RECENT IMPROVEMENTS IN THE 21AXP22 COLOR KINESCOPE

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Summary—*The quality of the 21AXP22 color kinescope has been steadily improved since the tube was first announced in September 1954. As a result of experience gained in the manufacture of thousands of tubes and changes in tube construction and processing, nearly perfect color purity and white uniformity have been achieved. A large proportion of the improvements obtained are the result of changes in the "lighthouse" on which the phosphor screens are exposed. After a brief review of the principles of the tube and data on its operation, there is a discussion of the changes which have been made in the tube and in the lighthouses used to produce the tubes. Equipment used to obtain data for the changes is also described.*

Introduction

The 21AXP22[1], shown in Figure 1, is a shadow-mask color kinescope employing a formed mask. A simplified internal view of the tube is shown in Figure 2. The front section, or "top cap," of the two-piece metal envelope contains the spherical faceplate and formed aperture mask. The mask has a radius of curvature slightly smaller than that of the faceplate and is welded to a light metal frame which is supported from the side walls or panel section of the top cap by a unique three-point stud and spring arrangement, as shown in Figure 3. Excellent mask replaceability is achieved with this arrangement. The phosphor-dot pattern is placed directly on the inner surface of the faceplate, and consists of 357,000 dot trios, one for each of the apertures in the formed mask. Each trio is composed of equal-sized dots of red-, green-, and blue-emitting phosphor. The glass funnel-neck section sealed to the small end of the conical metal shell contains three complete electron guns arranged in a delta pattern. This gun structure, shown in Figure 4, employs electrostatic focusing, and a combination of mechanical and magnetic methods for obtaining convergence of the three beams.

The electrostatic focusing lenses are formed by the No. 3 and No. 4 grids of the guns. Corresponding lens elements are connected in

[1] H. R. Seelen, H. C. Moodey, D. D. VanOrmer, and A. M. Morrell, "Development of a 21-Inch Metal-Envelope Color Kinescope," *RCA Review*, Vol. XVI, pp. 122-139, March, 1955.

Fig. 1—Photograph of 21AXP22 color kinescope.

parallel, so that only a single focusing adjustment is used. Approximate static convergence is obtained by mechanical tilt of the three guns toward the tube axis. Precise static convergence is obtained by means of the three sets of beam-converging pole pieces located at the top of the gun structure, and the single set of blue-positioning pole pieces. The beam-converging and blue-positioning pole pieces can be coupled to the fields of external magnets and permit, respectively, radial positioning of the three beams with respect to the tube axis, and tangential positioning of the blue beam. The external purifying mag-

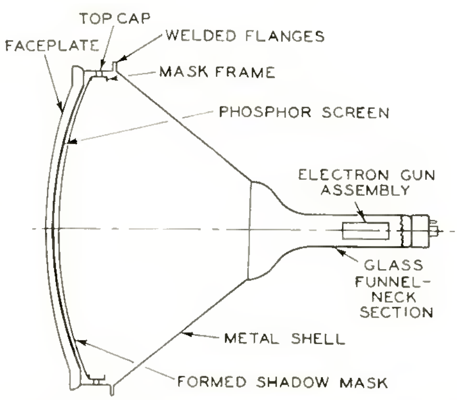

Fig. 2—Schematic diagram of 21AXP22 color kinescope.

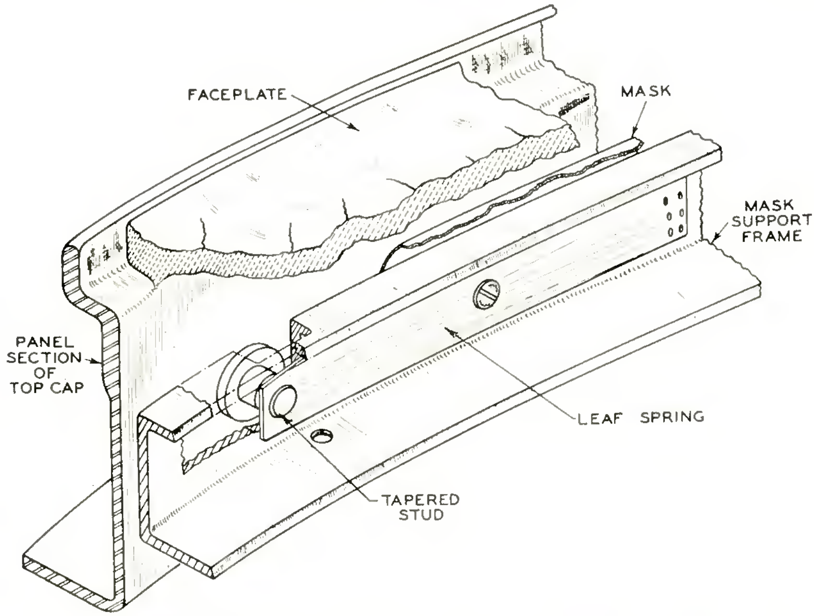

Fig. 3—Detail of spring mounting for shadow-mask support frame.

net is installed on the tube neck, and provides a transverse magnetic field which is used to correct for misalignment between the gun assembly and top cap and for the effects of the earth's magnetic field.

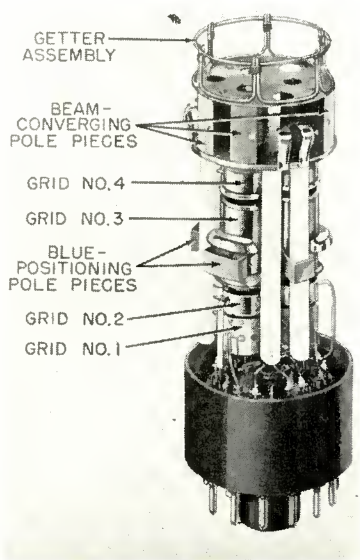

Fig. 4—Photograph of electron-gun assembly.

