K E Weitzel

LB-1026

FOCUSING-GRILL COLOR KINESCOPES

RADIO CORPORATION OF AMERICA

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Focusing-Grill Color Kinescopes

Approved

Stuart W. Seeley.

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> This bulletin describes the principles of operation and theoretical considerations of focusing grill color kinescopes. Some experimental work on these tubes is also described.

I. ELECTRON-OPTICAL PRINCIPLES

Grill Focusing

Focusing grills consisting of closely-spaced parallel wires have been found useful in line-screen color kinescopes for minimizing the loss of beam electrons.[1-3] With different electrostatic fields established on either side of the grill the spaces between adjoining wires act as cylindrical electron lenses. It is the function of these lens elements to image the three beam cross sections in the deflection plane onto the appropriate phosphor lines on the viewing screen (Fig. 1). If the fields on the two sides of the grill are E_1 and E_2 the focal lengths are given by the familiar Davisson and Calbick formula[4]

$$f = \frac{2V}{E_1 - E_2} \tag{1}$$

V being the potential of the mask measured with respect to the gun cathode.

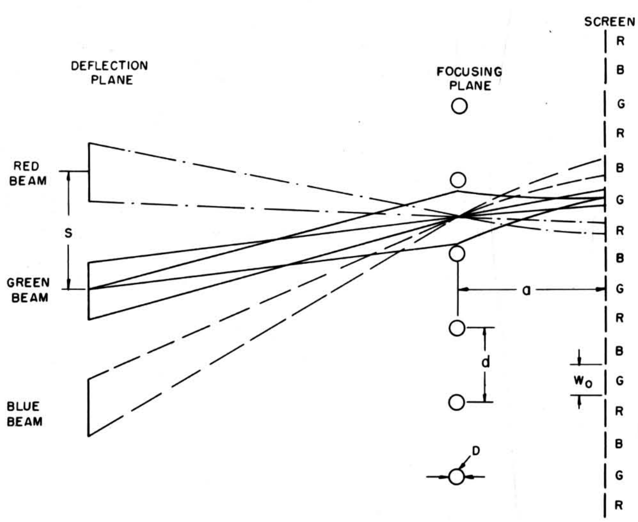

Fig. 1 – Imaging of deflection plane onto screen by focusing grill lens elements.

The Davisson-Calbick formula applies for beams which are essentially perpendicular to the mask. In a more general study of a system of essentially plane parallel electrodes provided with apertures it is convenient to consider the transverse velocity components imparted at the apertures in preference to the focal lengths, since the transverse velocity components experience changes only at the apertures. Displacements in a plane perpendicular to the tube axis are given directly by the products of the transverse velocity components and the transit time.

For the slit lens formed between wires of a grill the change in the velocity component in the x-direction, perpendicular to the grill wires, is given by

$$\Delta\sqrt{V}_x = \frac{h}{\sqrt{V_z}} \, \frac{E_2 - E_1}{2} \, \frac{1}{1 + \tan^2\theta \, \cos^2\phi} \tag{2}$$

Here $\sqrt{V_x}$ and $\sqrt{V_z}$ are, except for a common factor $\sqrt{2e/m}$, the transverse velocity component perpendicular to the grill wires and the velocity component parallel to the tube axis, respectively. θ is the inclination and ϕ the azimuth of the incident electron (Fig. 2), $\phi = 0$ corresponding to a plane perpendicular to the grill wires. h is the distance of the point of incidence on the aperture from its center.

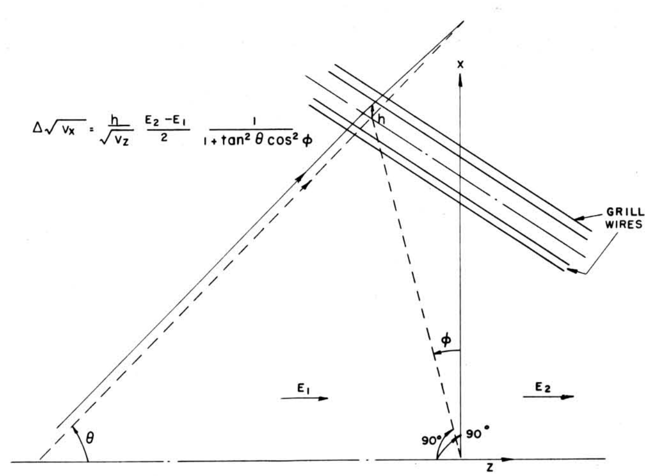

Fig. 2 – Refraction of an oblique beam.

Eq. (2), which may be regarded as a generalization of the Davisson-Calbick formula, was obtained by calculating the transverse impulse given the electron in the known electric field of the wire grill. It has been derived very elegantly by Carpenter, Helstrom, and Anderson with the aid of Gauss theorem.[3]

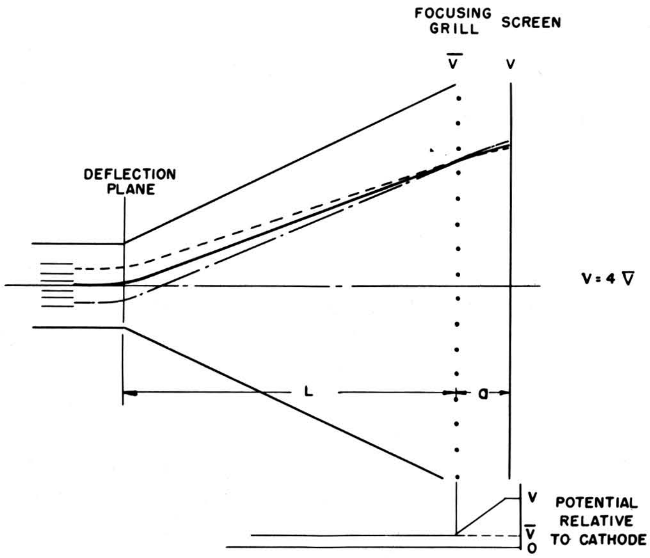

Fig. 3 – Postacceleration focusing grill tube.

In the simplest focusing grill system the focusing grill is connected to the tube cone and an accelerating field is applied between the screen and the focusing grill (Fig. 3). The formulas show that, under these circumstances, a beam of electrons incident parallel to the axis on a wire grill is focused into sharp lines on the screen if the ratio of screen potential to grill potential is 4 to 1.

Undesired Bombardment

While the accelerating field, in this instance, makes possible the concentration of the beam electrons on the desired phosphor areas, it also, incidentally, causes the unintended bombardment of other screen areas with high-velocity electrons. The undesired bombardment arises from two sources. On the one hand, secondary electrons emitted by the grill with low velocities are drawn toward the screen and strike it with a kinetic energy which is 3/4 of the kinetic energy of the primary electrons. On the other hand, the beam electrons incident on the screen are in part reflected or back-scattered with energies comparable to the primary energy. These back-scattered electrons travel along parabolic paths in the opposing electric field and return to the screen with their velocity of emission. The effects of both kinds of electrons are readily observed experimentally.

Secondary Emission

The secondary electrons which are emitted from the edges of the grill wires trace out diffuse lines which are displaced from the scanning lines toward the center of the screen (Fig. 4a). In addition, secondary electrons emitted on the gun side of the grill are drawn, by the fields penetrating through the grill apertures, toward the screen, producing large-scale patterns on the screen, which are strongly influenced by the electrode structures surrounding the grill. The last effect may be largely suppressed by giving the grill a slight negative bias with respect to the tube cone.

