose the signal from the blue camera tube is $B+b\cdot\sin(\omega t)$. The function $1+\cos(\omega_s t)$

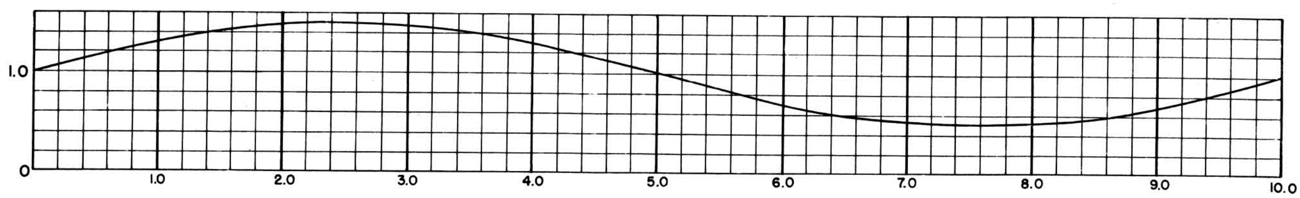


Fig. 25(a) – Signal out of the blue camera tube, $1+\frac{1}{2}\sin(\omega t)$, with a frequency of 0.1 Mc.

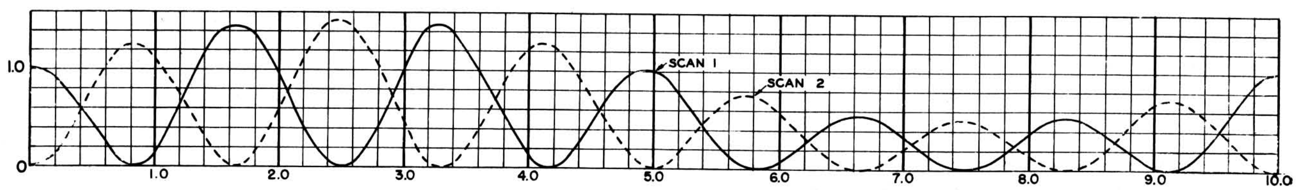


Fig. 25(b) – Effective light intensities for two scans on the same line of the blue tube. Sampling frequency is 0.6 Mc.

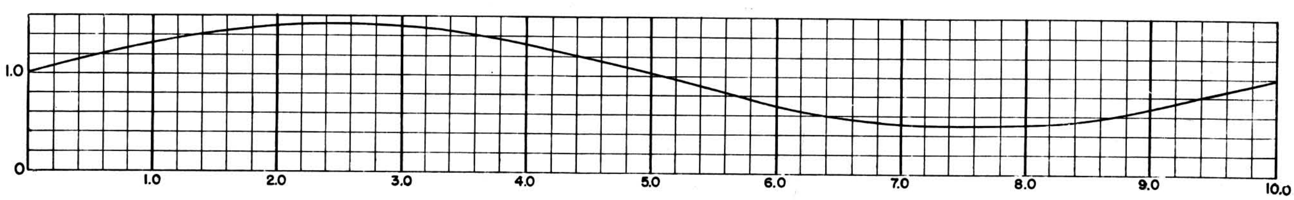


Fig. 25(c) – Sums of the light intensities for the two scans of Fig. 25(b).

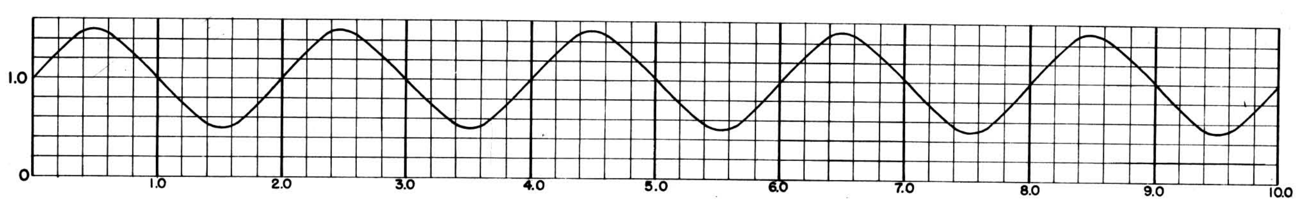


Fig. 26(a) – Signal out of the blue camera tube, $1+\frac{1}{2}\sin(\omega t)$, with a frequency of 0.5 Mc.

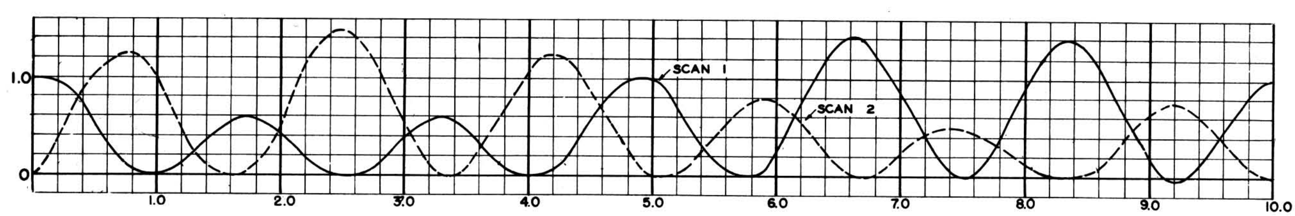


Fig. 26(b) – Effective light intensities for two scans on the same line of the blue tube. Sampling frequency is 0.6 Mc.

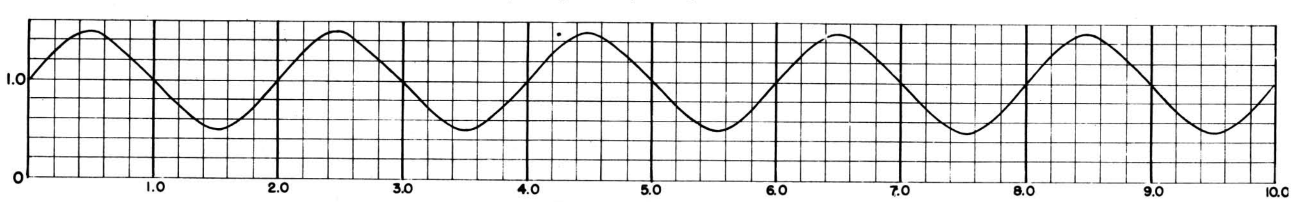


Fig. 26(c) – Sums of the light intensities for the two scans of Fig. 26(b).

will be used for sampling. When the frequency f is less than $f_s/2$, the signal out of the sampler and the low-pass filter is simply $B + b \cdot \sin(\omega t)$. This signal at the receiver is again sampled, this time by the function $\frac{1 \pm \cos(\omega_s t)}{2}$, giving

$$[B + b \sin(\omega t)]\left[\frac{1 \pm \cos(\omega_s t)}{2}\right]$$

Fig. 25 has been prepared, using

$$B = 1$$
$$b = \tfrac{1}{2}$$
$$f = 0.1 \text{ Mc}$$
$$f_s = 0.6 \text{ Mc}$$

Fig. 25(a) shows the original function, while Fig. 25(b) shows the effective light intensities for two scans. Fig. 25(c) shows the sums of the light intensities for the two scans of Fig. 25(b).

