A 45-degree Reflection-Type Color Kinescope

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A One-Gun Shadow-Mask Color Kinescope

Introduction

This bulletin describes a direct-view shadow-mask three-color kinescope employing a single electron gun. Color selection in this tube, is accomplished by controlling the direction of approach of a single electron beam to a direction-of-approach sensitive color screen. For sequential presentation the beam is shared in time sequence between the three primary colors. For simultaneous presentation the beam is shared continuously among the three primary colors. The new problems presented by the one-gun shadow-mask color kinescope arise from the special requirements placed on the electron optical system, from the need for deflecting the beam into different color positions, and in the case of sequential presentation, from the necessity for blanking-off the beam as it is switched from one color-position to the next. Practical solutions to these and other problems are presented.

General Discussion

This one-gun shadow-mask color kinescope is an outgrowth of the RCA work on all-electronic color television. It makes use of a single electron gun and a direction-of-approach sensitive color screen which emits light of any combination of the three primary colors depending upon the direction of arrival of the impinging electrons. Because an electron beam has very little inertia and its direction of approach can readily be changed, a single beam from a single electron gun can be shared in time sequence between the primary colors to reproduce a color television picture from any color television signal capable of sequential[1] presentation; alternatively, by the use of appropriate color signal circuits, the single beam can be shared continuously among the three primary colors to achieve simultaneous reproduction from signals which so permit. In each case the brightness signal is applied to the electron gun control grid, but the method of color selection depends upon the mode of presentation. In the case of field-sequential or line-sequential presentation, stepwise switching from color to color is desired. In the case of dot-sequential presentation, sine-wave switching by circular deflection with uniform angular velocity is preferred. In the case of simultaneous presentation, the color signals determining hue and saturation are applied to the color-selection deflection system to vary the direction of approach continuously.

In one successful application[2], the direction of approach of a single electron beam is changed from picture element to picture element as it is made to scan a screen which employs a multiplicity of color dots and an apertured shadow-mask[3] registered therewith. Thus the electrons approaching from a particular direction can strike only a single color phosphor no

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[1] "The Present Status of Color Television", *Proc. I.R.E.*, Vol. 38, pp. 980-1002, Sept. 1950.

[2] "General Description of Receivers for the Dot-Sequential Color Television System which employ Direct-View Tri-Color Kinescopes," *RCA Review*, vol. 11, pp. 228-232, June 1950.

[3] H.B. Law, "A Three-Gun Shadow-Mask Color Kinescope," An Accompanying paper.

matter which part of the raster is being scanned. In this manner it is possible to reproduce a color television signal[4] in which a line on the raster consists of dots of the three primary colors arranged from left to right in the sequence red, blue, and green.

The concept of the one-gun tube is understood as follows. Electrons may be "color-tagged" as they leave the electron gun by imparting to them a desired direction. This is possible, because in an axially symmetric electron optical system, within the limits imposed by aberrations, electrons emerging from a common source-point at the gun may be reconverged to a common image-point at the screen carrying intact their original direction-of-approach "color tag". Control of current to represent brightness is accomplished in the conventional manner.

The operation of the one-gun color kinescope is different from the operation of the three-gun color kinescope[3] in that the beam from the single gun may be deflected away from the axis by any amount and in any direction, so that it will return to the axis with any desired direction and angle of approach. In case a dot-sequential presentation is employed, the beam is deflected, so that, in effect, it occupies in time sequence the three positions of the three guns in the three-gun kinescope. If a simultaneous presentation is employed, the direction of deflection is changed continuously to vary the angle of approach in accord with the hue and saturation information. The problems unique to the one-gun kinescope arise in part from the differences in electron optics, the need for deflecting the beam into the different color positions, and, in the case of sequential presentation, the necessity for blanking off the beam as it is switched from one color position to the next.

First, the electron optics of the one-gun color kinescope is analyzed in regard to both the basic optical principles and the fundamental limitations imposed by space charge. Second, the problem of "sampling" as used in a sequential presentation is examined, with particular regard to the color purity to be expected when the beam is keyed on and off in synchronism with the changes in direction of approach to provide automatic sampling. Third, these findings are compared with the performance of practical tubes working in accord with these principles.