Principle of Operation

The operating principles of the 21AXP22 are basically the same as those of the planar-mask color kinescope described by H. B. Law.[2] Each of the three electron beams is used to produce one of the primary colors. As shown in Figure 5, the three beams are converged at the shadow mask, and after passing through a common aperture, strike the appropriate phosphor dots of a color trio lying behind the aperture.

The spacing, D, between phosphor dots of the same color, or between the centers of adjacent color trios, is a magnification of the spacing, a, between mask apertures. That is,

$$\frac{D}{p+q} = \frac{a}{p},$$

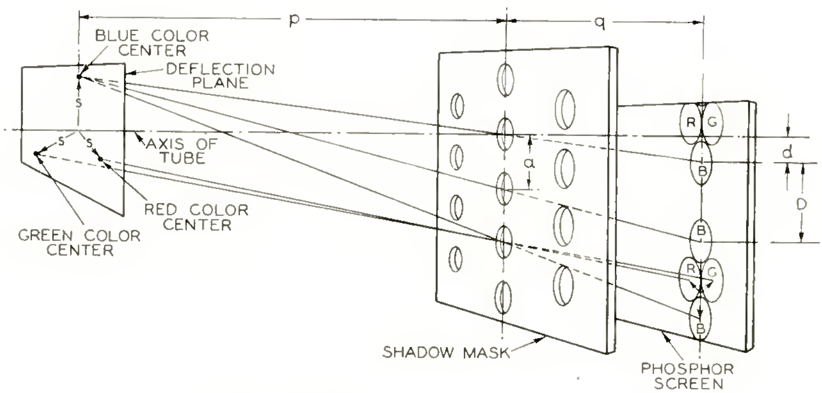

Fig. 5—Geometry of planar-mask system.

where p is the spacing between deflection plane and mask, and q is the spacing between mask and screen.

The spacing, d, of a phosphor dot from the center of its trio is proportional to the spacing, s, between the corresponding deflection center or color center and the tube axis in the deflection plane. That is,

$$\frac{s}{p} = \frac{d}{q}.$$

In a planar-mask tube the spacing between phosphor dots of one color or between adjacent phosphor-dot trios, is a constant magnification of the mask-aperture spacing, regardless of the deflection angle,

[2] H. B. Law, "A Three-Gun Shadow-Mask Color Kinescope," *Proc. I.R.E.*, Vol. 39, pp. 1186-1194, October, 1951.

and the spacing of the phosphor dots within a color trio is a constant demagnification of the deflection-center or color-center spacing in the deflection plane. These constant magnification and demagnification properties permit the screen of a planar-mask tube to be covered completely with tangent phosphor dots.

It is desirable that the formed-mask tube also have constant magnification and demagnification properties in order to obtain optimum utilization of the phosphor screen. However, as explained by Seelen,[1] and shown in Figure 6, precisely constant magnification cannot be obtained when both the aperture mask and the phosphor screen are curved. If the faceplate or screen has a radius of curvature R_f, a mask having a slightly smaller radius of curvature R_m and its center of curvature at point *D* will give constant magnification for a single electron source located at point 0. When three electron sources equidistant from the tube axis and spaced 120 degrees apart are employed, the center of curvature of the mask must be located on the tube axis at point *E*. This change of center causes a slight deviation from constant magnification. The consequences of this deviation will be discussed later.

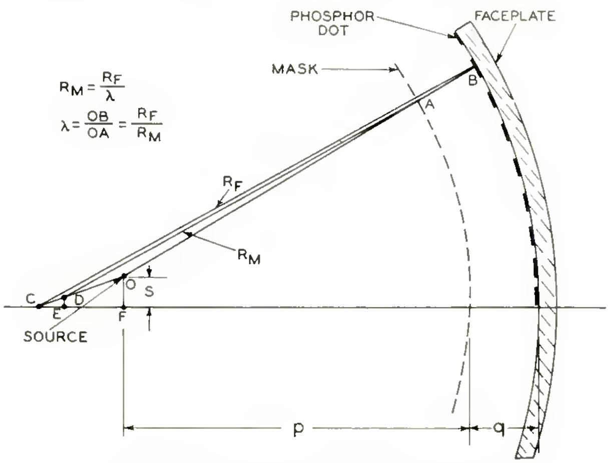

Fig. 6—Geometry of spherical system.

Phosphor-Screen Fabrication Technique

Positioning and formation of the phosphor dots on the faceplate of the 21AXP22 are accomplished photographically in a special optical device called a "lighthouse." This device, shown in Figure 7, contains a small high-intensity light source placed in the same geometrical position with respect to the mask and screen as one of the deflection centers, or color centers, of the tube. This light source can be rotated about the central axis of the system in steps of 120 degrees so as to place it successively in the positions of the three effective deflection centers. At each of these positions light from the source passes through the mask apertures and strikes the screen at points which would be struck by an electron beam passing through the corresponding deflection center and traveling in straight lines.