When the frequency f is greater than $f_s/2$, the response of the preceding circuits must be doubled. Hence the signal arriving at the sampler will be $B + 2b \sin(\omega t)$. After sampling at the transmitter by the function $1 \pm \cos(\omega_s t)$ the signal at the receiver second detector is $B \mp b \sin(\omega_s - \omega)t$. The second sampling at the receiver by the function $\frac{1 \pm \cos(\omega_s t)}{2}$ yields

$$\frac{B\,[1 \pm \cos(\omega_s t)]}{2} + \frac{b}{2}\sin(\omega t) \mp \frac{b}{2}\sin(\omega_s - \omega)t$$

Fig. 26 has been prepared, using

$$B = 1$$
$$b = \tfrac{1}{2}$$
$$f = 0.5 \text{ Mc}$$
$$f_s = 0.6 \text{ Mc}$$

Fig. 26(a) shows the original function, while Fig. 26(b) shows the effective light intensities for two scans. Fig. 26(c) shows the sums of the light intensities for the two scans of Fig. 26(b).

This procedure illustrates the use of dot interlacing to obtain 0.6 Mc resolution with a channel width of 0.3 Mc.

The high-frequency sampling has been omitted from consideration in the above analysis. The signals from the blue channel are, of course, sampled at frequency f_0 just as the red and green signals, but the filter at the receiver removes all traces of this sampling on the blue tube.

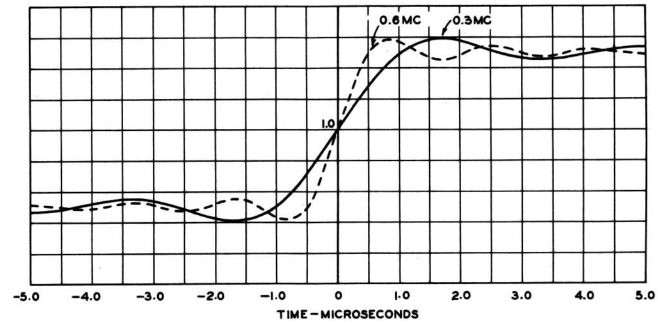


Fig. 27– Change in step function for two frequency bands, one limited to 0.3 Mc and the other limited to 0.6 Mc.

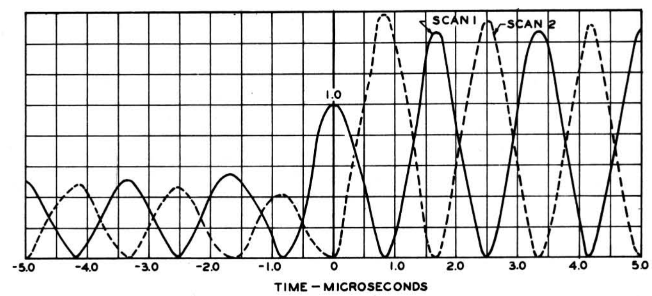


Fig. 28– Step function response on grid of blue kinescope tube with dot-interlacing and sampling.

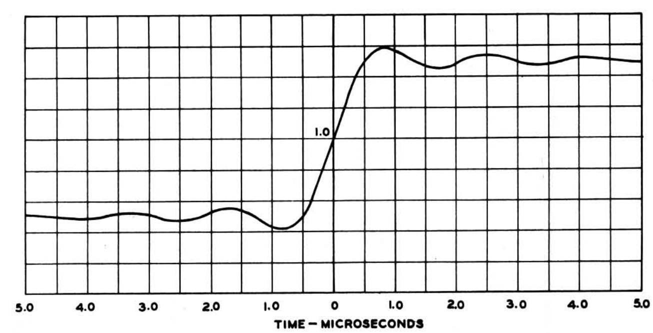


Fig. 29– Addition of light intensities on the blue tube, obtained by adding the curves of Fig. 28.

Fig. 27 shows the change in a step function for two cases, first where the frequency band is limited to 0.3 Mc, and secondly where the band is restricted to 0.6 Mc. The increased steepness due to the wider band is apparent.

The step function response on the grid of the blue kinescope is given by

$$\text{B.K.S.} = \frac{[1 \pm \cos(\omega_s t)]}{2}\left[1 + \frac{2M}{\pi} \cdot Si(\omega_s t)\right] \pm \frac{M}{\pi}\sin(\omega_s t)\left[Ci\left(\frac{\omega_s t}{2}\right) - Ci(\omega_s t)\right] \qquad (36)$$

Fig. 28 shows Eq. (36) plotted for two line scans, where $M=\frac{1}{2}$ and f_s is 0.6 Mc. Fig. 29 shows the addition of light intensities from Fig. 28. It may be seen that Fig. 29 is an exact reproduction of the dotted curve of Fig. 27.

Conclusion

Cross talk as a function of the width of the sampling pulse at both the transmitter and the receiver has been examined and limits established for reasonable cross talk. It is shown that narrow sampling at the receiver is more important than narrow sampling at the transmitter.

The sampling procedure was examined for large areas of color with a sinusoidal variation of the color. It was shown that the frequency pass-band was divided into three regions, the lower in which no cross talk existed, a middle region where 50 per cent cross talk was possible, and an upper region where signal-mixing was expected because of the adoption of mixed highs. For the various cases, the role of dot interlacing was explained. In addition, the action on conventional black-and-white receivers as well as on color receivers was examined.

The sampling procedure has been examined as it applies to step functions of light intensity. The response of a black-and-white receiver has been examined and the desired and undesired responses of a color receiver have been displayed.

A method of cross-talk elimination in the middle region is described. This method might be applied as an experiment in three parts. First, a simple cross-coupling and phase-shifting network is applied to the transmitter sampler. This circuit eliminates the cross talk between the red and the green channels in the middle region. No change is necessary at the receiver to take this first step. As a second improvement, a low-pass filter might be added in the blue channel at the receiver to knock out cross talk from the red and green into the blue channel. This step restricts the definition of the blue channel. A third step is suggested which doubles the resolution of the blue channel by a sampling and interlacing procedure.

The analysis and display of curves show that the sampling process in the RCA Color Television System, together with the use of mixed highs provides a good uncoupling of the color channels together with full resolution equivalent to black-and-white transmission in the same channel.

The construction leading to Fig. 10(g) emphasizes that the output of the sampler is the *product* of input signal and the gating function. This fact, together with the principle of mixed highs, produces full detail limited only by total bandwidth available. A study of Eq. (31) shows that the rise time of the envelope is determined by the highest frequency passed in the mixed-highs circuit at the transmitter.

Throughout this report, the signals were considered as having originated from a single primary color. If an area is a mixture of colors, the analysis may be carried out on the basis of the superposition of the individual responses to the three primary colors. Where, in the mixture of colors, the two stronger primaries are nearly equal in intensity the variation due to the sampling frequency shown in Figs. 7(c) and 8(c) virtually disappears, particularly on a standard black-and-white receiver.