Electron Optics of the One-Gun Color Kinescope

As is well known, in an axially symmetric electron optical system, in the absence of space charge and within the limits imposed by aberrations, electrons emerging from a common source-point may be reconverged to a common image-point[5]. Thus, in the electron optical system of Fig. 1, the three separate beam pencils, r, b, and g, emerge from a common object-point, o, on the axis of symmetry. They may be reconverged to a common image-point, i, also on the axis of symmetry, with direction-of-approach angles such that they might excite the phosphors, red, blue, or green, of a direction-of-approach sensitive color screen. Further, within the same basic limitations, and if the current through the dynamic convergence coil is adjusted to compensate for the fact that less convergence is required as the beam is deflected from the center, the three-pencil beam will still reconverge at a common image-point, i', on a flat screen even after it has been caused to trace out a raster by the anastigmatic deflection yoke. When an individual beam pencil is traced through the system, it will be found that the direction of approach of the beam pencil at the image is related to the direction of emergence of the beam pencil from the object.

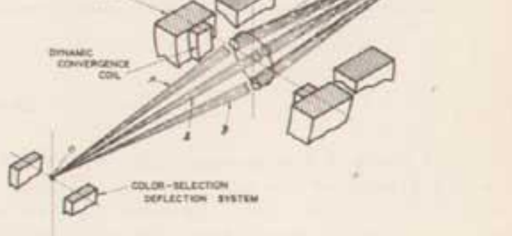

FIG.1

Fig. 1 - Electron optics of the one-gun color kinescope.

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[4] RCA Laboratories Division, "A 6-Mc Compatible High-Definition Color Television System," *RCA Review*, vol. 10, pp. 504-524, December 1949.

[3] loc. cit.

[5] Bruche und Scherzer, "Geometriche Electronoptik," Julius Springer 1934.

Thus, a single beam pencil may be used to give any one of the desired primary colors by deflecting the beam pencil into any one of the positions, r, b, or g. It should be emphasized that the functions of the color selection deflection system and the anastigmatic deflection yoke are quite independent: the color selection deflection system serves to "color-tag" the electrons as they leave the gun; the anastigmatic deflection yoke serves to deflect the beam over the raster. As a result the "color-tagged" beam may be focused on the screen and deflected over a raster in much the same manner as the beam in a conventional cathode ray tube except for the greater diameter of the composite beam which necessitates a wider aperture electron optical system.

The requirements on the elements of this electron-optical system will become less stringent as the beam pencils are crowded closer and closer together. But it will be seen from Fig. 1, that as the angle-of-approach is reduced, the individual beam pencils must be made smaller and smaller if they are not to overlap. The question now arises whether space charge mutual repulsion effects will permit the individual beam pencils to be made as small as desired. This problem of space charge is of much greater concern for the one-gun tube than for the three-gun tube because of the different current requirements. When the one-gun color kinescope is used to reproduce a color television picture sequentially[2], the single electron beam is shared in time sequence between the three primary colors and blanked off as it is switched from one color position to the next. As a result, the average beam current to any particular color phosphor can only be a small fraction of the peak current capability of the single electron gun. When allowance is made for this low duty factor and the loss of electrons on the shadow-mask, peak beam currents of several milliamperes may be required to give a picture of adequate brightness.

A rigorous analysis of space charge effects is beyond the scope of this presentation, but a simple approximate analysis suffices to give a satisfactory indication of the point where space charge effects may become important. In terms of the geometry of Fig. 2, by making certain simplifying assumptions, Thompson and Headrick[4] have shown that for a beam of circular cross section the minimum radius is

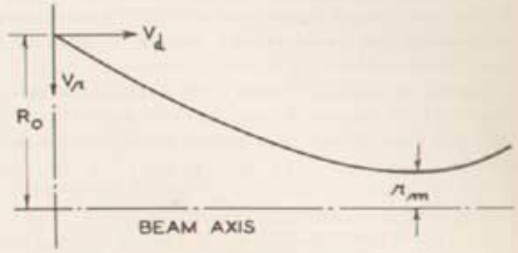

Fig. 2 - Diagram of a half-longitudinal section of a beam of circular cross section beyond an electron lens.

given by

$$r_m = R_o e^{-(V_d m/4Ie)V_r^2} \qquad (1)$$

where:

R_o - Initial radius of outer beam surface, cm.

r_m - Minimum radius of beam, cm.