In phosphor-screen processing, the inside of the cap is first covered with a thin, uniform, layer of a mixture containing one color phosphor

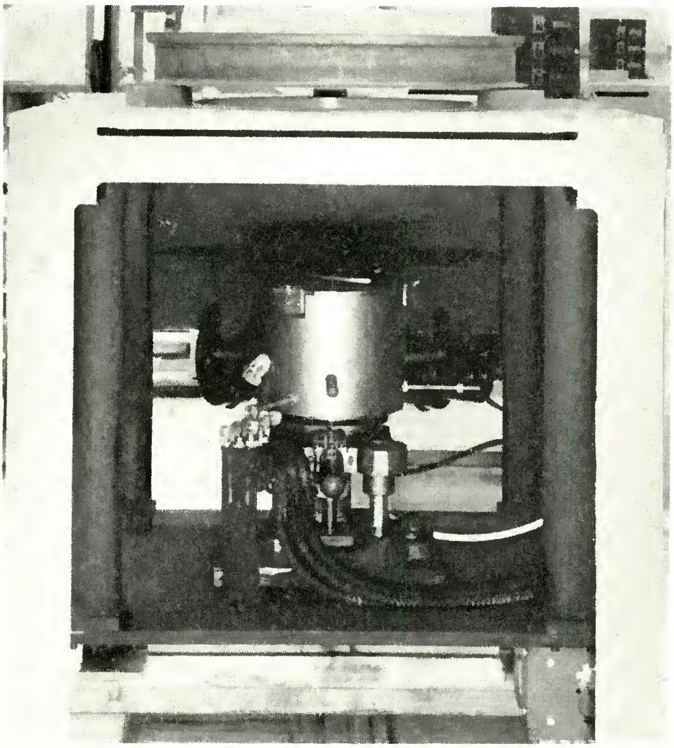

Fig. 7—Optical lighthouse used for phosphor-screen production.

and a photoresistive material. The formed mask is then installed in the top cap and the entire cap assembly placed on the lighthouse. Proper positioning of the cap with respect to the light source is assured by three dimples in the top cap flange which fit into grooves in the lighthouse table.

The phosphor-photoresist mixture is then exposed by allowing the light from the high-intensity source to pass through the mask apertures. The screen is then developed to produce a pattern of phosphor dots of one color.

These steps are repeated for the second and third color phosphors. Between exposures the light source is rotated about the axis of the system in 120-degree steps so that it falls in the proper position for each color field.

Factors Affecting Tube Quality

The screen of an ideal shadow-mask tube would be completely covered with tangent phosphor dots of uniform diameter. In addition, each electron beam of such a tube would have perfect "landing"—that is, it would be in perfect register with all phosphor dots of a particular color—and the resulting electron spots at the screen would have the same uniform diameter as the phosphor dots. An ideal shadow-mask tube would therefore be capable of producing three separate color fields, each having perfect color purity and uniform brightness. If these three fields were produced simultaneously in the proper relative brightness,* the result would be a uniform white field. This last consideration is extremely important, since in the present (compatible) system color tubes must be capable of producing high quality black-and-white pictures.

The following effects must be taken into consideration in making color tubes capable of displaying pure color fields and good black-and-white pictures:

1. Effects of the earth's magnetic field.
2. Mechanical deformation of faceplate and shadow-mask.
3. Change of deflection center of yoke with deflection angle.
4. Asymmetrical spreading ("degrouping") of the electron-spot trios when dynamic convergence is applied.
5. Asymmetrical compression ("grouping") of phosphor-dot trios resulting from nonuniform magnification.
6. Variation in phosphor-dot size due to nonuniformities in the optical lighthouse.

A typical register pattern for one beam of an early formed-mask tube is shown in Figure 8. The scale of the figure is distorted to emphasize the amounts by which the beam-landing spots are displaced from the phosphor dots in many regions of the screen. The numerical values shown at the misregister points represent mils, or thousandths of an inch. Perfect register at the center of the screen was obtained

* Obtained at the following ratios of individual beam currents to total ultor current: red, 51 per cent; blue, 19 per cent; green, 30 per cent.

by positioning the electron beam in the deflection plane of the yoke so that the effective deflection center for the beam, or color center, had the same geometrical location as the light source used to produce the phosphor dots. The beam is positioned at the center of the screen by adjustment of the purifying magnet referred to previously.

A change in the position of the deflection yoke will cause a radial change in register. In this instance the yoke was positioned so that there was no radial misregister at the left-hand end of the horizontal line.

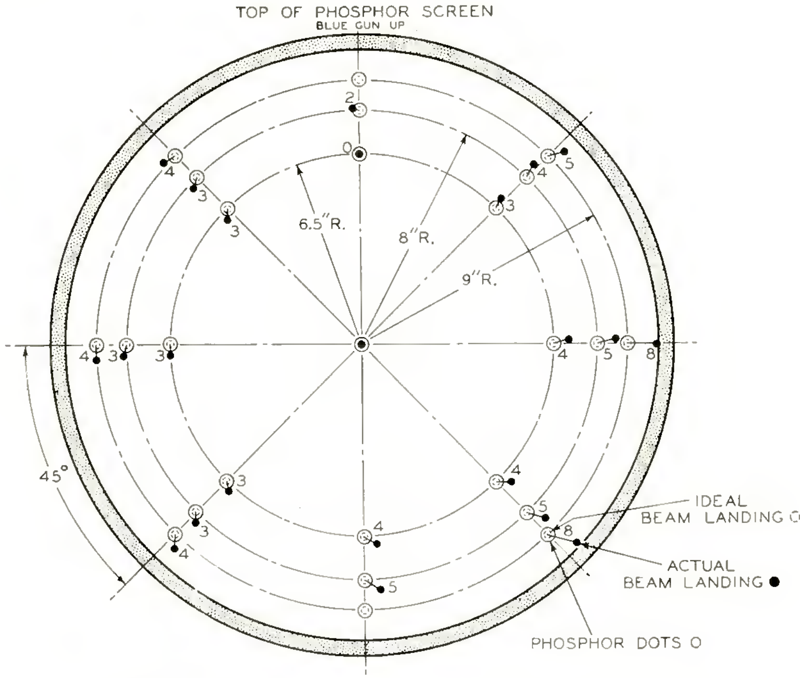

Fig. 8—Typical register pattern on an early tube.