During November, 1949, the sampling frequency of the RCA Color Television System used experimentally in Washington was reduced from 3.8 to approximately 3.6 Mc. Many of the calculations contained in this report were already completed at that time and were made on the basis of a sampling frequency of 3.8 Mc. Rather than repeat the many laborious computations for the slight change in sampling frequency, the remainder of the calculations were continued at a sampling frequency of 3.8 Mc. No very major change would have been apparent in the plotted results. The region free of cross talk in the simplest form of the system $(0<f<f_B-f_o)$ would have been extended from 0.3 Mc to 0.5 Mc.

Appendix I

Reproduction of High-Frequency Detail with a Low Sampling Rate

The previous analysis illustrated by Fig. 10 showed the manner in which high-frequency detail was reproduced when the high-frequency component of the signal had a frequency in the mixed-high region. Specifically, in Fig. 10, the frequency of the picture component was chosen to be 3.4 Mc, while the sampling frequency was 3.8 Mc. Fig. 10(g) was noted to be a rather good reproduction of the original function shown in Fig. 10(a). However, it was realized that since the sampling frequency was only ten per cent greater than the signal frequency, the construction of Fig. 10 did not fully establish the fact that the high-frequency detail was produced by a multiplication of the input signal and the gating function. Accordingly, the calculations have been repeated in this appendix, but this time using a sampling frequency of 2.4 Mc and a picture signal component of 4.0 Mc. Here, the picture signal component is 67 per cent *higher* than the sampling frequency, so the phenomenon is well illustrated.

The signal from the green camera tube is $G+g\cdot\sin(\omega t)$. For purposes of this illustration, f has been chosen as 4.0 Mc, $G=1$ and $g=\frac{1}{2}$. Fig. 30(a) shows this signal $1+\frac{1}{2}\sin(\omega t)$.

The d-c signal G goes through the transmitter sampler, but since the a-c term is of a frequency lying in the region committed to "mixed-highs," this latter signal goes through Adder No. 2 and the appropriate band-pass filter into Adder No. 1 of Fig. 1. Hence the signal into the transmitter modulator is

$$\frac{G}{3}[1\pm2\cos(\omega_0 t)]+g\cdot\sin\omega t \qquad (37)$$

Equation (37) also applies to the voltage on the kinescope grid of a black-and-white receiver. The background term is sampled while the mixed-high signal, unsampled, is superimposed to supply fine detail. The positive polarity sign applies to the first scan of a line, while the negative sign applies to the second scan of the same line.

The signal out of the second detector of a color receiver also has the same form as Eq. (37). Sampling in the receiver results in a signal on the grid of the green kinescope of the form

$$\frac{1}{3}[G+g\cdot\sin(\omega t)][1\pm2\cos(\omega_0 t)] \qquad (38)$$

A plot of this expression is shown in Fig. 30(b) with a sampling frequency of 2.4 Mc.

The output of the blue sampler (the voltage on the grid of the blue kinescope) is

$$\frac{g}{3}\sin(\omega t)\ [1\pm2\cos(\omega_0 t+120^\circ)] \qquad (39)$$

while the voltage on the grid of the red kinescope is

$$\frac{g}{3}\sin(\omega t)[1\pm2\cos(\omega_0 t-120^\circ)] \qquad (40)$$

The voltage on the blue kinescope is shown in Fig. 30(c), while the voltage on the red kinescope is given by Fig. 30(d).

Following the procedure of Fig. 10, the positive values of Figs. 30(c) and 30(d) have been combined with the positive values of Fig. 30(b) to show the effect of the combined light intensities for two successive scans of the same line. The result of this combination is shown in Fig. 30(e).

Inspection shows that Fig. 30(e) is a satisfactory reproduction of Fig. 30(a). However, it is well known that the resolution of the eye is very poor in blue, so it seems better to combine only Fig. 30(d) with Fig. 30(b), with Fig. 30(f) resulting. This latter curve is an excellent reproduction of Fig. 30(a). It should be noted that the periodicity of the curve of Fig. 30(f) corresponds to a frequency of 4.0 Mc, and bears no relation to the periodicity of the sampling function.

The construction leading to Fig. 30(f), and particularly Fig. 30(b), emphasizes that the output of the sampler is the *product* of the input signal and the gating function. This fact, together with the principle of mixed highs, produces full detail limited only by total bandwidth available. This conclusion is further strengthened by examining the response of the system to a step function.

Fig. 31 has been constructed from Eq. (31) to show the signal on the green kinescope when

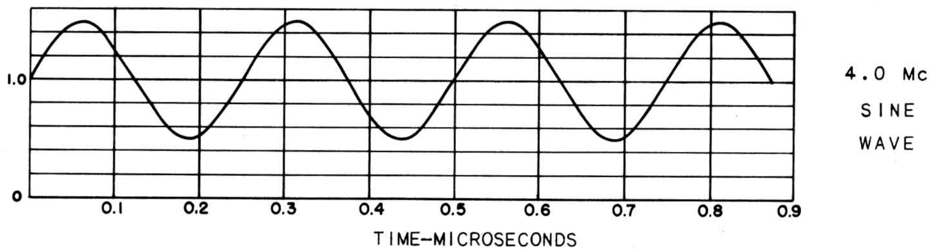


Fig. 30(a) - Signal out of green camera tube; f=4.0 Mc, $G+g.\sin(\omega t) = 1+\frac{1}{2}\sin(\omega t)$

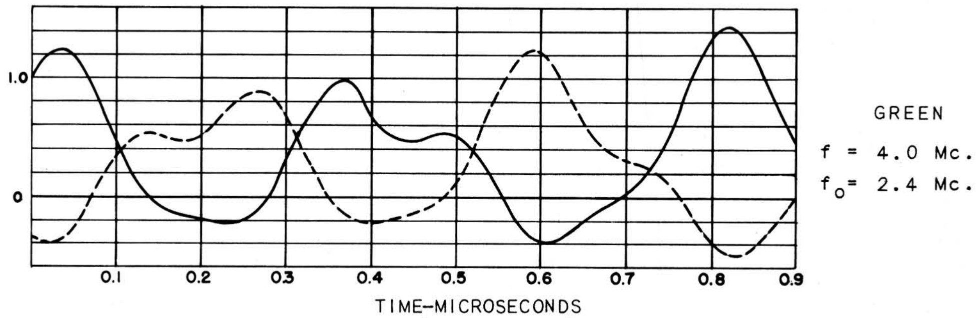


Fig. 30(b) - Signal on the green kinescope grid of a color television receiver.