Backscattering

Measurements of the angular and velocity distributions of the backscattering from 25.6-kv electrons at an aluminum surface have been made by Gentner.[5] He finds a maximum of the angular distribution for a glancing angle of 15 degrees; for 30 degrees the intensity has already dropped to a very low value. Less than 20 percent of the backscattered electrons have kinetic energies exceeding

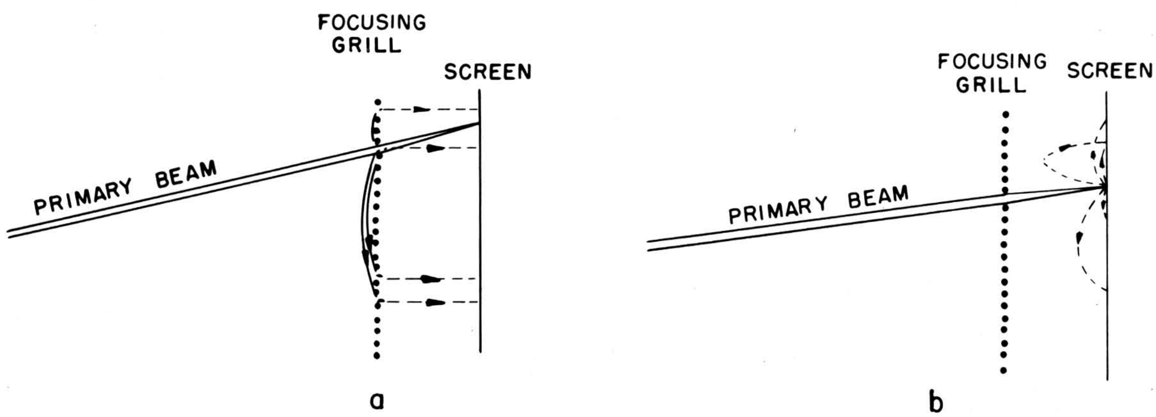

Fig. 4 – Effect of (a) secondary electrons and (b) back-scattered electrons in postacceleration focusing grill tube.

75 percent of the energy of incidence and less than 20 percent of them have energies below 1/5 of the energy of incidence. Thus, practically all of the backscattered electrons are returned to the screen by the field between screen and grill (Fig. 4b).

For an angle of emission θ and an energy of emission eV^*, the point at which the electrons return to the screen is at a distance R from their point of origin:

$$R = 2a \frac{V^*}{V - \bar{V}} \sin(2\alpha) \qquad (3)$$

Here, a is the distance between screen and grill, V is the potential of the screen, and $\bar{V}$ is the potential of the grill. For $V/\bar{V} = 4$, the backscattered electrons are thus distributed over a halo about the beam spot with a maximum radius of

$$R = 2.67\ a$$

corresponding to $V^* = V$, $\alpha = 45$ degrees; and a radius of maximum intensity of

$$R = 0.7\ a$$

corresponding to $V^* = 0.5\ V$, $\theta = 15$ degrees.

According to measurements by Palluel[6] the coefficient of backscattering is, for elements of atomic number less that about 30 and electron energies in the range from 12 to 18 kv, very nearly 1/100 of the atomic number. Thus, for aluminum the backscattering coefficient is approximately 13 percent. Since the average energy of the backscattered electrons is about 45 percent of the initial energy, the backscattered electrons returned to the screen carry about 6 percent of the energy of the incident electrons.

The intensity ratio of the backscattering to the direct image (for white light) might be expected to be somewhat less than this, since the aluminum film will absorb a greater fraction of the energy of the backscattered electrons than of that of the primary electrons; the fact that the conversion efficiency of the screen increases somewhat with voltage operates in the same direction. In the opposite direction, the backscattering factor of the screen may be expected to be considerably greater than 13 percent, since the effective atomic number of the screen material is up to twice that of aluminum.

Two means of reducing the intensity due to backscattering relative to the primary intensity suggest themselves. On the one hand, the screen might be coated with a relatively thick layer of material with a very low backscattering coefficient, such as beryllium; on the other, a fine mesh might be deposited directly on the screen, so that the mesh wires intercept the electrons scattered at small glacing angles. Either technique would result in a considerable loss in brightness of the primary picture.

Two-Grill Systems

As an alternative, light emission arising from both backscattered and secondary electrons can be suppressed completely by taking care that the screen potential is no higher than the potential of any other electrode in the target structure. The creation of the converging lens fields at the focusing grill apertures then requires the addition of a further electron-permeable electrode, which will be called the auxiliary grill. In the resulting tube neither backscattering at the screen nor secondary emission at the grills contribute to color dilution and to contrast loss.

In the simplest arrangements realizing the complete suppression of contrast reduction and color dilution by backscattering and secondary emission the screen voltage is set equal to the voltage of the focusing grill, leading to either System I or System II (Fig. 5), depending on whether the focusing grill or the auxiliary grill adjoins the screen. System III represents a modification of System II which does not completely suppress the return of backscattered electrons, but has the compensating advantage

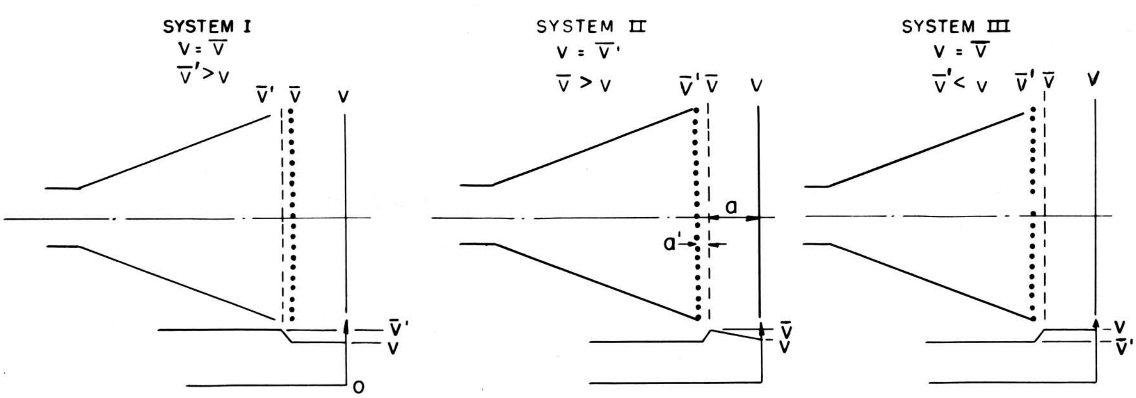

Fig. 5 – Double-grill focusing Systems I, II, III.

that the maximum tube voltage is applied to the screen. Since, here, the peak of the angular backscattering distribution, at a glancing angle of 15 degrees, cannot return to the screen at a distance closer to the point of origin than

$$R = 2\ a \cot 15^{o} = 7.5\ a$$

and since a considerable number of the scattered electrons will be intercepted by the auxiliary grill, their adverse effect on contrast and color purity is greatly reduced. Electron-optically, the properties of System III are very similar to those of System II.

Even if attention is confined to System I, II, and III, a choice can be made between tubes in which the focusing grill and auxiliary grill wires are aligned and tubes in which they are unaligned.

Aligned Grills

In an aligned-grill tube, two corresponding apertures in the focusing grill and auxiliary grill form a single electron lens system for an electron pencil passing through them. The ratio of the voltages which must be applied to the two grills in order to obtain sharp focus at the center of the screen may be deduced from the Davisson-Calbick formula (1). They are shown in Table I for two different ratios of the distance a′ between the two grills to the distance a between the screen and the grill nearest it. It is seen that the required voltage difference decreases as the spacing between grills is reduced. This is to be expected, since the field-strength between the grills largely determines the refractive power.

Unaligned Grills

In a tube with unaligned grills, the phosphor lines are registered only with the focusing grill wires. The lens action at the unaligned auxiliary grill becomes simply a random perturbing factor. Its effect on the picture can be minimized by:

1. Orienting the auxiliary grill wires at right angles to the focusing grill wires; then the lens action at the auxiliary grill causes no electron displacement transverse to the color lines and hence does not detract in any way from the color purity of the image (Fig. 6).

2. Making the spacing between the auxiliary grill wires small; this minimizes the random spread of the electron spot in a direction along the phosphor lines and, consequently, the reduction in resolution in this direction.

With the auxiliary grill wires at right angles to the focusing-grill wires the transverse fields at the auxiliary grill no longer counteract the focusing action at the focusing grill. Hence, as shown in Table I, the voltage ratios required for sharp focus at the screen are considerably closer to unity than for aligned grills. At the same time, as shown in Table II, the transverse fields at the

Table I. Ratio of Grill Voltage to Screen Voltage for Aligned Grills and Unaligned Grills

	Aligned Grills			Unaligned Grills		
	Systems			Systems		
	I	II	III	I	II	III
a′/a = 1/4	2.07	1.88	0.545	1.5	1.44	0.677
a′/a = 1/8	1.68	1.60	0.635	1.25	1.23	0.802

Table II. Ratio of Maximum Spot Broadening Along Phosphor Lines to Width of Clear Space between Wires in Auxiliary Grill

	System		
	I	II	III
	1	$\sqrt{V/\overline{V}}$	$(2\sqrt{\overline{V}/V}-1)$
a′/a = 1/4	1	0.833	0.646
a′/a = 1/8	1	0.900	0.791

auxiliary grill cause a maximum broadening of the spot in a direction along the phosphor lines, which is at most equal to the wire separation in the auxiliary grill. For equal wire separation in the focusing grill and the auxiliary grill, the spot broadening in a direction along the phosphor lines is thus of the same order as the maximum spot displacement transverse to the phosphor lines resulting from the focusing process. Both are very much smaller than a picture element and detract negligibly from picture quality.