Effect of Earth's Magnetic Field

The greatest difficulty encountered in evaluating the various factors responsible for misregister was distinguishing individual effects. The earth's magnetic field, for example, is always present, and can cause appreciable misregister despite its weakness and the high velocity with which the electron beams travel from the cathodes to the phosphor screen. Figure 9 shows the misregister caused by the earth's magnetic field on a 21AXP22 at Lancaster, Pennsylvania, facing north.

In setting up a shadow-mask kinescope in a test set or receiver, the effects of the earth's magnetic field on the undeflected beams are minimized by adjustment of the purifying magnet on the tube neck. The earth's field is not uniform over the limited region occupied by the kinescope because of the effect of the metal envelope. Misregister produced at the screen during scanning is corrected by means of a ring-shaped "magnetic-field equalizer" installed at the periphery of the screen. The eight-pole equalizer described by Seelen[1] has since been replaced by the six-pole type shown in Figure 10.

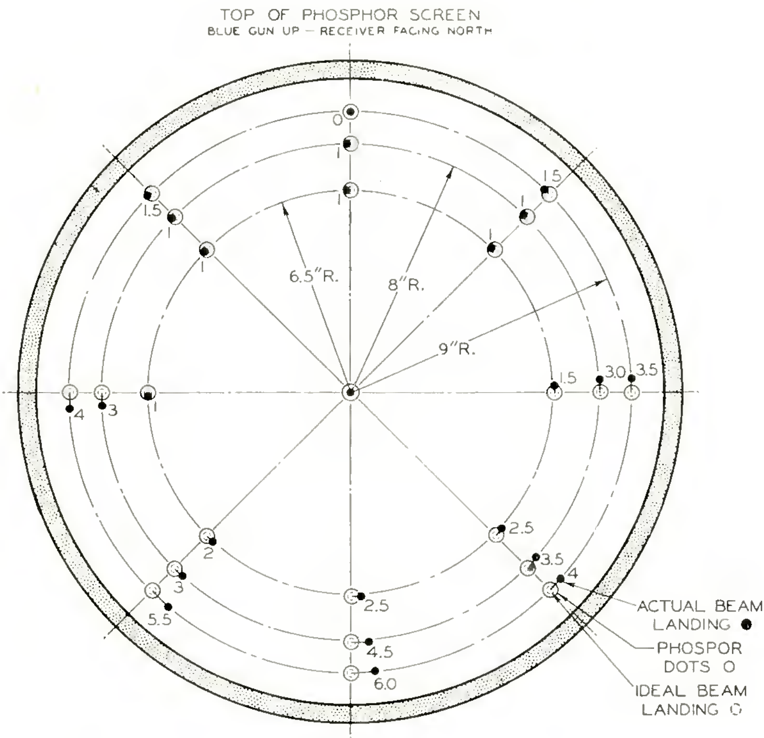

Fig. 9—Misregister caused by earth's magnetic field on the 21AXP22 located at Lancaster, Pa.

The most satisfactory method for evaluating the effects of the earth's magnetic field is to simulate it by means of the six-coil arrangement shown in Figure 11. With such an arrangement (called a Helmholtz-Coil Field Simulator), the magnitude and direction of the earth's magnetic field at any location can be simulated by applying the proper currents to the coils. No attempt is made either to shield out or to cancel the earth's field in these measurements. Instead, the simulated field is added to the field already present.

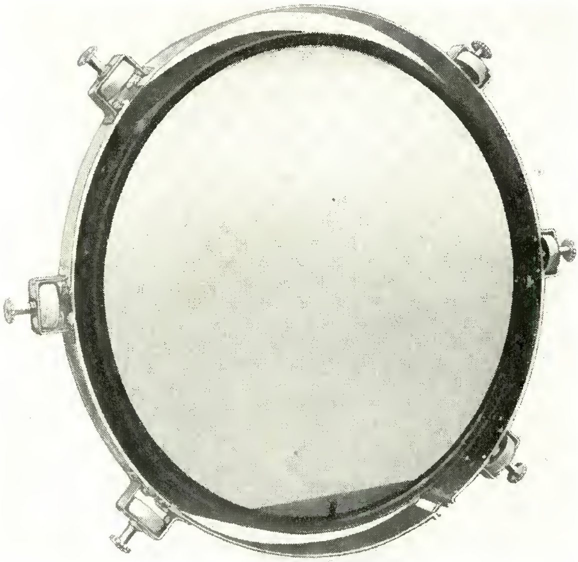

Fig. 10—Six-pole magnetic field equalizer.

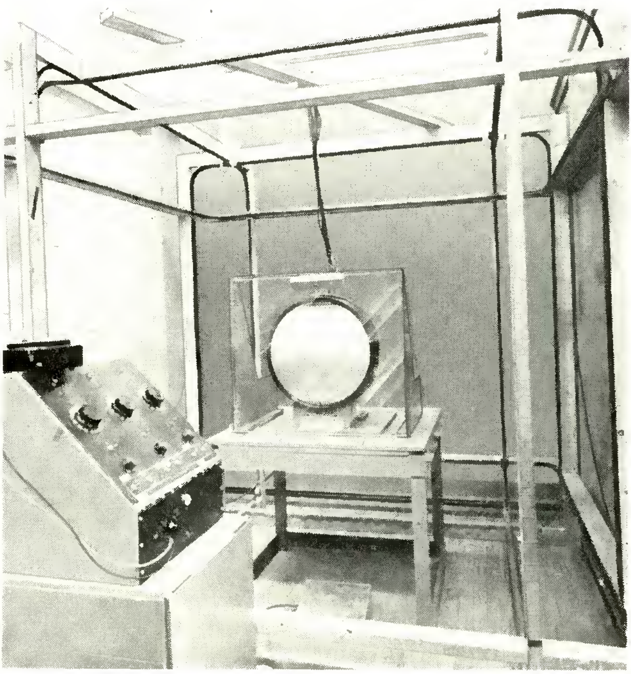

Fig. 11—Coils used to simulate the earth's magnetic field.