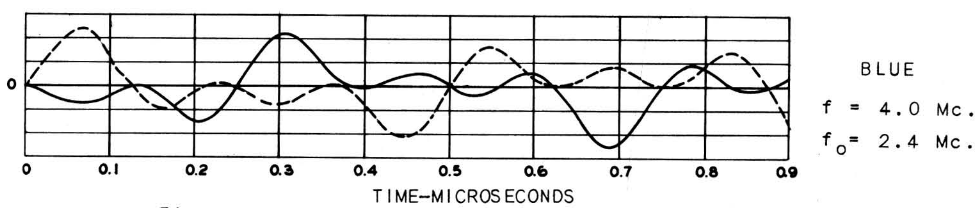


Fig. 30(c) - Voltage on the blue kinescope grid.

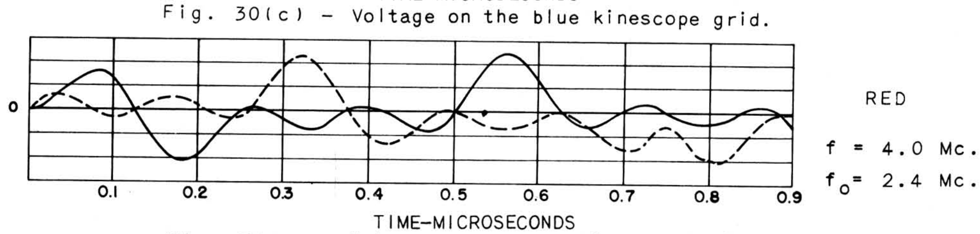


Fig. 30(d) - Voltage on the red kinescope grid.

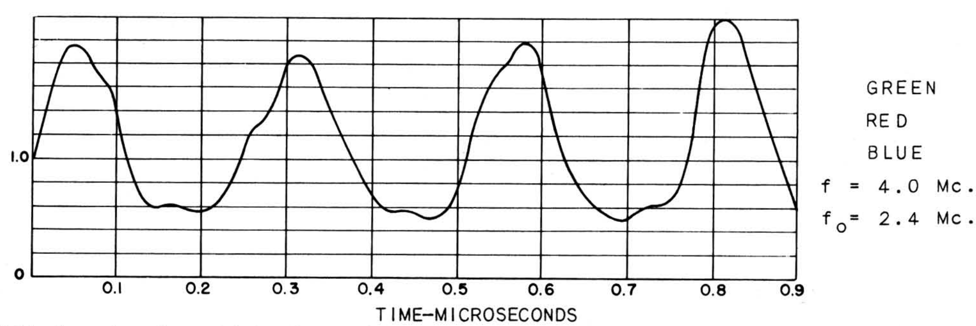


Fig. 30(e) - Combined light intensity of two successive scans of the same line, obtained by adding light intensities of the green, red and blue tubes.

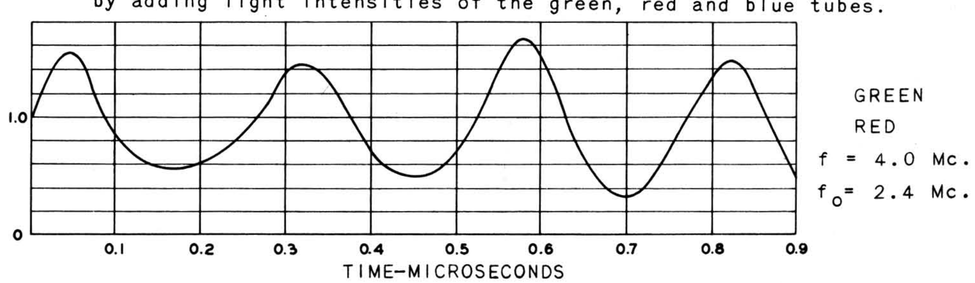
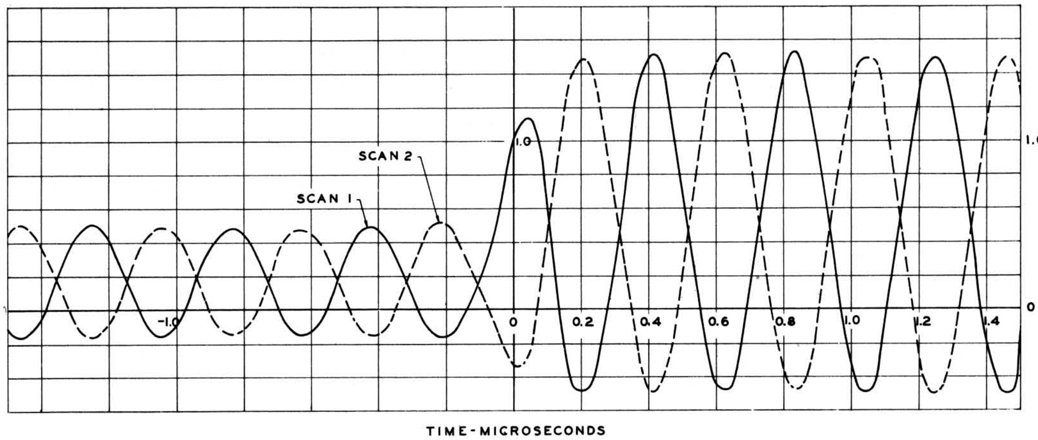


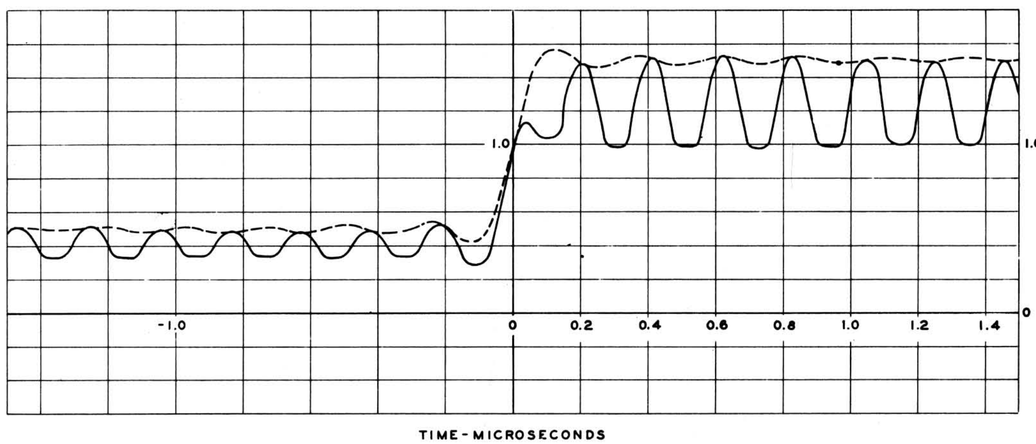
Fig. 30(f) - Combined light intensity of two successive scans of the same line, obtained by adding light intensities of the green and red tubes. The sampling frequency is 2.4 Mc.



GREEN RESPONSE
TO BAND LIMITED
STEP FUNCTION
f_O= 2.4 Mc.
f_B= 4.1 Mc.