Other Picture Defects Arising from Fields in Target Structure

Apart from the slight amount of defocusing at the auxiliary grill there are certain other effects introduced by the focusing grill structure which may detract from the quality of the picture and the ease of screen preparation. These are:

1. Pattern distortion,
2. Trio grouping,
3. Variation of grill focus with deflection.

By pattern distortion is meant the deviation from geometrical similarity between the system of lines representing the centers of the focusing grill apertures and the system of lines formed on the screen by a scanning beam diverging from the point of intersection of the tube axis with the deflection plane. Whereas the first system of lines is straight and equidistant, the second system of lines, which represent the desired center lines of the phosphor trios, exhibits slight cushion-shaped distortion for System I tubes and slight barrel-shaped distortion of System II and III tubes. This arises from the curvature of the electron paths in the regions between the electrode planes of the target structure, where the electrons are subjected to electrostatic fields. If the pattern distortion is appreciable, phosphor screens cannot be prepared by simple lighthouse projection, since this can lead only to geometrically similar patterns on a flat screen.

By trio grouping is meant a variation with deflection of the separation of the lines formed by electrons from the different guns passing through the same focusing grill aperture or, for a properly made phosphor screen, a variation with deflection in the separation of the phosphor lines constituting a trio. It is found that System I yields an increase in the trio line separations with increasing deflection, generally called "degrouping", whereas Systems II and III yield a decrease in trio line separations with increased deflection called "grouping." Trio grouping effects are closely related to pattern distortion, but are of considerably greater importance. Thus, with degrouping, there is a tendency of overlapping of adjoining trios in the peripheral portions of the picture, whereas with grouping the trios are crowded together, leaving blank spaces. Since dynamic convergence systems generally produce a certain amount of degrouping, a compensating amount of grouping, such as is produced by Systems II and III may actually be advantageous. In general, a variation in the

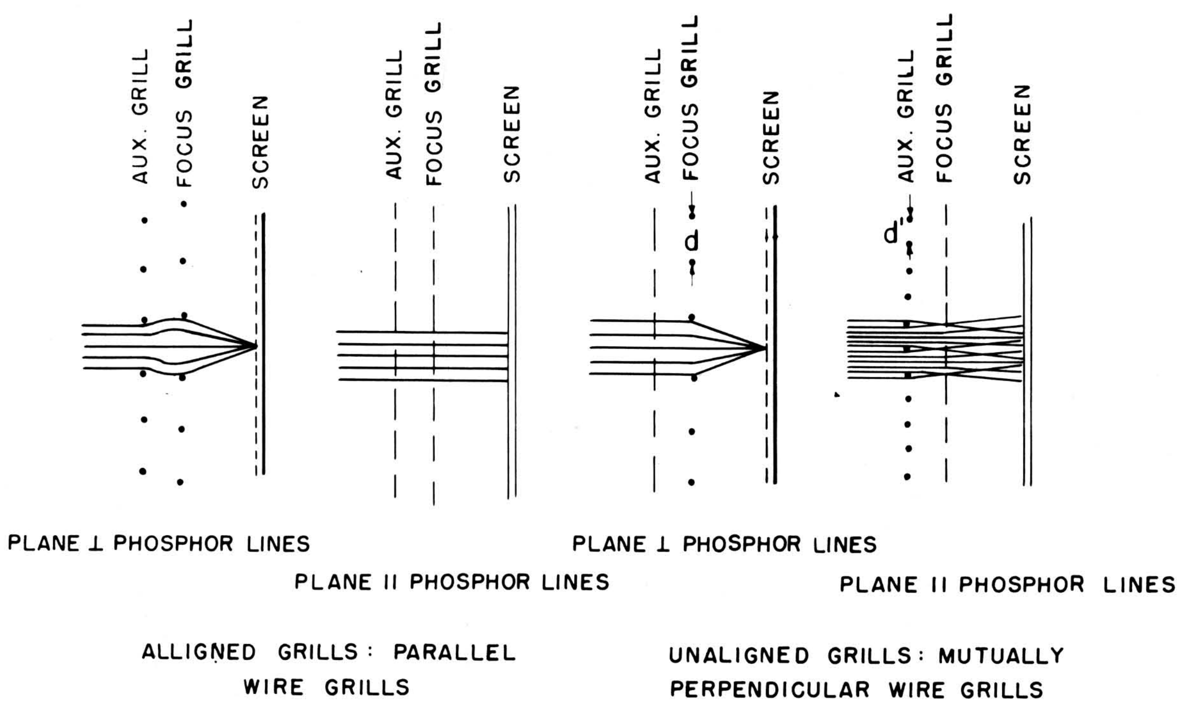

Fig. 6 – Lens action of aligned and unaligned grills.

trio dimensions over the picture area, whether caused by grouping or degrouping, reduces tolerances and is hence undersirable.

Pattern distortion and trio grouping are conveniently expressed in terms of the variation with deflection of the tangential pattern magnification M_t and the radial pattern magnification M_r, which both approach the pattern magnification M_o at the center of the picture. If δx_s is the deviation of the actual line pattern produced by a single gun on the screen from the geometrically similar pattern which coincides with the actual pattern at the center of the picture, and dx_s is the deviation of the separation of the center of adjoining lines of a trio from its value w_o at the center, then

$$\frac{\delta x_s}{w_o} = \frac{M_t - M_o}{w_o} r_g \cos\phi; \quad w_o = \frac{M_o d}{3}; \quad M_t = \frac{r_s}{r_g}; \quad M_r = \frac{dr_o}{dr_g} \tag{3}$$

$$\frac{dx_s}{w_o} = \frac{1}{M_o - 1}\left\{\left(\frac{M_r M_t}{M_t\cos^2\phi + M_r\sin^2\phi} - M_o\right) + \frac{M_r - M_t}{M_t\cos^2\phi + M_y\sin^2\phi}\,\frac{y_c}{2x_c}\,\sin 2\phi\right\} \tag{4}$$

$$= \frac{M_r - M_o}{M_o - 1} \text{ for } \phi = 0; \qquad = \frac{M_t - M_o}{M_o - 1} \text{ for } \phi = 90^\circ \tag{5}$$

Here r_s is a radial displacement from the center of the screen and r_g a radial displacement from the center of the focusing mask, ϕ is the azimuthal angle, and (x_c, y_c) are the coordinates of the centers of the two lateral beams relative to the central beam as reference. The significance of pattern distortion and grouping is indicated graphically in Fig. 7.

Several facts can be read from these formulas. First, the change in $\frac{\delta x_s}{w_o}$ for a displacement of a phosphor line width w_o in the x-direction is only $(M_t-M_o)/M_o$, whereas the change in phosphor line separation is of the order of $(M_t-M_o)/(M_o-1)$; hence the overlapping of trios for magnification increasing with deflection and the leaving of blank spaces for magnifications decreasing with deflection. Second, since the displacement r_s at the screen can be expanded in a series of odd powers of the displacement r_g at the focusing mask, the deviation in line spacing within a trio for 0 degrees azimuth, i.e., for a direction perpendicular to the phosphor lines, is, for moderate angles of deflection, 3 times as great as for 90 degrees azimuth or a direction parallel to the phosphor lines. Third, whereas the spacings within a trio are symmetrical throughout for an in-line gun ($y_c = 0$), they are symmetrical only for the principal azimuths for a delta gun ($y_c/x_c = \pm\sqrt{3}$). For a delta gun, the deviation from symmetry becomes a maximum for the 45 degree azimuths. The absence of the asymmetry terms constitutes a material advantage of the in-line gun.