For analysis the earth's field may be separated into its horizontal and vertical components. The horizontal component varies in both magnitude and direction with the geographical location and orientation of the tube. Because the vertical component is always perpendicular, misregister caused by this component is always in the same direction (to the left in the northern hemisphere) when looking into the tube face and varies only in magnitude with geographical location.

In the United States, the average strength of the horizontal component is 0.21 gauss, and that of the vertical component 0.54 gauss. Since the vertical component is by far the predominant factor, the amount of correction required for resulting misregister can be minimized by offsetting the entire top-cap assembly to the right of the lighthouse axis. Tests conducted in the Helmholtz-coil setup under a variety of conditions have made it possible to predict the amount of misregister which will be caused by the earth's magnetic field at any geographical location or with any orientation of the kinescope in the normal (horizontal) operating plane. As a result of these tests, an offset of the top-cap is now being used in the lighthouse. This offset is based on the average magnitude of the vertical component in the United States, weighted for population density.

In order to eliminate the effects of the earth's magnetic field and other magnetic fields in the evaluation of the various factors responsible for misregister, the magnetically shielded room shown in Figure 12 was constructed. This room is constructed of Allegheny 4750 metal 3/32 inch thick and is eight feet square and eight feet high. The earth's magnetic field within the room is less than 0.01 gauss.

Mechanical Deformation

Because the phosphor screen of each 21AXP22 is a photographic image of its own aperture mask, it is not necessary that masks or screens from various tubes be interchangeable. To assure tubes of uniformly good quality, however, it is necessary that the contours of all aperture masks and faceplates be as close as possible to the design values. Originally, these contours were measured by means of dial-gauge and jig-borer arrangements. This method, however, is cumbersome and time consuming and these contours are now measured by means of Moore air gauges. In this method, the part to be measured is positioned over a number of preset measuring heads, as shown in Figure 13. Each of these heads contains a small valve through which air is allowed to escape. Deviations from the design dimensions cause changes in the valve apertures and the resulting changes in back pressure on the individual air lines are used to indicate the amounts of deviation. Displacements as small as 0.003 inch can be measured by this method.

During processing, the faceplate and aperture mask are subjected to mechanical stresses which can change the geometry of the system sufficiently to cause misregister. Extensive tests on the 21AXP22 have indicated that the most serious deformations occur during the exhaust operation.

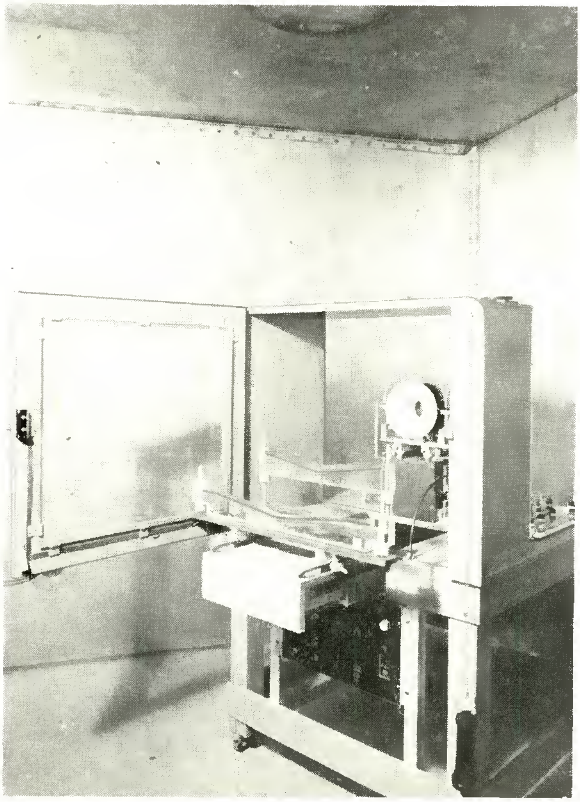

Fig. 12—Magnetically shielded room used for yoke tests.

The movements and deformations of the faceplate and aperture mask during exhaust were measured by means of dial gauges and depth-measuring microscopes. Figure 14 illustrates the changes observed in a typical top-cap assembly. There is a minute flattening of the faceplate, and the aperture mask moves closer to the faceplate but is not appreciably changed in shape. These changes all have radial symmetry about the tube axis, and are responsible for an outward

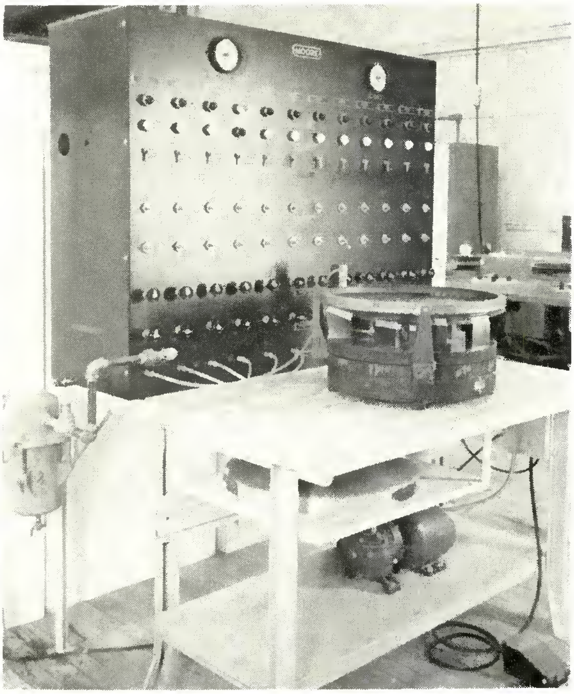

Fig. 13—Moore air gauge used for measuring face-plate and mask contours.

radial misregister of 0.0010 inch to 0.0015 inch at the edge of the screen.