V_r - Initial inward component of velocity of outer electrons, cm/sec.

V_d - Axial component of velocity of the beam, cm/sec.

I - Electron beam current, e.s.u.

e - Electronic charge, e.s.u.

The assumptions made in developing this relationship are: first, the radial component of the velocity of the electrons as they leave the electron lens is assumed to be proportional to their distance from the beam axis; second, the beam is assumed to be a uniform cylinder of electrons moving in a field-free space, except for the field due to the electron charge density of the beam; and third, the axial velocity of the electrons in the beam is assumed to be constant. In practice the deviations from the assumptions will tend to increase the size of the focused spot. For the purpose of this analysis, this relation will be construed as setting a lower limit to the beam size obtainable in a high vacuum rather than being a measure of the spot size.

In a practical design of the one-gun shadow-mask color kinescope the lens-to-screen distance is 14 inches, the angle of approach is 1.2 degrees and the second anode voltage is 18

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[2] loc. cit.

[4] B.J. Thompson and L.B. Headrick, "Space Charge Limitations on the Focus of Electron Beams", *Proc. IRE*, Vol. 28, pp. 318-324, July 1940.

kilovolts[2]. In this case, a simple computation based on the geometry of Fig. 1 will show that if the beams are not to overlap, the diameter of the individual beam pencils in the plane of the converging lens cannot exceed 0.52 inch. Translated in terms of the geometry of Fig. 2, R_b cannot be greater than 0.26 inch. Furthermore, if the converging lens is adjusted so that the beam comes to a point focus in the absence of space charge corresponding to low levels of beam current, V_r cannot be greater than 0.0187 V_a. Under these specific conditions, the variation of r_m with I as computed by equation (1) is shown in the following Table I.

Table I

I (milliamperes)	r_m (inches)
15	0.035
9	0.009
6	0.002

The practical tube for which the above calculations were made gives a picture approximately 9 inches high[2]. For 500-line vertical resolution the spot should not be more than 0.009-inch radius, and if space charge effects are to be unimportant, r_m as computed above must certainly be less than 0.009 inch. If the point where space charge effects limit the performance is arbitrarily taken to be that point were r_m equals 0.009 inch, Table I shows that the beam current should not exceed 9 milliamperes.

By a similar calculation one may determine the limiting beam current corresponding to other beam-approach angles. The results of these calculations are shown in the following Table II. As is to be expected, the limiting beam current varies as the square of the beam-approach angle.

Table II

Maximum beam current that can be focused in spot (milliamperes)	Beam-approach angle (degrees)
9	1.2
3	0.7
1	0.4

In the preceding calculation for a tube with a lens-to-screen distance of 14 inches and an angle-of-approach of 1.2 degrees, we saw that the individual beam pencils might approach one-half inch in diameter at the plane of the converging lens. By similar reasoning, it is easily shown that the composite beam may exceed one inch in diameter. It has been possible to provide an electron optical system which will handle this relatively large diameter beam. As already pointed out in connection with Fig. 1, this system includes a large aperture primary converging lens, an auxiliary dynamic convergence lens to compensate for the fact that less convergence is required as the beam is deflected from the center, and an anastigmatic deflection system. Some of these problems have been encountered in the design of projection tube systems. It is known that a large aberration-free aperture can be obtained with a sufficiently large magnetic lens located outside the tube envelope[7]. When such a primary magnetic converging lens is used, dynamic convergence is conveniently accomplished by an auxiliary coil inside the main lens. The solution of dynamic convergence and anastigmatic deflection problems are similar in both the three-gun and one-gun color kinescopes and are discussed in detail elsewhere[8].