TIME-MICROSECONDS

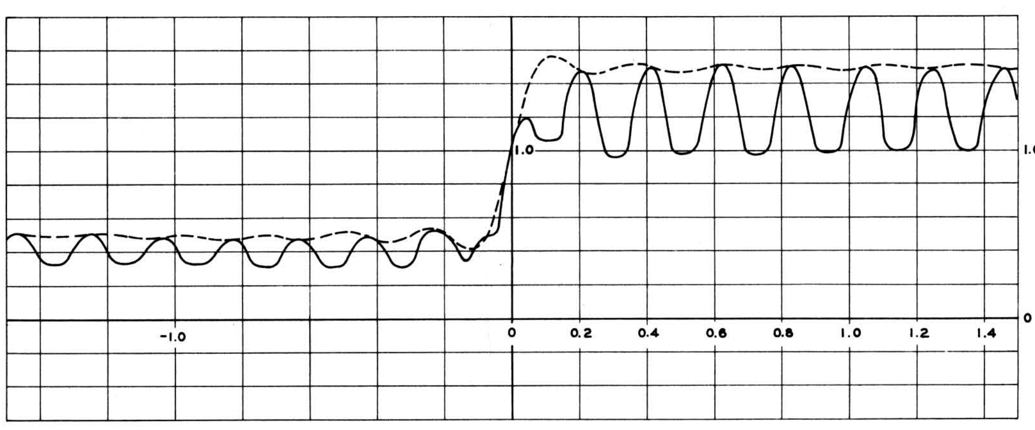
Fig.. 31– Response to step function. Signal on the green kinescope grid of a color television receiver. Sampling frequency is 2.4 Mc.



GREEN RESPONSE
TO BAND LIMITED
STEP FUNCTION
SUMS OF SCANS
f_O= 2.4 Mc.
f_B= 4.1 Mc.
f_A= 2.0 Mc.

TIME-MICROSECONDS

Fig. 32– Response to step function. Combined light intensity of two successive scans of the same line on the green kinescope of a color television receiver. Sampling frequency is 2.4 Mc.



GREEN RESPONSE
WITH CROSS TALK
ADDED
f_O= 2.4 Mc.
f_B= 4.1 Mc.
f_A= 2.0 Mc.

TIME-MICROSECONDS

Fig. 33– Response to step function. Combined light intensities from the red and the green kinescopes. Sampling frequency is 2.4 Mc.

the initial signal is a step function as shown in Fig. 11, with $M=\frac{1}{2}$, and with a sampling frequency of 2.4 Mc. The transmission band has been limited to 4.1 Mc. Fig. 31 corresponds to Fig. 15, except for the choice of sampling frequency.

Fig. 32 shows the combined light intensity of two successive scans of the same line on the green kinescope of a color television receiver, obtained by adding the positive values of the two curves of Fig. 31. The dashed line in Fig. 32 is taken from Fig. 12 to show the best response possible in a frequency band limited to video frequencies less than 4.1 Mc.

The mixed-high signal on the red kinescope grid due to the step function in the green channel is given by Eq. (35). The positive values of this function, when added to the curve of Fig. 32, result in Fig. 33. It should be noted that Fig. 32 corresponds to Fig. 16 and Fig. 33 corresponds to Fig. 24, except that in Figs. 16 and 24, the sampling frequency is 3.8 Mc, and in Figs. 32 and 33, the sampling frequency is 2.4 Mc.

Appendix II

Transmission of the RCA Color Television Signal on Coaxial Cables of Restricted Bandwidth

Presently available coaxial cables used in networking of monochrome television signals will pass no signals of frequencies greater than approximately 2.7 Mc. Since the sampling frequency in the RCA Color Television System as used experimentally in Washington is approximately 3.6 Mc*, color information is lost when the composite signal usually used to modulate the transmitter is transmitted over the coaxial cable.

While it is anticipated that coaxial cables of at least 4-Mc bandwidth will be made available by the time that such cables are needed for commercial color television transmission, it is desirable to make use of the present cables for experimental purposes in the interim period.

When a standard monochrome television signal containing information out to 4 Mc is passed over the 2.7-Mc cable, the picture definition is reduced accordingly. It is the purpose of this appendix to describe two versions of a method of transmitting the RCA color television signals over the present coaxial cables, retaining color information and accepting loss of resolution corresponding to that suffered by a monochrome signal over the same transmission medium.

Fig. 34 shows a diagram of the first method of transmission. The normal color system components are shown with dashed lines at the left. The components added for the low-frequency cable transmission are shown with solid lines at the right.

The crystal oscillator which provides the normal sampling signal feeds into a regenerative multiplier which produces a sampling signal which is exactly two-thirds the frequency of the normal sampling signal, namely, 2,388,750 cycles. This latter signal, together with the synchronizing signals and the simultaneous green, red and blue signals from the camera are fed to a transmitter-type sampler especially provided at the originating station. The output of this sampler then feeds into the coaxial cable. A color synchronizing burst with a frequency of 2,388,750 cycles is placed on the back porch of the horizontal synchronizing pedestal for transmission over the cable. At the receiving end of the cable, a receiver-type sampler is provided, with sampling of each color taking place at a rate of 2,388,750 times per second. Low-pass filters, with cutoff below this sampling frequency, are placed in the green, red and blue outputs of this sampler. These three signals are then used to feed a normal transmitter sampler at the station which is being programmed by the coaxial cable transmission. The 2,388,750-cycle burst over the cable is multiplied up to 3,583,125 cycles to provide the sampling control for the latter station.

The method shown in Fig. 34 is a direct approach to the problem of transmitting the color information over the limited bandwidth coaxial cable. A second method is shown by the block diagram of Fig. 35. This version applies mixed highs to utilize more effectively the bandwidth available for transmission. Color information is transmitted with detail up to 0.3 Mc, with signal mixing to apply mixed highs extending upward from 0.3 Mc.

To illustrate the principles of operation, assume that the signal from the green camera tube is

$$G.C.S. = G + g \cdot \sin \omega_1 t + g_2 \sin \omega_2 t \qquad (41)$$

where $f_1 < 0.3$ Mc

and $0.3 < f_2 < 2.1$

The signal into the 2.4-Mc sampler at the sending end of the cable is simply

$$G + g_1 \sin \omega_1 t \qquad (42)$$

*In the above report, the sampling frequency was assumed to be 3.8 Mc. Since November, 1949, the sampling frequency used at the WNEW transmitter in Washington has been 3,583,125 cycles per second. The ratio of this latter number to the scanning line frequency of 15,750 lines per second is 227½. This fractional relationship affords a direct means of obtaining the dot interlace. At the present time, the color synchronization is obtained by transmitting a burst, several cycles duration, of the sampling signal on the back porch of the horizontal synchronizing pedestal. This burst, as well as the sampling component in the picture signal, is removed by the bandwidth limitations of the coaxial cable.