Change in Deflection Center

The effective deflection center in a magnetic deflection yoke moves forward as the angle of deflection is increased. This effect occurs

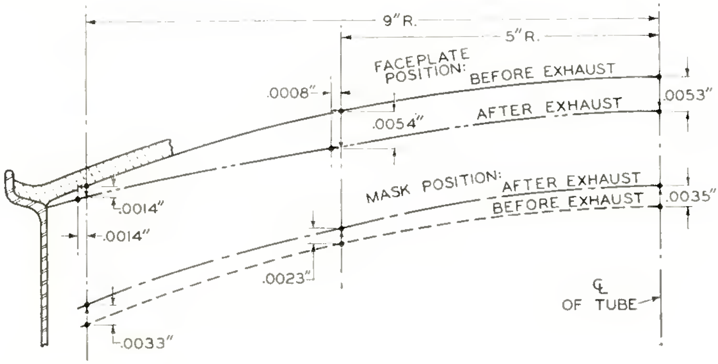

Fig. 14—Face-plate and aperture-mask deformation during tube exhaust.

whether the yoke field is an ideal one having uniform length and strength, or a practical one in which fringing is present. The reason for this change in the apparent origin of the electron beam is shown in Figure 15. During scanning, the beam travels through the yoke field along a curved path. After leaving the field the beam travels in a straight line tangent to its previous curved path at the point of exit. When the strength of the yoke field is increased to obtain greater deflection the radius of the curved path is decreased, and the beam remains longer within the yoke field. If the resulting exit tangents are extended back to the tube axis it can be seen that the effective deflection center moves forward with each increase in deflection angle. For very small deflection angles the beam apparently originates at the

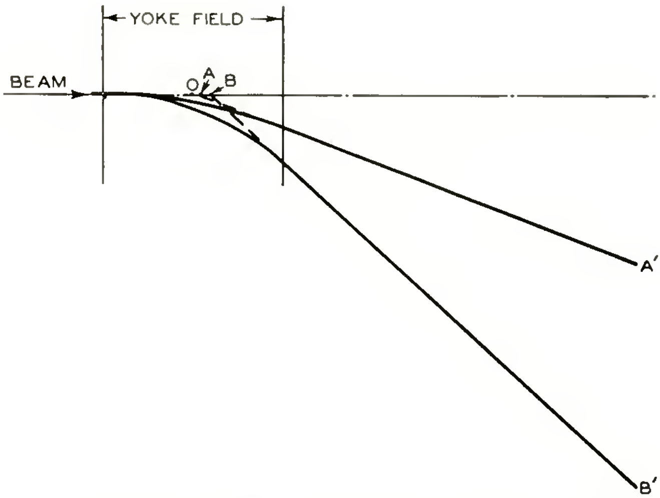

Fig. 15—Sketch illustrating motion of deflection centers.

center of the yoke (point 0 in Figure 15). For successively larger deflection angles the source of the beam apparently moves forward to A and then B. The effective distance between electron source and mask therefore decreases with increased deflection angle. However, the light-source-to-mask distance p used to produce the phosphor screen is constant for all deflections.

These differences between the values of p obtained in operation and the value of p used in the lighthouse can cause radial misregister between the beam spots and their corresponding phosphor dots. This effect is shown in Figure 16. The scale of this figure has been distorted for clarity. It can be seen that as the deflection center moves forward an amount Δp an outward misregister Δr results. This misregister is not easily distinguished in an operating tube, from that caused by mechanical deformation described above.

A large number of tubes were checked for register in the magnetically shielded room. Only one beam, or color field, was used in these tests in order that any misregister observed would be solely the result of changes in the deflection center of the yoke and the mechanical deformations described above. Each amount of misregister observed during these tests was broken down into its radial and tangential components. The average tangential was found to be small in magnitude and random in direction. The average radial component, however, proved to be large and to have constant magnitude and direction. Figure 17 shows plots of this radial misregister versus distance from

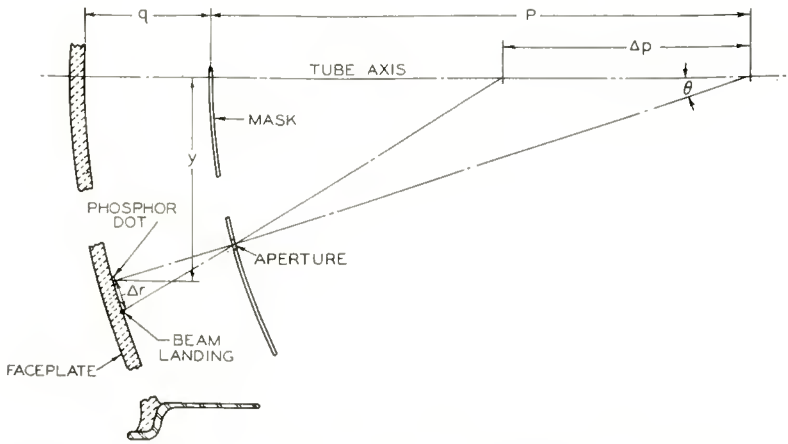

Fig. 16—Radial register change Δr versus deflection-center motion Δp.

the tube axis for an average tube. The three curves show the results obtained with the deflection yoke in different positions on the tube neck. With the yoke in the design position (curve 1), there is an outward radial misregister of 0.005 inch at the 9 inch radius. If the yoke is pulled back on the neck, curves such as 2 and 3 result. It is apparent that the yoke can be positioned so as to correct for radial misregister at any given radius on the tube face, but not so as to correct for misregister at all radii.