An electron source which meets the requirements schematically indicated in Fig. 1 was suggested and developed by D.A. Jenny of RCA Laboratories. As indicated in Fig. 3, it includes a standard 5TP4 projection-type electron gun, a color selection deflection system

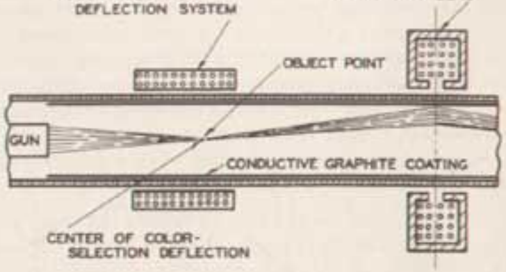

Fig. 3 - Electron optics of a developmental one-gun color kinescope.

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[2] loc. cit.

[7] R.R. Law, "High Current Electron Gun for Projection Kinescopes," *Proc. I.R.E.* vol. 25, pp. 954-976, August 1937.

[8] A.W. Friend, "Deflection and Convergence in Color Kinescopes." An accompanying paper.

which serves to deflect the beam into the successive color positions, and a converging lens which bends the beam pencils back toward the axis to form the image. The voltages applied to the electrodes of the gun are so adjusted that the beam comes to a focus at the object-point. The electron optical requirements are met when the longitudinal position of the object-point is so adjusted that the virtual object-point coincides with the virtual center of deflection of the color selection deflection system. This relationship is shown in greater detail in Fig. 4. In the field-free region beyond the deflection system the electrons are assumed to travel in straight lines. Insofar as the converging lens is concerned, the electrons appear to have originated from a virtual source at the apex of the dashed-outline cone formed by tracing the straight line trajectories back into the deflection system. Because of the finite length of the deflection system, the virtual center of deflection lies somewhat ahead of the geometric center of the color selection deflection system. Also, because the beam is bent somewhat before it reaches the virtual center of deflection, the true object-point traces out a circle around the virtual object-point.

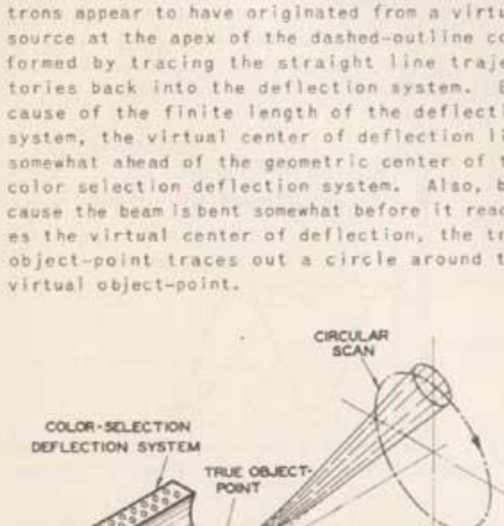

Fig. 4 - Electron trajectories in the region of the color selection deflection system.

Such a system was used with the one-gun color kinescope in the March 1950 demonstrations[2]. The standard 5TP4 projection-type electron gun was used to form the object-point. This gun, itself, is unnecessarily long for this application. Also, as the first anode voltage is lowered to move the object-point in close to the gun, less than normal beam current for the gun is obtained. By placing an auxiliary magnetic-type electron lens over the electrostatic electron lens formed by the first-to-second-anode transition as shown in Fig. 5, it is possible to raise the first anode voltage and increase the beam current several fold. This arrangement was suggested by F.H. Nicoll of RCA Laboratories. To reduce the length of the tube further, the simplified shortened electron gun shown in Fig. 6 was developed. The electron optics of this arrangement are of course similar to those encountered in the system of Fig. 5. The details of the performance of these several practical designs are reported in a later section.

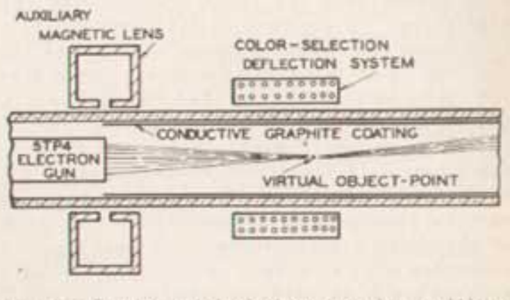

Fig. 5 - Developmental electron gun with auxiliary magnetic lens.