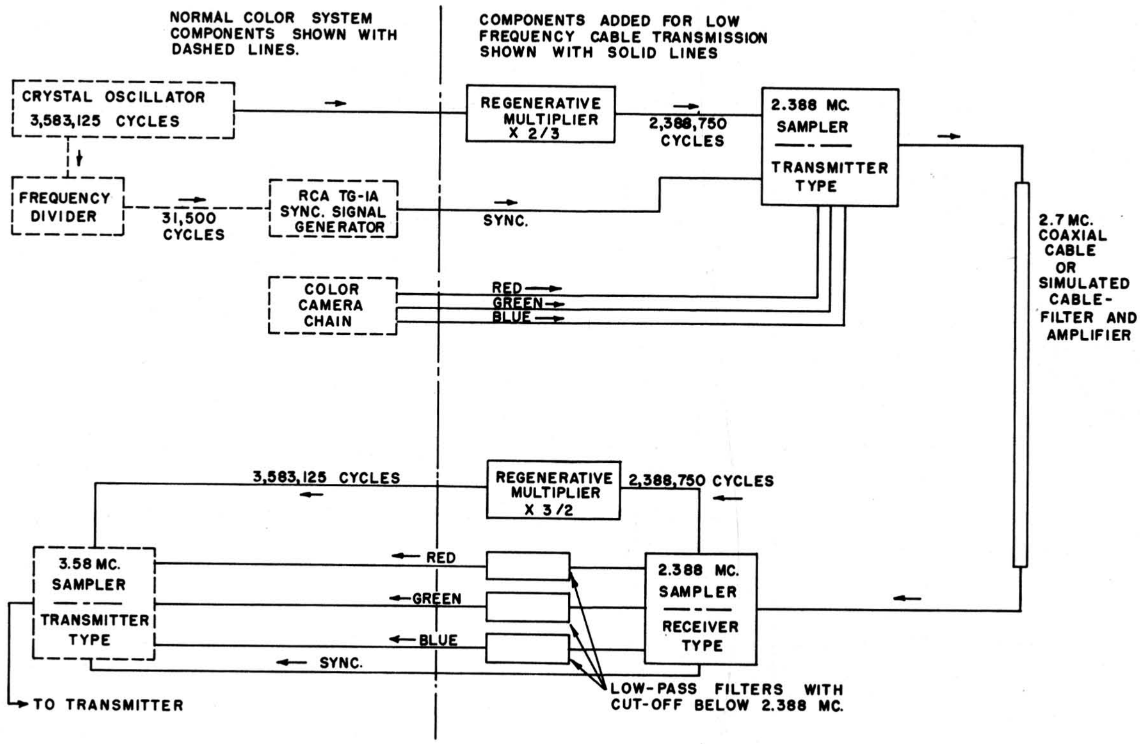


Fig. 34- Block diagram of the equipment used to transmit color television signals over coaxial cables of restricted bandwidth.

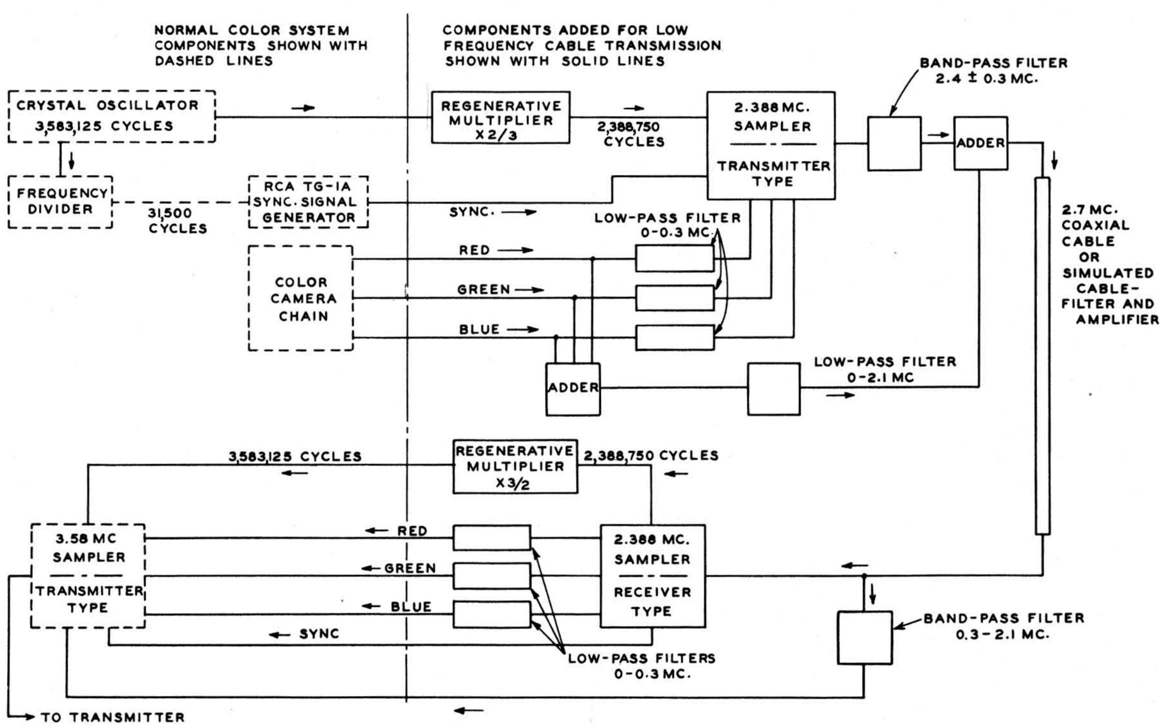


Fig. 35- A modification of the cable equipment which makes more effective use of the available band.

since the low-pass (0-0.3 Mc) filters remove the last term of (41).

When the signal of Eq. (42) is sampled in the usual fashion, there obtains

$$K_1[G+g_1 \sin \omega_1 t]\left[\frac{1+2\cos(\omega_s t)}{3}\right]$$
$$=\frac{K_1 G}{3}+\frac{K_1 g_1}{3}\sin \omega_1 t+\frac{2K_1}{3}[G+g_1 \sin \omega_1 t]$$
$$\cdot \cos(\omega_s t) \qquad (43)$$

where f_s is the sampling frequency of 2.4 Mc. The band-pass filter following the sampler wipes out the first two terms of Eq. (43) so the remaining signal going to the adder is simply

$$K_2\ [G+g_1 \sin \omega_1 t]\cdot \cos(\omega_s t) \qquad (44)$$

It should be noted that this filtering action has removed any requirement of short duty factor in sampling. In fact, the sampler can be an ordinary balanced modulator.

The entire signal given by Eq. (41) is bypassed around the sampler. The output of the adder feeding the cable is then the sum of Eqs. (41) and (44),

$$\text{cable signal} = K_3[G+g_1 \sin \omega_1 t+g_2 \sin \omega_2 t]$$
$$+K_2[G+g_1 \sin(\omega_1 t)]\ \cos(\omega_s t) \qquad (45)$$

At the receiving end of the cable, the signal $K_3 g_2 \sin \omega_2 t$ goes through the band-pass filter and is used on retransmission as a regular mixed-highs signal.