Noncoincidence of Horizontal and Vertical Deflection Centers

It was also found that the deflection centers of the horizontal and vertical deflection fields of a yoke are not always coincident. This lack of coincidence is responsible for a difference in maximum radial misregister in the horizontal and vertical directions. With some commercial yokes this difference was greater than .002 inch.

Radial Correction Lens

The discovery that the radial misregister caused by a change in the effective deflection center of the yoke was constant from tube to tube suggested that it could be corrected by means of a lens in the optical lighthouse. A suitable correction lens[3] was, therefore, designed

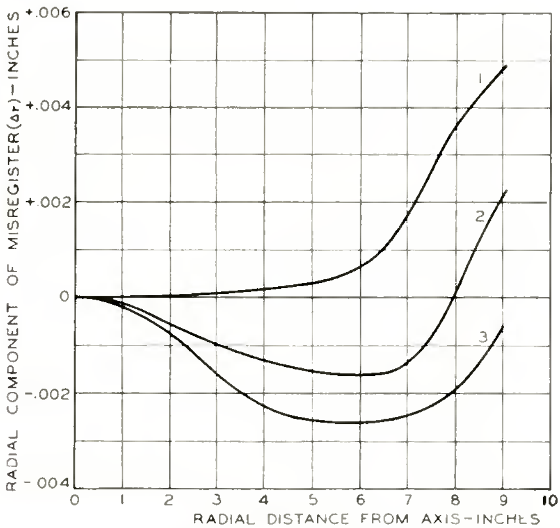

Fig. 17—Radial component of misregister as a function of distance from tube axis.

and constructed. This lens almost completely eliminated the uniform radial misregister, and such lenses are now used in all factory lighthouses.

The correction lens is placed between the light source and the top cap containing the phosphor screen to be exposed. Its action is shown in Figure 18. Without the lens (Figure 18) a ray of light originating at 0 and traveling at an angle θ with respect to the deflection axis will pass through a mask aperture at point A, and strike the phosphor screen at point E. During the exposure of the screen a phosphor dot

[3] D. W. Epstein, P. Kaus, and D. D. VanOrmer, "Improvements in Color Kinescopes Through Optical Analogy," *RCA Review*, Vol. XVI, December, 1955.

will be located at this point. When the completed tube is operated with a conventional yoke, the apparent source of the electron beam for a deflection angle θ will be point B, and the resulting beam path will be BAF. The beam landing spot F, therefore, will be displaced radially outward from its corresponding phosphor dot by an amount Δr.

When a correction lens having the proper curvature is placed between the light source and the phosphor screen to be exposed, as shown in Figure 18, some ray of light OC will be refracted so that on leaving the lens it travels along the path DAF. Since this path is coincident with the path BAF in Figure 18, the phosphor dot created by this ray during the screen exposure will lie at the same point F at which the electron beam will land in an operating tube. In order to provide the

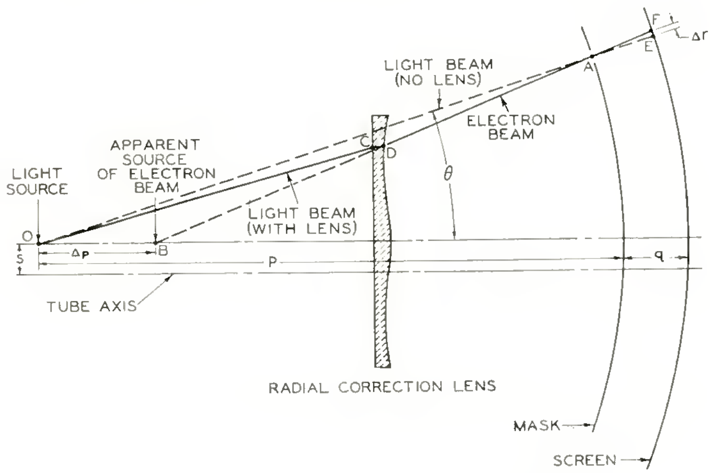

Fig. 18—Action of radial correction lens.

proper amount of correction at each point on the screen the lens curvature must vary from center to edge in such a manner that the spacing between the actual light source O and the virtual light source B increases with deflection angle in the same manner as Δp increases in an operating tube.

Since the deflection point B for each beam lies a distance S from the tube axis, the center of the correction lens must also lie off the axis by this amount. When the light source is rotated to put it in position for the production of the second and third sets of phosphor dots, the lens is rotated with it. In order to eliminate adverse effects which might result from tilting, i.e., improper alignment of the lens in the lighthouse structure, the lens was made as large as possible. The large size of the lens also simplified the coating procedure (described later in the paper).

Figures 19 and 20 show the lens installed in the lighthouse.

Improved Coincidence of Horizontal and Vertical Deflection Centers

Improvements have also been made in the yoke to reduce the spacing between horizontal and vertical deflection centers.[4]

Investigation showed that differences in the positions of the horizontal and vertical deflection centers of yokes could be minimized by changing the shielding materials used to prevent yoke fields from affecting convergence. In early commercial color yokes, ferrite washers were used as shielding for the low-frequency vertical-deflection field and copper discs as shielding for the high-frequency horizontal-deflection field. With these materials, the difference in maximum horizontal and vertical misregister for a typical yoke was 0.0013 inch.

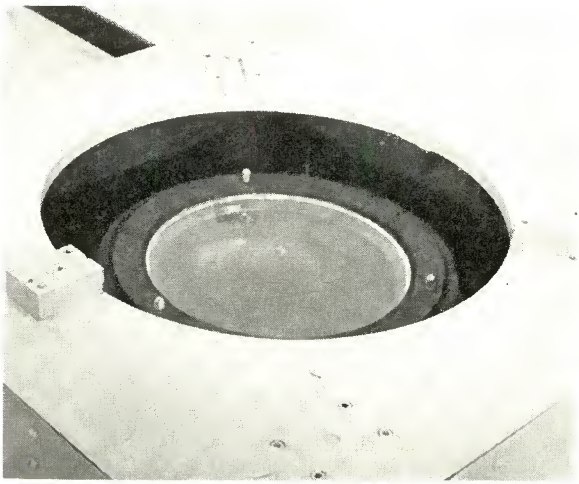

Fig. 19—Mounting of radial correction lens.