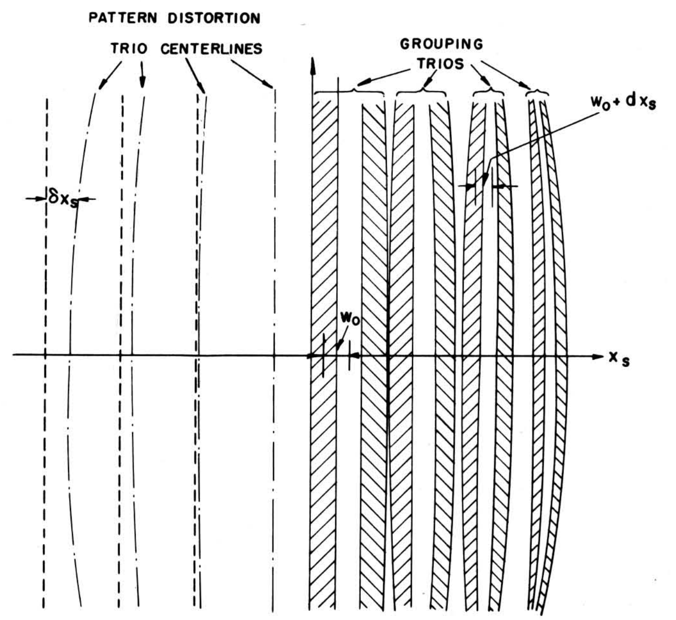

Fig. 7 – Definition of pattern distortion and trio grouping.

Formulas for the variation of the tangential and radial magnification with deflection angle ϕ are given below for the three Systems I, II, III.

$$\text{I} \quad \frac{M_t - 1}{M_o - 1} = \frac{q(1+X)\,[L(1+q) + 2\alpha']}{X(1+q)\,[L(1+X) + 2\alpha']}$$

$$\frac{M_r - 1}{M_o - 1} = \frac{q^3(1+X)^2\,[L(1+q) + 2\alpha']}{X^2(1+q)\,[LX(1+X)^2 + 2\alpha'(q^2+X)]} \tag{6}$$

$$M_o - 1 = \frac{\alpha(1+q)}{q\,[L(1+q) + 2\alpha']}$$

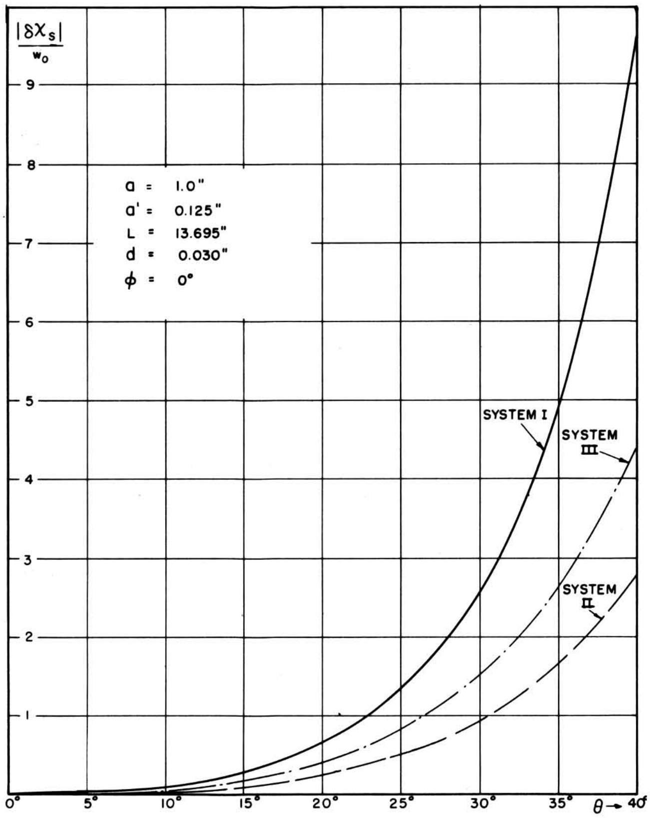

Fig. 8 – Pattern distortion of Systems I, II, III and the principal azimuths.

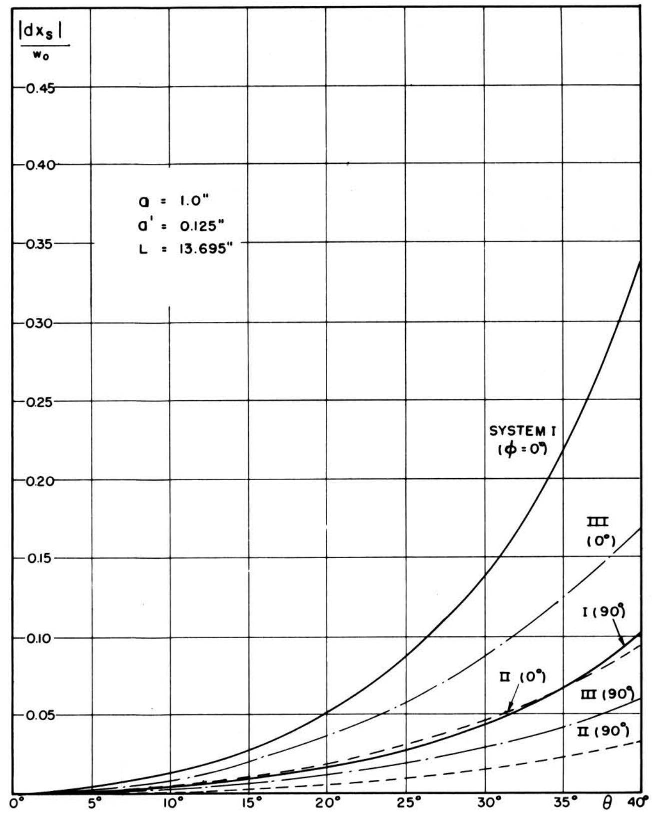

Fig. 9 – Trio degrouping (System I) and trio grouping (Systems II and III) in the principal azimuths.

II
$$\frac{M_t-1}{M_o-1} = \frac{1+q}{1+X} \qquad \frac{M_r-1}{M_o-1} = \frac{(1+q)(q^2+X)}{X(1+X)^2}$$
$$M_o-1 = \frac{2(\alpha+\alpha')}{L(q+1)} \tag{7}$$

III
$$\frac{M_t-1}{M_o-1} = \frac{q(1+q)\,[\alpha(1+X)+2\alpha' X]}{X(1+X)\,[\alpha(1+q)+2\alpha' q]}$$
$$\frac{M_r-1}{M_o-1} = \frac{q(1+q)\,[\alpha q^2(1+X)^2+2\alpha' X^2(q^2+X)]}{X^3(1+X)^2\,[\alpha(1+q)+2\alpha' q]} \tag{8}$$
$$M_o-1 = \frac{\alpha}{Lq} + \frac{2\alpha'}{L(q+1)}$$
$$X = \sqrt{q^2+(q^2-1)\tan^2\theta} \qquad q = \sqrt{\bar{V}/\bar{V}'}$$

Figs. 8 and 9 show plots of the trio grouping deviations and the pattern distortion for the specific example of a spacing, α, between the screen and the nearest grill equal to 1 inch and a spacing, α', between grills of 1/8 inch. The spacing, L, between the deflection plane and the nearest grill, which influences the results only slightly, was taken to be 13.695 inches. The maximum deviation from the geometrically similar pattern selected to minimize this maximum deviation is approximately 1/3 the value δx plotted in Fig. 8.

The plots show that the magnitudes of the grouping effects as well as the pattern distortion are much smaller for Systems II and III than for Systems I. Thus for System II the degrouping does not exceed 7 percent for an overall deflection of 70 degrees in a direction perpendicular to the phosphor lines. At the same time, the maximum deviation from a straight-line pattern is approximately 1/2 of a phosphor line. The qualitative behavior of the three systems is of course precisely that to be expected for layered refractive media whose index varies as the square root of the potential.

Whereas trio grouping and pattern distortion affect the location of the electron spots on the screen and, hence, the appropriate positioning of the phosphor lines, the variation of grill focus with deflection affects the size of these spots in a direction transverse to the phosphor lines. A large variation in grill focus makes it impossible to employ large beam cross sections in the deflection plane and hence reduces the advantages derived from the high electron-transparency of the focusing grill.

It is convenient to define as grill defocusing at the deflection angle θ and azimuth ϕ, the width $2\Delta x_s$ of the electron trace on the screen for a parallel beam incident from the center of deflection in this direction, when the operating voltages are so adjusted as to make the width of the trace at the center of the picture equal to zero, i.e., for sharp grill focus at the center* (Fig. 10).