Before studying the action of the sampler at the receiving end of the cable, it is assumed that the gain controls at the transmitting end have been set so that $K_2 = 2K_3$. Then the cable signal of Eq. (45) becomes

$$K_3[G+g_1 \sin \omega_1 t][1+2\cos \omega_s t]+K_3 g_2 \sin \omega_2 t \qquad (46)$$

Reference to Eqs. (14) and (15) and the adjacent text shows that when the signal of Eq. (46) goes through the sampler *and* low-pass filter at the receiving end of the coaxial cable, the signal on the green output is

$$K_4[G+g_1 \sin \omega_1 t] \qquad (47)$$

This signal goes directly to the 3.6-Mc sampler of the station which is programmed by the coaxial transmission.

This latter method provides color detail up to 0.3 Mc, and intensity detail up to 2.1 Mc.

Appendix III

The Action of the RCA Color Television System in the Presence of an Abrupt Red-Green Transition

The analysis presented in the main body of the report, as it related to step functions, was confined to changes in a single color, that is, to intensity changes. Another effect which is encountered is that of abrupt changes in color where the colors are almost identical in intensity values.

For an illustration of this effect, refer to Fig. 36. Here a small patch of a scene is depicted where the scene is red on the left and green on the right. It shall be assumed that the red and green areas are of such color values that equal average electrical signals are produced by the red camera tube and the green camera tube.

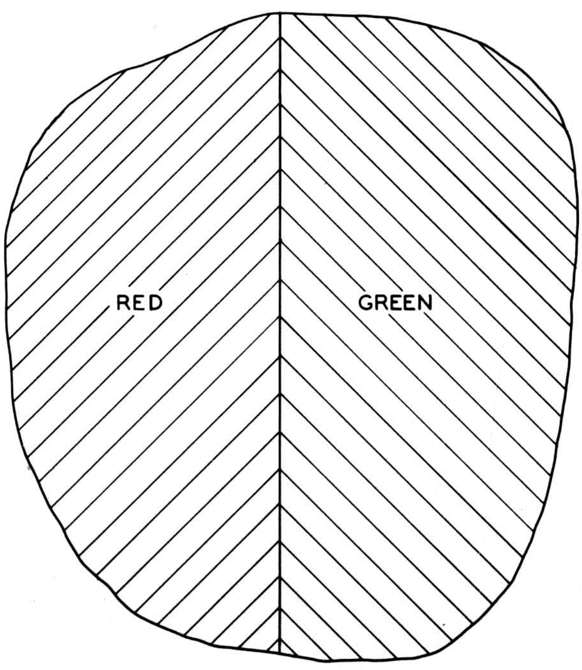


Fig. 36– An area where the transition from red to green produces constant light intensity.

The signal out of the green camera tube (with no frequency limitations) would be similar to that shown in Fig. 11, with M set equal to unity. The signal out of the red camera tube would be an opposite step, that is, the signal would have a prescribed value for t less than zero and would have zero value for t greater than zero. This would be achieved analytically by setting M equal to −1.

If the signal from each camera is limited to less than the top pass frequency, f_B, the green camera signal is obtained from Eq. (28). Then (with M=1)

$$G.C.S. = 1 + \frac{2}{\pi}\int_{\beta=0}^{\beta=\infty} d\beta \int_{\omega=0}^{\omega=2\pi f_B} \sin(\omega\beta)\sin(\omega t)\,d\beta$$

$$= 1 + \frac{2}{\pi}\int_{\beta=0}^{\beta=\infty} d\beta \int_{\omega=0}^{\omega=2\pi f_A} \sin(\omega\beta)\sin(\omega t)\,d\omega + \frac{2}{\pi}\int_{\beta=0}^{\beta=\infty} d\beta \int_{\omega=2\pi f_A}^{\omega=2\pi f_B} \sin(\omega\beta)\sin(\omega t)\,d\omega \qquad (48)$$

and the red camera signal is (with M=−1)

$$R.C.S. = 1 - \frac{2}{\pi}\int_{\beta=0}^{\beta=\infty} d\beta \int_{\omega=0}^{\omega=2\pi f_B} \sin(\omega\beta)\sin(\omega t)\,d\beta$$

$$= 1 - \frac{2}{\pi}\int_{\beta=0}^{\beta=\infty} d\beta \int_{\omega=0}^{\omega=2\pi f_A} \sin(\omega\beta)\sin(\omega t)\,d\beta - \frac{2}{\pi}\int_{\beta=0}^{\beta=\infty} d\beta \int_{\omega=2\pi f_A}^{\omega=2\pi f_B} \sin(\omega\beta)\sin(\omega t)\,d\omega \qquad (49)$$

The mixed-highs signal is found to be the sum of the last term in Eq. (48) and the last term in Eq. (49). This sum is seen to be zero. Physically, this result comes about from the fact that the alternating terms which make up the green step are identical except for a reversal of polarity to the alternating terms which make up the red step. For a standard monochrome camera viewing the patch of Fig. 36, no transition would be visible.

Although it is shown above that no mixed-high signal exists, the action of a color television receiver for this situation may still be analyzed by utilizing the principle of superposition. That is, the green step may be analyzed just as if the red step did not exist, and vice versa. Then the two solutions may be superimposed.

The signal on the green kinescope of a color television receiver, due to the green step alone, is found from Eq. (31) to be

$$(G.K.S.)_g = \frac{1}{3}\left[1 \pm 2\cos(\omega_o t)\right]\left[1 + \frac{2}{\pi}Si(2\pi f_B t)\right] \qquad (50)$$

According to Eq. (35), this green step alone produces a signal on the red kinescope grid which is

$$(R.K.S.)_g = \frac{2}{3\pi}\left[1 \pm 2\cos(\omega_o t - 120°)\right]\left[Si(2\pi f_B t) - Si(2\pi f_A t)\right] \quad (51)$$

Conversely, the signal on the red tube from the red step alone is found from Eq. (31) by setting M equal to −1, and taking account of the fact that the red sampler lags the green sampler by 120 degrees. This latter signal is

$$(R.K.S.)_r = \frac{1}{3}\left[1 \pm 2\cos(\omega_o t - 120°)\right]\left[1 - \frac{2}{\pi}Si(2\pi f_B t)\right] \quad (52)$$

The cross talk term on the green kinescope due to the red step is likewise found from Eq. (35) to be

$$(G.K.S.)_r = \frac{-2}{3\pi}\left[1 \pm 2\cos(\omega_o t)\right]\left[Si(2\pi f_B t) - Si(2\pi f_A t)\right] \quad (53)$$

The total signal on the green kinescope grid due to the color transition shown in Fig. 36 is found by adding Eqs. (50) and (53), yielding

$$G.K.S. = \frac{1}{3}\left[1 \pm 2\cos(\omega_o t)\right]\left[1 + \frac{2}{\pi}Si(2\pi f_A t)\right] \quad (54)$$

The total signal on the red kinescope grid due to the color transition shown in Fig. 36 is found by adding Eqs. (51) and (52).

$$R.K.S. = \frac{1}{3}\left[1 \pm 2\cos(\omega_o t - 120°)\right]\left[1 - \frac{2}{\pi}Si(2\pi f_A t)\right] \quad (55)$$

These last two equations show that the response to the transition in color shown in Fig. 36 produces no detail greater than the frequency f_A. In other words, the mixed-high signals have cancelled to zero.