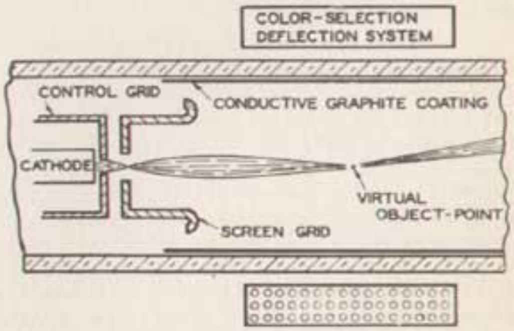

Fig. 6 - Developmental simplified short electron gun.

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[2] loc. cit.

Color Selection in the One-Gun Color Kinescope

Color selection in the one-gun color kinescope is accomplished by deflecting the beam into appropriate color positions. Because the energy stored in a magnetic field makes it difficult to suddenly change the direction of deflection, the choice of magnetic deflection or electrostatic deflection for color selection will depend upon the color system under consideration. In the case of field-sequential or line-sequential color systems, stepwise switching from color to color is desired. This problem is no more difficult than the raster scan and it should be possible to accomplish the switch by magnetic means during the beam retrace time. If the direction of approach is to be changed from picture element to picture element to provide a dot-sequential presentation of the color signal, magnetic-deflection color selection with sine-wave switching by circular deflection with uniform angular velocity is preferred since it leads to considerable circuit simplification. In the case of simultaneous presentation of the three primary colors with the brightness signal applied to the gun control grid and the color signals determining hue and saturation applied to the color selection system, the ability to change continuously is desired. The rate of change of direction of approach required will be determined by the bandwidth of the hue and saturation information. Ordinarily this bandwidth will be great enough to make electrostatic color-selection deflection desirable.

In the receiver previously described[2], dot-sequential presentation of the color signal is employed and color selection is done magnetically. The required circular deflection is provided by a small deflection yoke having two sets of coils which are fed with quadrature currents at color-sub-carrier frequency to produce a rotating field. Service adjustment of color phasing is provided by mechanical positioning of this yoke. The amplitude of the circular deflection is adjusted to produce the proper convergence angle as required by the mask and phosphor-dot screen. The duty factor of the beam is controlled by a signal having a frequency three times the color-sub-carrier frequency which is injected into the kinescope cathode circuit. The amplitude and phase of this signal are determined by the alignment of a filter circuit which utilizes the third harmonic of the circular-deflection driver tube.

The performance of the one-gun, color kinescope under the above operating conditions is well illustrated by analyzing the case of a large area single-primary-color at various relative brightness levels. The essential features of such an analysis are illustrated in Figs. 7, 8, 9, and 10. All amplitudes in these figures are expressed as relative values. Inasmuch as the circular scan is synchronized and locked in phase with the incoming signal, time may be expressed in either electrical degrees at the color-sub-carrier angular velocity or azimuth angle of the circular scan. The phase is adjusted so that the beam is centered on the desired phosphor at the moment the desired single-primary-color signal is a maximum. In the present analysis time arbitrarily starts at this instant.

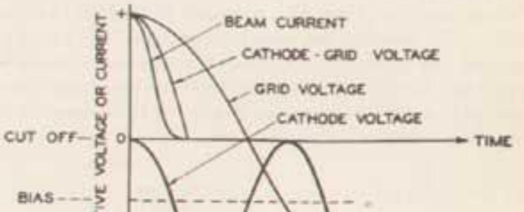

Fig. 7 - Time variation of voltage and current when reproducing a single primary color of uniform brightness.

Proceeding now to the detailed analysis, the voltage arriving at the grid is a sine wave of fundamental frequency whose amplitude is proportional to the brightness of the desired monochrome area. In keeping with the requirement that the current must be zero with zero signal, this sine wave is plotted in Fig. 7 about a voltage axis corresponding to the cut-off voltage. It is indicated by the curve labeled grid voltage. As already mentioned, the duration of the beam pulse is controlled by a signal having a frequency three times the color-sub-carrier frequency which is injected into the kinescope cathode circuit. This signal is represented in Fig. 7 by the curve labeled cathode voltage and is plotted about a voltage axis marked bias voltage equal to the peak

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[2] loc. cit.

third-harmonic voltage amplitude. The algebraic sum of these voltages is the resultant signal between the cathode and the grid. It is represented in Fig. 7 by the curve labeled cathode-grid voltage. In the particular case portrayed, the third harmonic amplitude is one-half the fundamental amplitude. When the kinescope is operated in the space-charge-limited region of its characteristic the beam current is very nearly proportional to the five-halves-power of the cathode-grid voltage. It is represented here by the curve labeled beam current.