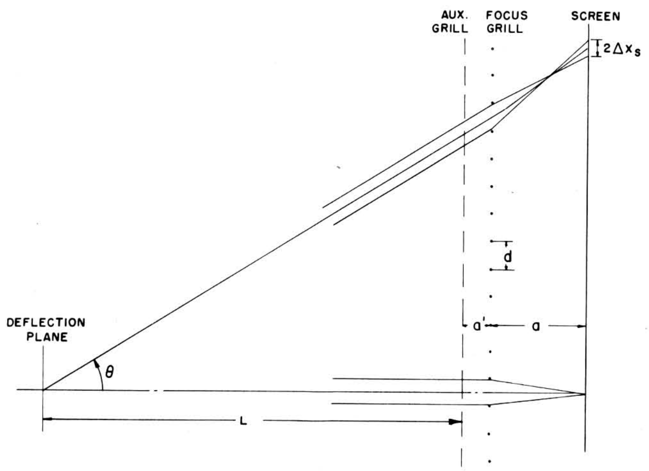

Fig. 10 – Definition of grill defocusing.

Three factors influence the variation of Δx_s with angle of incidence. They are

1. the variation of the transverse velocity increment $\Delta\sqrt{V_x}$ imparted to an electron on the edge of a lens element ($h = (d\text{-}D)/2$) as given by Eq. (2) with θ and ϕ;

2. the variation in the transit time t between focusing grill and screen with the angle of incidence; and

3. the variation of the difference in transit time Δt between an electron incident on the edge of the lens element and one passing undeflected through its center.

Quantitatively

$$\sqrt{m/(2e)}\,(\Delta x_s - h) = \Delta\sqrt{V_x}\,t + \sqrt{V_x}\,\Delta t$$

$$= \left(\frac{h}{V_z}\,\frac{E_2-E_1}{2}\,\frac{1}{1+\tan^2\theta'\cos^2\phi}\right)_{\text{foc. grill}} \cdot \int_{\text{foc. grill}}^{\text{screen}} \left(1+\frac{V_r\cos^3\phi}{V(z)-V_r}\right)\frac{dx}{\sqrt{V(z)-V_r}} \qquad (9)$$

where θ' is the angle of incidence on the focusing grill. Whereas the coefficient of the integral, namely the transverse velocity change, either decreases or is unchanged in magnitude with increasing deflection angle, the integral terms, derived from the transit time and transit time change, increase monotonically with deflection angle and outweigh the variation of the velocity increment. Consequently, Δx_s is in all instances a negative quantity which increases with deflection angle. With respect to the dependence on azimuth, also, the two factors act in opposition. A closer examination shows that for System I the dependence on azimuth cancels out altogether; for Systems II and III grill defocusing is slightly less in a direction transverse to the phosphor lines than in a direction parallel to the color lines.

Eq. (9) leads to the expressions for the grill defocusing for Systems I, II, and III in Eqs. (10) thru (12):

$$\text{I} \qquad 2\Delta x_s = -(d\text{-}D)\left[\frac{a}{2a'}\left(\frac{1-X^2}{X^2}\right)-1\right] \qquad (10)$$

$$\text{II} \qquad 2\Delta x_s = -(d-D)\left[\frac{a+a'}{a'}\,\frac{X-1}{X}\,\frac{X+\tan^2\theta\cos^2\phi}{1+\tan^2\theta\cos^2\phi}-1\right] \qquad (11)$$

$$\text{III} \qquad 2\Delta x_s = -(d-D)\left[\frac{a}{2a'}\,\frac{X^2-1}{X^3}\,\frac{X^2+\tan^2\theta\cos^2\phi}{1+\tan^2\theta\cos^2\phi} + \frac{X-1}{X}\,\frac{X+\tan^2\theta\cos^2\phi}{1+\tan^2\theta\cos^2\phi}-1\right] \qquad (12)$$

The quantity $\Delta x_s/w_o$, namely the grill defocusing measured in phosphor line widths, is plotted for Systems I, II, III with $a' = 0.125$, $a = 1$ inch, $L = 13.695$ inches in Fig. 11, for the principal azimuths $\phi = 0$ and $\phi = 90$ degrees. It may be noted that if the voltage ratio is reduced so as to make the amount of defocusing at the center equal to that at the edge, the maximum line broadening is reduced to a value slightly less than Δx_s, or half the maximum line broadening for sharp center focus, so that the figure gives, approximately, the maximum line broadening in phosphor line widths for an overall deflection given by twice the angle θ plotted as abscissa.

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*For convenience in analysis, the distance L between the deflection center and the nearest grill is regarded as infinite in questions relating to grill focusing. To take account of the finiteness of L, it is necessary to multiply the difference of the voltage ratio from unity by a factor of the order of $(1 + a/L)$, provided that $a' << a$.

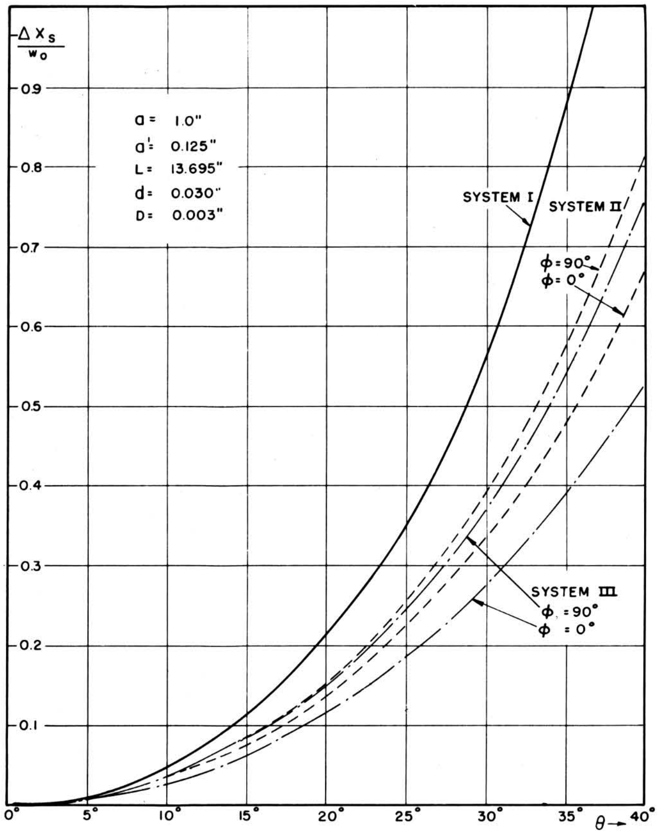

Fig. 11 – Grill defocusing of Systems I, II, III in the two principal azimuths.

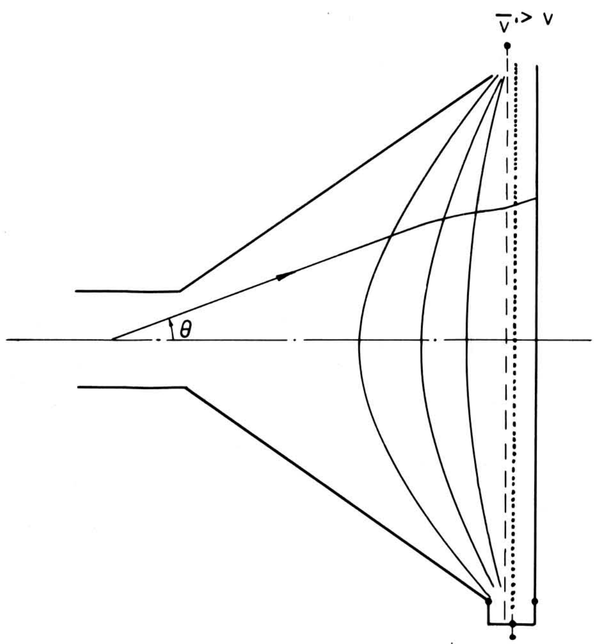

Fig. 12 – Modification of System I by connecting cone to screen

Again, the grill defocusing is seen to be considerably less serious for Systems II and III than for System I. However, the performance, in this respect, of System I can be made approximately equal to that of System II by connecting the cone to the focusing grill and screen instead of to the auxiliary grill (Fig. 12). If this is done, the converging electrostatic lens formed in front of the auxiliary grill reduces the angle of incidence of the electrons on the target structure and reduces consequently the magnitude of the grill defocusing. At the same time, the degrouping characteristic of the unmodified System I is changed to grouping, as is characteristic of Systems II and III.