The green kinescope signal as found from Eq. (54) for two successive scans of the same line is shown in Fig. 37. The sum of the positive values of these two responses is also shown. This latter curve may be regarded as the light intensity, under the usual assumptions of kinescope and system linearity. The sampling frequency f_o, hasbeen taken as 3.8 Mc.

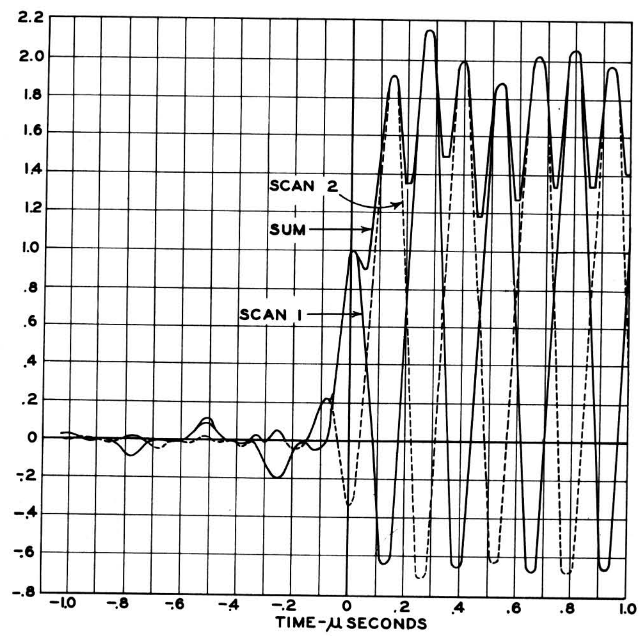


Fig. 37– Signal on the green kinescope grid of a color television receiver in the transition region of Fig. 36. The sum curve may be regarded as the combined light intensity of two successive scans.

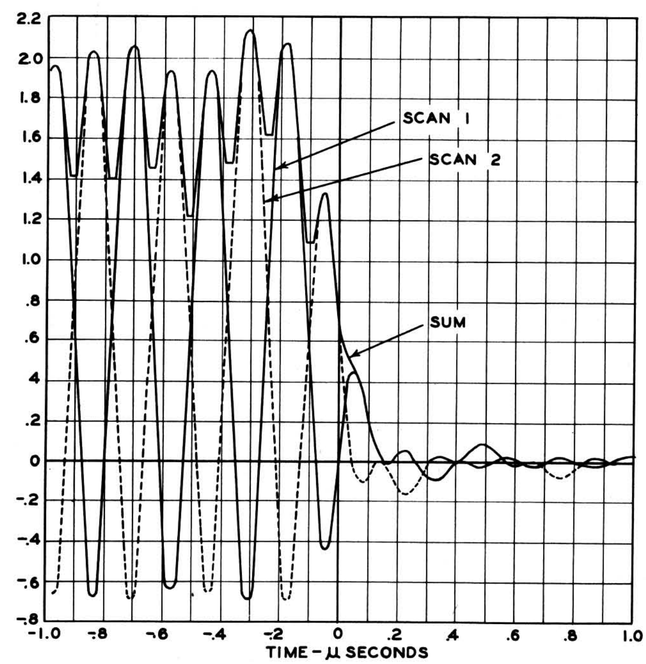


Fig. 38– Signal on the red kinescope grid of a color television receiver in the transition region of Fig. 36. The sum curve may be regarded as the combined light intensity of two successive scans.

Similar calculations, using Eq. (55), are displayed in Fig. 38. The sampling frequency, f_o, was taken to be 3.8 Mc.

The red and green light intensity sums are shown in Fig. 39, where it may be seen that the steepness of rise of the green and the steepness of fall of the red is limited to 2 Mc, since f_A has been set at 2 Mc in these calculations.

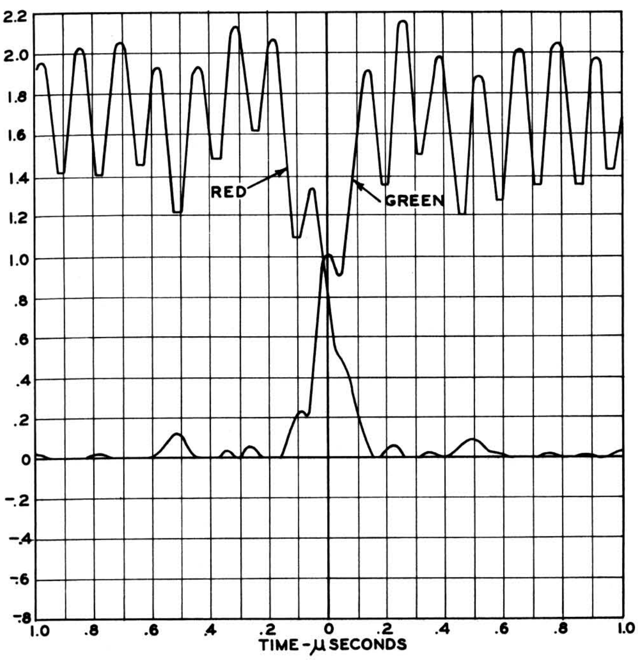


Fig. 39- Combined light intensity for two successive scans of the same line, for the transition region of Fig. 36. The light intensity on the red and green tubes are shown separately.

It is apparent that for a color transition such as shown in Fig. 36, the detail at the transition is limited to frequencies no greater than f_A, the lower frequency limit of the mixed highs, and that detail between f_A and f_B is lost.

This effect might at first thought be considered to be serious defect in the RCA color television system. On the contrary, it is on this point that RCA color television system again makes use of the ability of the eye to distinguish detail in brightness and the inability of eye to see detail in color differences. Observer tests which have been made by RCA show that the acuity of the eye for detail residing in color differences is less than half as great as the acuity for detail residing in brightness. To satisfy the eye observing a color television picture at a particular distance, it is not necessary to transmit information regarding the *color* of certain tiny areas even though these areas are large enough to be distinguished by differences in brightness. Accordingly, it is not necessary in scanning from area to area of the picture to be able to change from one color to another as quickly as it is necessary to change from one brightness to another. These tests have demonstrated the ability of the RCA color television system to produce brightness detail to an extent limited only by the total bandwidth allowed. Since the frequency f_A, the lower limit of the mixed-high region, has been chosen to be 2 Mc with a 4-Mc bandwidth, the system operates well within the limits set by physiological effects. As a matter of fact, the detailed results* show that the choice of the lower limit of the mixed highs has been a very sound one.

It is of interest to note from Fig. 39 that a standard black-and-white receiver subjected to this color signal would show no distinction between the two areas. Likewise, a standard monochrome camera viewing the area showed in Fig. 36 would not produce significant information on a black-and-white receiver.

*These results will be released in a forthcoming bulletin, *Mixed Highs in Simultaneous Color Television*.