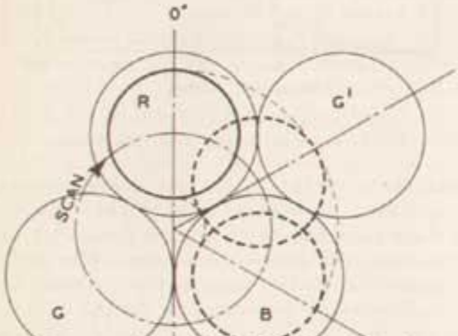

Fig. 8 - Diagram of beam positions assumed during circular color scan.

The shadow-mask screen is described elsewhere[3]. Two features are of importance in the present analysis. First, the phosphor dots of contrasting colors occupy adjacent tangent circles. Second, to provide a factor of safety for errors in mechanical alignment, the openings in the shadow mask are of such size that the electron beam transmitted by each opening arrives at the phosphor plate in a spot smaller than the individual phosphor dots. Due to the circular deflection of the beam the electron spot scans the trio of contrasting phosphor dots with a uniform circular motion as shown in Fig. 8. The position of the hole in the mask, the mask to phosphor-dot-screen distance, and the convergence angle are so related that the spot traverses a circular path from the center of the desired phosphor dot through the centers of each of the undesired phosphor dots and returns to the center of the desired phosphor dot. Thus in Fig. 8, at zero electrical degrees or zero angle of scan, it is centered on the desired phosphor dot R. At 60 degrees it impinges equally on the desired phosphor dot R and the undesired phosphor dots G' and B. G' will be recognized as one of the phosphor dots of an adjacent trio. In a similar manner, the remainder of the cycle may be traced out in detail. In the following analysis, the relative area of the spot on each of the phosphor dots has been computed for the case where the diameter of the electron spot is 80 percent of the diameter of the phosphor dots. The results of this analysis are indicated in Fig. 9. The relative areas at various angles of scan are shown by the curves r, g', and b. The analysis has been carried out for the remainder of the scanning cycle, but for reason of simplicity is not reproduced here.

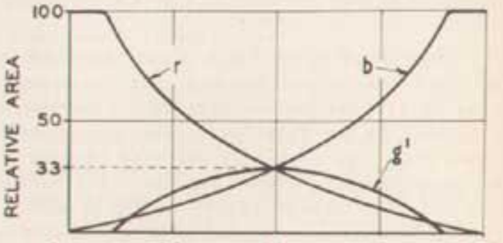

Fig. 9 - Time variation of area of each color bombarded by beam with uniform angular velocity circular scan.

The instantaneous relative excitation of the several phosphor dots is now of course the product of the relative instantaneous values of current and area. The variation of instantaneous excitation with scanning angle for one-third cycle is shown by the curves R, G', and B in Fig. 10. And finally, the relative light output of each color is numerically equal to the relative area under each of these curves. When the complete cycle is traced out in this manner, it can be shown that light of the two undesired colors is produced in equal small quantities. Since an equal small portion of the desired color may be combined with the undesired colors to produce white, the net contaminating effect may be expressed as a slight dilution. For the purpose of this analysis, dilution is arbitrarily defined as:

$$\text{Dilution} = \frac{\Sigma\,\text{Light output of undesired colors}}{\text{Light output of desired color}}$$

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[3] loc. cit.