Correction of Grill Defocusing

However, even the grill defocusing of Systems II and III is sufficiently large that it would detract materially from the performance of color kinescopes with large

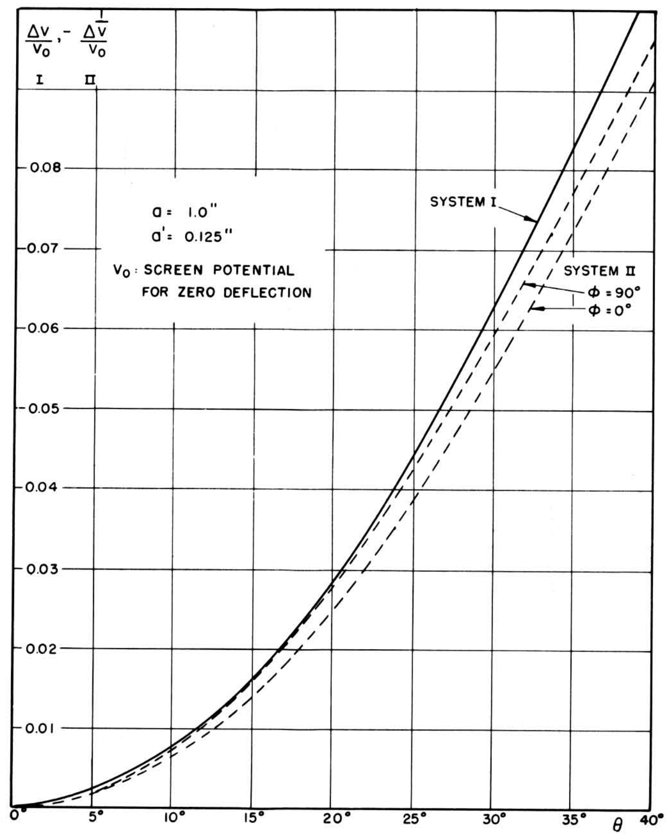

Fig. 13 – Voltage variation with deflection required to nullify grill defocusing.

overall deflection angles. This makes it desirable to modify the construction or operation of the tubes so as to minimize grill defocusing over the entire screen area. The grill defocusing vanishes throughout if the expressions in brackets in Eqs. (10) thru (12) are made equal to zero for all angles θ and ϕ. This may be accomplished in any one of three ways:

1. modulating the voltage of the screen or auxiliary

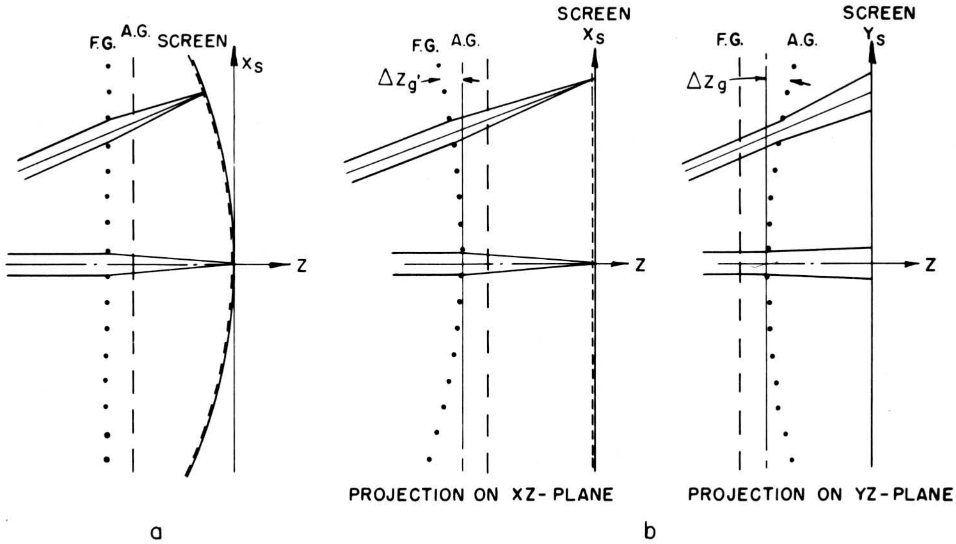

Fig. 14 – Correction of grill defocusing by (a) curving screen and (b) curving grill supports.

Table III. Residual Defocusing and Trio Spacing for a 90° System II Tube with Curved Grills

ϕ	90°	60°	41°25′	30°	0°
cos ϕ	0	0.5	0.75	0.866	1
$2\Delta x_s/w_o$	0	0.046	0.050	0.025	0
$\Delta z_g{}'$	0	0.0296"	0.0657"	0.0657"	0.0657"
Δz_g	0.1136"	0.0861"	0.0509"	0.0221"	0
dx_s/w_o	0.046	0.042 ±0.060	0.040 ±0.070	0.030 ±0.048	0.022

grill as a function of deflection (varying X with θ and ϕ),

2. curving the screen (varying a with θ and ϕ), or
3. curving the grill supports (varying a′ with θ and ϕ).

Correction of grill defocusing by modulating the electrode voltages as a function of deflection requires a voltage variation with deflection which is shown, for the principal azimuths $\phi = 0$ and $\phi = 90$ degrees and for Systems I and II, with $a'/a = 0.125$, in Fig. 13. The total range of variation is of the order of 10 percent of the screen voltage. For System I the variation with deflection is independent of azimuth, whereas for System II there is a slight dependence on azimuth. In both instances (as well as for System III) pattern distortion disappears entirely if the voltage modulation is made a function of the deflection angle θ only and of such magnitude as to correct grill defocusing for the azimuth $\theta = 90$ degrees (deflection along the phosphor lines). A practical drawback of grill defocusing correction by voltage modulation is that the relatively large alternating fields which must be applied tend to set the grill wires into vibration.

The geometrical methods of correcting grill defocusing are free of this drawback (Fig. 14). On the other hand, if the correction is achieved by giving the screen an appropriate curvature, an excessive amount of trio grouping, arising from the reduced separation between focusing grill and screen, is obtained in the peripheral parts of the picture. Even for a 60-degree overall deflection the trio dimensions in the corner are only 3/4 of those in the center. The central radii of curvature of the screen are, for the dimensions L = 13.695 inches, a = 1 inch, a′ = 0.125 inch assumed before, 89 inches for a System I tube and 102 and 114 inches, respectively, for a System II tube. In the first instance the screen shape is a figure of revolution about the tube axis, whereas in the second instance it is approximated by a toroid.

If, instead, grill defocusing is corrected by curving the grill supports the effect on trio grouping is greatly reduced, since the variation in the mask-to-screen distance becomes relatively small. At the same time, complete grill defocusing correction becomes possible only in the principal azimuths, namely along the picture diameters parallel to the phosphor lines and perpendicular to them. However, with complete correction along these diameters, the residual defocusing in the remainder of the picture becomes entirely negligible. This is shown by the values for a 90 degree System II tube with curved grills and $L = 13.695$ inches, $a = 1$ inch, and $a' = 0.125$ inch given in Table 3. The values given in this table apply for a 45 degree deflection angle. It is seen that the maximum line broadening contributed by mask defocusing is only 1/20 of a phosphor line width. Similarly, the degrouping is only of this order; the plus-or-minus terms represent the asymmetry introduced by a delta gun. The terms $\Delta z'_g$, and Δz_g represent the deviations of the focusing grill and auxiliary-grill shapes, respectively, from a plane. They correspond to the very large central radii of curvature of 785 and 803 inches. The shape of the grill supports is almost exactly circular. The pattern distortion also is small; the maximum deviation of the trio pattern from a pattern of straight equidistant lines for a 90 degree field is only one phosphor line or a third of a trio width; for a 70 degree field it is only about 1/3 of a phosphor line.

Summary

In summary, the employment of two separate grills makes technically possible the design of large-angle color line-screen tubes which are characterized by high beam-transmission efficiency and effective suppression of electron sources of color dilution and contrast reduction. However, the techniques for making such structures are not sufficiently developed to make tubes of this type practical or economical at this time.

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II – CONSTRUCTION AND OPERATION

General Considerations

Considerable experimental work has been done on wire, double-grill, focusing-type tubes using line phosphor screens. The experimental tubes that have been built have contained two wire grills used in the ways described in part I. As indicated, there are several ways of connecting and operating the two grills and the cone and phosphor screen, to produce a color kinescope. Before discussing the construction and operation of a particular type of tube, such as system I, II or III, there are certain factors that apply equally well to all these tube types that will be discussed first.