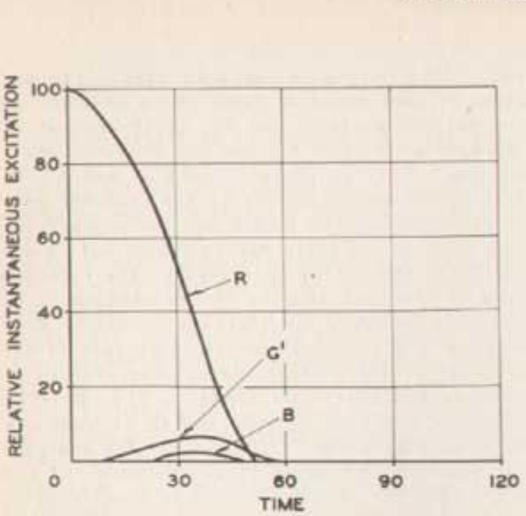

Fig. 10 – Time variation of relative instantaneous excitation of each color due to single primary-color signal.

The foregoing analysis gives the dilution and the light output for one particular operating point. During modulation corresponding to changes in the brightness level of the monochrome area, the signal on the grid changes but the third-harmonic signal applied to the cathode does not. By repeating the analysis using a fixed third harmonic signal with various relative amplitudes of the fundamental, it is possible to deduce a transfer characteristic and the dilution at corresponding points. The effect of using other relative values of the third harmonic may be computed in the same manner. The results of these computations are shown in Fig. 11. As is to be expected, the dilution decreases as the relative amplitude of the third harmonic is increased. Of particular interest from a practical standpoint is the fact that dilution can be substantially eliminated by the addition of a third-harmonic component. For example, the introduction of a 20 percent relative amplitude third harmonic reduces the dilution to about 6 percent. Also, the relative transfer characteristic is observed to change very little as the third harmonic content is changed.

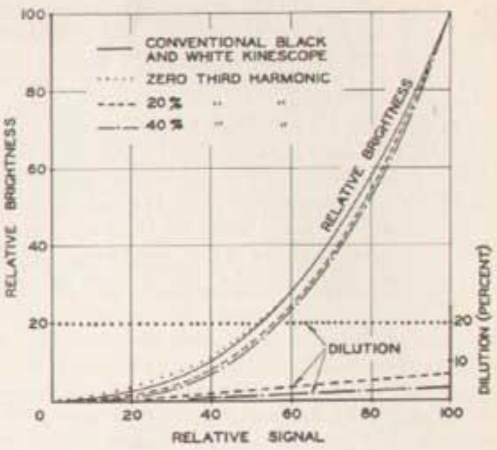

Fig. 11 – Kinescope transfer characteristic and dilution for various values of third harmonic.

To translate relative brightness into true brightness, it is necessary to know the duty-factor, i.e., the ratio of average beam current to peak beam current. Inasmuch as highlight brightness is measured in the "whites" of the picture, the duty-factor of greatest interest is that for a white field. The duty-factor for a white field is readily determined from Fig. 7; it is simply the ratio of the area under the desired beam-current-versus-time curve to the area possible if the beam current remains as peak amplitude throughout the cycle. Fig. 12 shows the results of such a graphical analysis

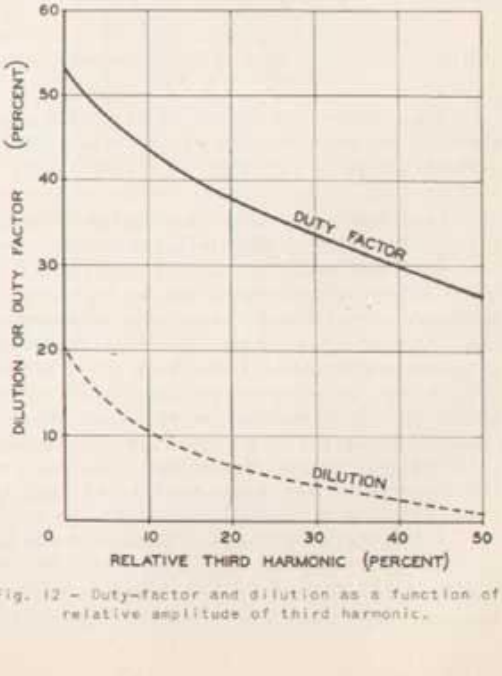

Fig. 12 – Duty-factor and dilution as a function of relative amplitude of third harmonic.

for various third-harmonic-amplitude ratios. To better show the relation of dilution to duty factor, the dilution data of Fig. 11 are replotted in Fig. 12 with relative third harmonic as the independent variable. It will be observed that the introduction of a 20 percent relative third harmonic which reduces the dilution by a factor of more than three, reduces the duty factor, and consequently the brightness, by less than one-third.

It should be pointed out that the foregoing questions of dilution and duty factor do not arise when appropriate means of simultaneous reproduction are employed. In one method of simultaneous presentation proposed by G.C. Sziklai of RCA Laboratories, the rest position of the beam is on the axis of the electron optical system. In the rest position the beam strikes the three phosphor dots equally to produce white; as the current is varied a black and white picture is reproduced so long as the beam remains on the axis. Color information is imparted by deflecting the beam from the axis to vary the direction of approach; the direction of deflection in azimuth serves to determine the hue of the color; the amplitude of deflection serves to determine the saturation of the color.

This method can take advantage of the principle of mixed highs since the relative beam direction need only be changed as color changes are required. Furthermore, because of the symmetry of the three phosphor dots with respect to both the electron optical axis and the hole in the shadow mask, off-axis excursions of the beam are large only for high saturation. On this account less accurate convergence may be tolerated. It should be emphasized, however, that stringent requirements are made upon the accuracy of the shadow-mask screen assembly in any system where hue and saturation are directly dependent on direction of approach. Thus, deviations in the shape and uniformity of the phosphor dots and in alignment of the shadow mask holes with respect to the phosphor dots may lead to less faithful color rendition.

Performance of Practical One-Gun Shadow-Mask Color Kinescope

As already indicated, to move the object point in close to the gun, the first anode of the standard 5TP4 projection-type electron gun used in the tube for the March 1950 demonstrations[2] was operated with a lower than normal first anode potential. Instead of the normal six kilovolts, it was necessary to operate the first anode at about three kilovolts. Under this condition, tests indicate that the peak beam current is less than 0.5 milliampere.

Although a detailed correlation of peak beam current and observed highlight brightness involves details of colorimetry beyond the scope of this paper, an approximate analysis is of interest because it indicates the influence of the several operational factors. The details of colorimetry may be incorporated in an assumed value for the "white" visual output in lumens per watt. For the present calculation, assume that the tube is operated under the following conditions:

"White visual output	7 lumens/watt
Shadow-mask transmission factor[3]	0.20
Relative third-harmonic sampling voltage	0.20
Duty-factor (From Fig. 12)	0.40
Peak beam current	0.5 ma
Anode voltage	18,000 volts
Picture size	9" x 12"

Under these conditions a highlight brightness of 7 foot-lamberts is to be expected. When allowance is made for the 0.6 transmissivity of the "minus-yellow" filter employed for color correction of the phosphors in use at that time[9], the highlight brightness is reduced to 4 foot-lamberts. This checks the observed value[10]

With the improved phosphors presently available no filter is required. Also, as already indicated, the performance of the tube is greatly improved by adding an auxiliary magnetic-type electron lens over the electrostatic lens as shown in Fig. 5. By this means it is possible to increase the useful beam current several fold. Tests of this by V.D. Landon and associates of RCA Laboratories indicate that peak beam currents of 1.5 milliamperes may be used. Under these conditions pictures with

[2] loc. cit.

[3] loc. cit.

[9] *Television Digest*, vol. 6, No. 15, April 1, 1950.

[10] *Television Digest*, vol. 6, No. 14, April 18, 1950.

good fidelity and color rendition and with 20 foot-lamberts highlight brightness are obtained. Substantially the same result is obtained with the simplified shortened electron gun of Fig. 6. This gun makes possible an improved tube, for not only is the first-anode voltage obviated, but the shorter gun makes it possible to reduce the tube length by approximately seven inches.

A further improvement is brought about by using a shadow-mask with reduced angle of approach. As already indicated, when the beam pencils are crowded closer together, the requirements on the electron optical system become less stringent. Tubes of this design were built using a shadow-mask screen with 0.7 degree angle of approach. The most noticeable difference is simplification of dynamic convergence.

R. R. Law

R. R. Law