For example, all the experimental tubes that were built employed electrostatically focused triple guns which, in some cases, were very much like the triple guns used in the present commercial shadow mask tube. Smaller, more compact triple guns have also been used with the three guns arranged in delta fashion or in-line. The in-line arrangement is particularly suited to the wire-grill focusing-type tube.

In most cases the individual guns in the trio were aimed at the center of the screen to obtain mechanical convergence at the center of the screen while dynamic convergence was obtained by magnetic means.

As for the envelope, each of the tube types requires a high-voltage lead insulated from the cone for about 1/4 of the maximum potential supplied by the high-voltage power supply.

In general, flat, internal, phosphor plates have been used although some work has been done with curved phos-

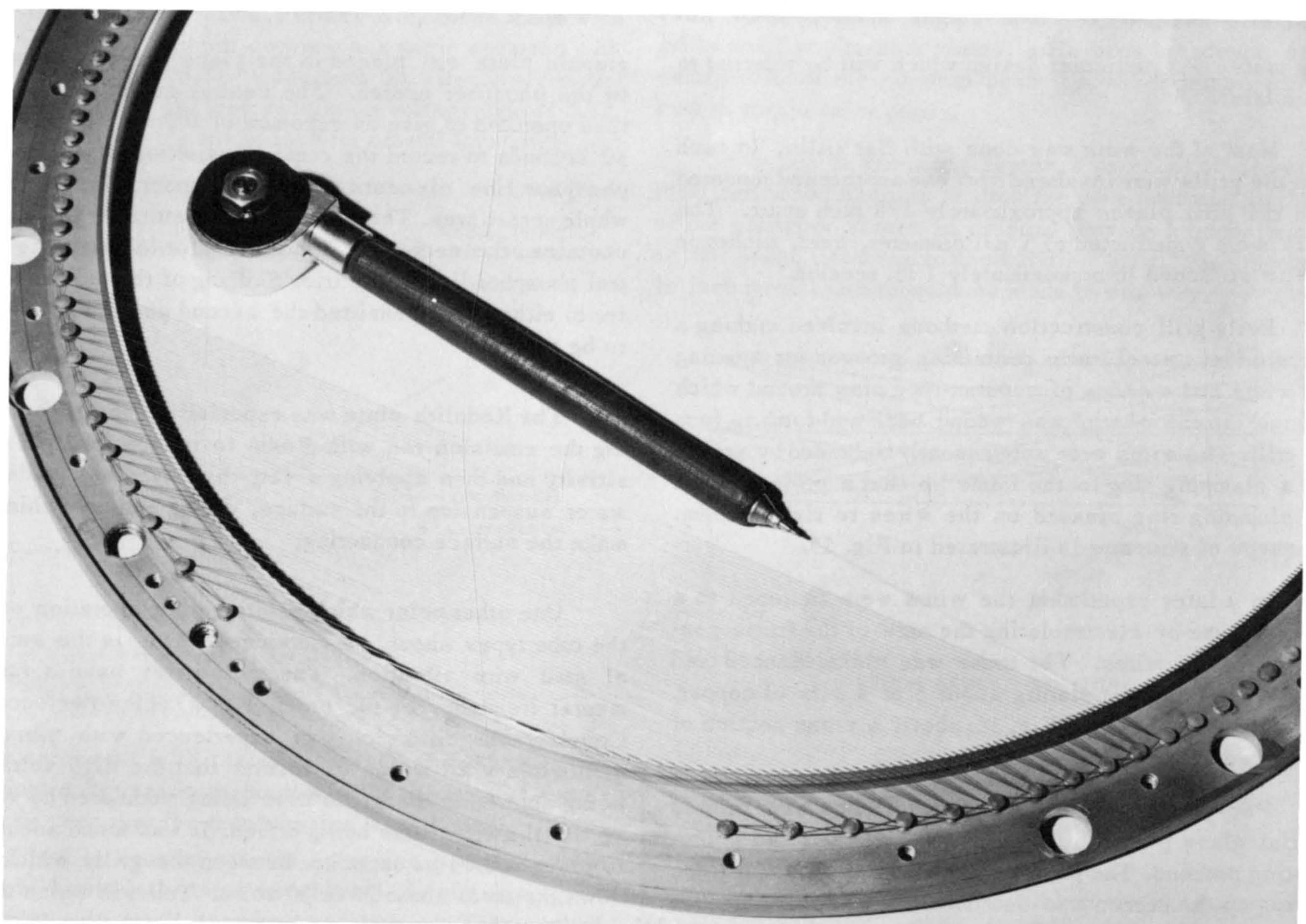

Fig. 15 – Early type of grill structure.

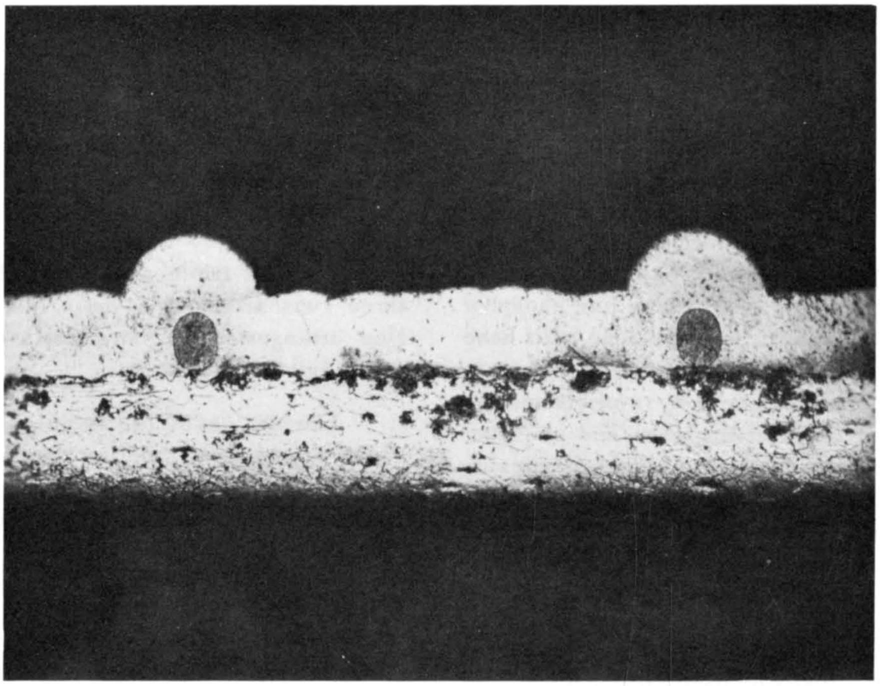

Fig. 16 – Photomicrograph of grill wires held in place by copper plating.

phor plates of a particular design which will be referred to again later.

Most of the work was done with flat grills. In each case the grills were insulated from one another and mounted with the grill planes approximately 1/8 inch apart. The grills were constructed of 3 mil diameter, hard, nichrome V wire stretched to approximately 1 lb. tension.

Early grill construction methods involved making a 430 stainless steel frame containing grooves for spacing the wires and a series of capstan-type pins around which a single strand of wire was wound back and forth to form the grill. The wires were subsequently tightened by screwing a clamping ring to the frame so that a projection on the clamping ring pressed on the wires to tighten them. This type of structure is illustrated in Fig. 15.

In a later experiment the wires were fastened to a simple frame by electroplating the area of the frame contracted by the wires. The frame was nickel-flashed cold rolled steel and the plating about 3 or 4 mils of copper. The photomicrograph in Fig. 16 shows a cross section of the plated area.

Phosphor screens for experimental tubes were printed on flat glass plates by both the silk screen and photoprinting process. The position of elemental phosphor lines making up the screen was determined for individual tubes by operating the grill assembly in a demountable vacuum system in which an especially prepared Kodalith photographic plate was placed in the plane normally occupied by the phosphor screen. The central gun of the trio was then operated to give an exposure of 100 microamperes for 30 seconds to record the required position of the central phosphor line elements of the phosphor trios over the whole screen area. The Kodalith plate, suitably processed, contained the necessary information for locating the central phosphor line of the trio. Shifting of the printing master to either side permitted the second and third phosphor to be printed.

The Kodalith plate was especially prepared by dyeing the emulsion red with Eosin to reduce its light sensitivity and then applying a very thin layer of aquadag in water-suspension to the surface, drying and burnishing to make the surface conducting.

One other point which refers to the operation of all the tube types should be mentioned. This is the subject of grill wire vibration. The grill wires have a fundamental frequency of the order of 600 cycles per second. Considerable difficulty was experienced with vibrating grill wires until it was discovered that the high voltages being applied to the grills were being modulated by video so that the wires were being driven. It was found adequate to place a 0.03-μf capacitor between the grills which cut down the ac to about 20 or 30 volts. Tubes in which there was no arcing either inside or outside were then found to operate without detectable wire vibration.

Experimental System I Tubes

Turning now to particular tube types, recall that three ways were described of electrically connecting the grills and the cone and phosphor screen, to make a color kinescope. The three arrangements were called System I, System II and System III.

In System I the phosphor screen and adjacent focusing grill are tied together and operated at a potential lower than the cone and auxiliary grill. An advantage of this arrangement is that high velocity back scattered electrons from the phosphor screen are collected by the cone and do not contribute to a reduction in picture contrast. Since the phosphor screen supply voltage is lower than the maximum supply voltage, the light output for a given beam current corresponds to the lower of the two voltages, while the beam current and deflection power correspond to the higher.

One of the most important factors controlling the ratio of these two voltages is the effective beam convergence angle, that is the angle between an outside beam and the axis of the tube measured in a plane perpendicular to the focus grill wires. The smaller the convergence angle the higher the ratio. For example, tubes made with guns having a 51-minute convergence angle operated with a voltage ratio of 0.72. Guns with an effective convergence angle of 31 minutes required a voltage ratio of 0.82. These results apply for beams with normal incidence, and

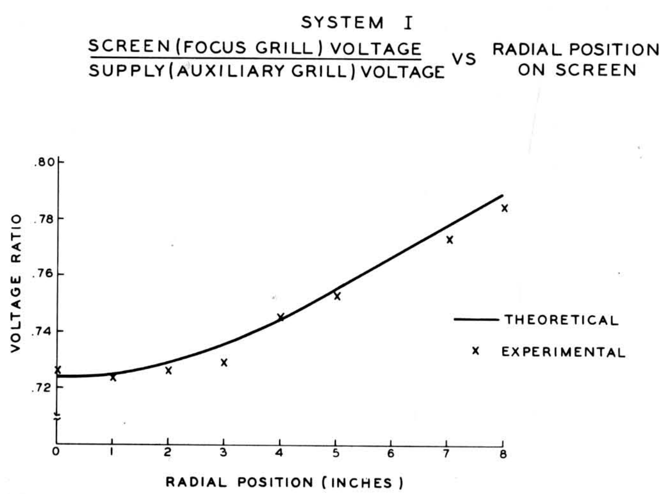

Fig. 17 – Radial variation of focus voltage ratio.

are in agreement with theory. Fig. 17 shows the radial variation in focus ratio together with the theoretical curve. It can be seen that the results agree with theory.

There is another way of achieving a high voltage ratio which avoids the mechanical problems of making guns with extremely small convergence angles. This method makes use of what is called second-order nesting. That is, the phosphor screen is placed at a position where three beams going through adjacent focusing grill apertures will converge on a phosphor trio instead of the usual case where the three beams go through the same lens to strike a phosphor trio. The geometry of the arrangement is shown in Fig. 18. However, if the phosphor screen is placed too far away, the cylindrical lenses of the focusing grill may not be able to produce an acceptable focus size to obtain color purity because of the magnification of the lens system. Also mechanical tolerance requirements become more severe and color purity becomes more sensitive to external field conditions.

It has been found in experimental tubes in which the two grills were spaced 1/8 inch apart, a potential difference of 5 KV is about the limit that may be applied across the grills without danger of arcing. However, should cold emission occur at the fine grill wires it will not cause spurious light on the phosphor screen because of the way the fields are arranged in the tube.

16 inch metal cone tubes with a total deflection angle of 45 degrees have worked well using System I. In fact, a receiver using this tube was demonstrated to the industry at RCA Laboratories in Princeton on April 14, 1953. However, for deflection angles above 45 degrees with flat grills and flat phosphor plates, grill focus broadening and enlargement of the electron beam trio makes it more difficult to obtain color purity.

A means of extending System I to about 60 degrees total deflection angle is to drop the cone potential to that of the phosphor screen in order to provide a normalizing action as the beam enters the auxiliary grill. Satisfactory 19 inch metal cone tubes were made in this way.

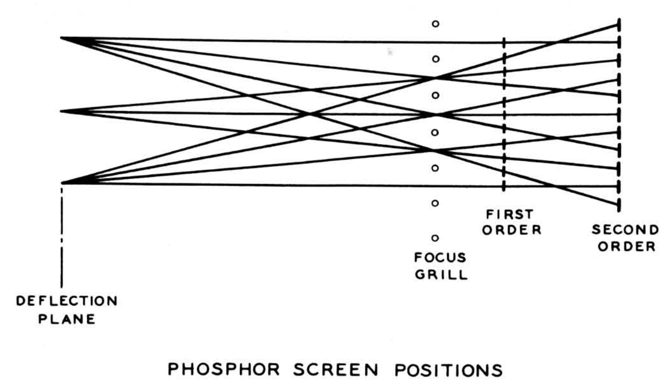

Fig. 18 – Geometry of second-order-nesting.

System II Tubes

System II also makes it possible to deflect more than 45 degrees. In this case, the first grill the beam encounters is at phosphor screen potential, but it is the

Fig. 19 – Focusing and auxiliary grill structure for a 24 inch rectangular tube.

focusing grill because the second grill is at a higher potential. Experiments with this system have confirmed the calculations made. The light output for a given beam current, the beam current itself and the deflection power all correspond to the lower of the two voltages that are supplied.

System III Tubes

Turning now to System III, the first grill the beam encounters is tied to the cone and is the focusing grill while the second grill is operated at a higher potential along with the phosphor screen. The potentials on the grills are such that the high velocity electron scatter from the phosphor does not, in general, affect the useful part of the screen. The light output for a given beam current corresponds to the higher of the two voltages supplied while the beam current and deflection power correspond to the lower.

Flat grills and flat phosphor screens for System III have been built for tubes as large as 24-inch rectangular with deflection angles of 65 degrees. Fig. 19 shows a focusing and auxiliary grill structure for one of these tubes. It became apparent in these tubes, as was predicted, that considerable color purity tolerance was lost at these large

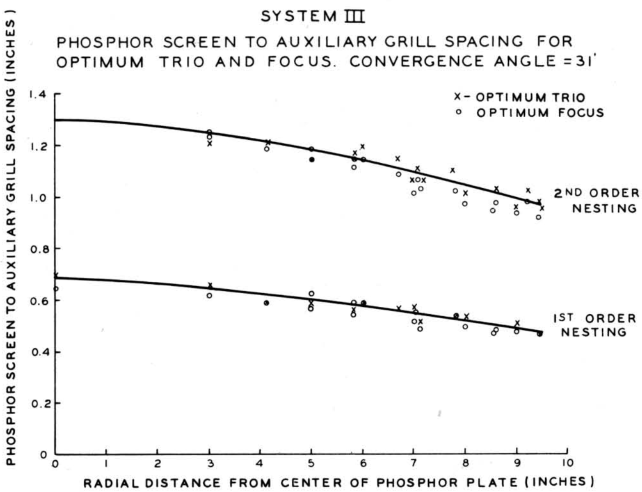

Fig. 20 – Optimum phosphor screen to grill spacings as a function of radial position.

angles due to the curved focal plane of the focusing grill and also the curved nature of the surface for which ideal nesting of the electron trio results. Also the desirability was recognized of being able to put the phosphor directly on the faceplate of the tube. An investigation was therefore undertaken to determine experimentally the optimum curvature of the phosphor plate for both focus and trio nesting so that electron optical and yoke effects would all be taken into account. Fig. 20 shows a plot of experimentally determined ideal phosphor screen-grill spacings as a function of radial position on the screen. Points are given on the curve for both ideal focused line width and trio nesting. It was found that the requirements for focus and nesting were fairly close and could be approximated quite well by a surface of revolution. To a first approximation with a 31 minute gun and 65 degree deflection the radius of curvature of the surface is approximately 100 inches although the shape is not spherical. Experiments have shown that by properly shaping the phosphor screen, it is possible to obtain satisfactory focus and grouping over the full screen area.

A theory has been presented for three systems of focusing-grill color kinescopes which minimize adverse effects of secondary emission and backscattering. Each system has been tried experimentally with results in agreement with the theory.

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