Substitution of a four-ply silicon-steel washer for the ferrite washer and of an aluminum disc for the copper disc reduced this difference to 0.0003 inch in the standard 230FD1 yoke. This difference is considered negligible, and was obtained without undesirable changes in the other characteristics of the yoke.

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[4] M. J. Obert, "Deflection and Convergence of the 21AXP22 Color Kinescope," *RCA Review*, Vol. XVI, pp. 140-169, March, 1955.

Dynamic Degrouping

As a result of the mechanical tilt of the three electron guns and the action of the beam-converging pole pieces, the undeflected beams converge on the tube axis at the plane of the aperture mask. During scanning the beams converge at a highly curved surface concave toward the deflection center. Because of the relative "flatness" of the aperture mask, at the larger deflection angles the beams converge before reaching the mask. This undesirable condition is corrected by the application of a "dynamic convergence" current derived from, and in synchronism with, the horizontal and vertical scanning waveforms and

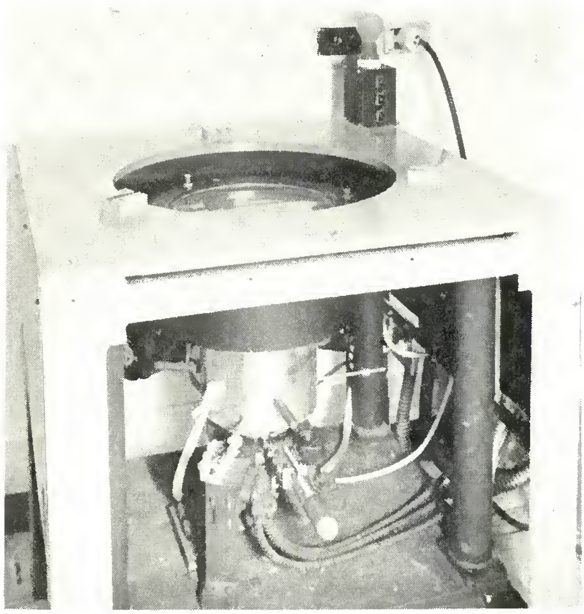

Fig. 20—Optical lighthouse with radial correction lens.

applied to the windings of the external convergence magnets. The effects of this current are shown in Figure 21. For simplicity only two of the three beams are shown.

In the absence of scanning, the beams pass through the deflection plane at points A and B, at equal distances S from the tube axis, and converge at the plane of the mask. The dynamic-convergence fields developed during scanning shift the beams away from the axis, so that at maximum deflection they pass through the deflection plane at points A' and B'. Since the spacing between beam spots at the screen is a constant demagnification of the spacing between beams in the deflection plane, the increase in beam spacing during scanning results in spreading or "degrouping" of the electron spots with respect to the phosphor dots. This "dynamic degrouping" increases with deflection angle in the manner shown in the inserts at the right of Figure 21. In early 21AXP22 tubes the average dynamic degrouping at the edge of the screen was 0.0023 inch—that is, the distance from the center of a beam landing spot to the center of the beam spot trio was 0.0023 inch greater than the distance from the center of a phosphor dot to the center of the phosphor dot trio.

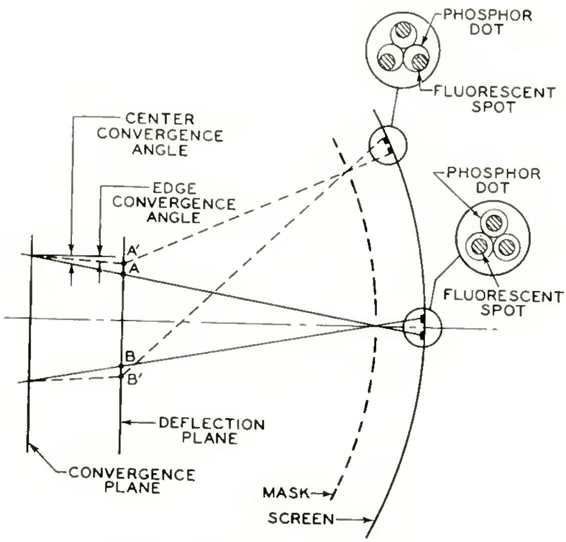

Fig. 21—Sketch illustrating effect of dynamic convergence.

Correction for Dynamic Degrouping

Various schemes for correcting this dynamic degrouping have been considered. The most practical solution developed to date has been the use of a compromise value of s in the optical lighthouse. The results of this modification are shown in Figure 22.

In the modified lighthouse, the light source is placed at point C, an increased distance s' from the tube axis. This change caused a corresponding degrouping of the phosphor dots at the screen, as shown at $B'B'$ and $B''B''$, so that it was necessary to decrease the spacing q between mask and screen in order to maintain the desired spacing within the dot trios. Since the original value of s is used in the gun assembly, the "dynamic degrouping" effects are redistributed in an operating tube. At zero deflection angle the electron beams again pass through the deflection plane at points *AA*, but, because of the reduced spacing *q*, are "grouped" at the screen—that is, they strike the screen at points which are slightly closer to the center of the phosphor dot trios than the centers of the individual phosphor dots. At large deflection angles the beam spots are still degrouped, but by much smaller amounts than in the original design. Perfect register between beam spots and phosphor dots is obtained at points approximately midway between the center and edge of the screen. The compromise value of *s* used on the lighthouse is 0.327 inch, as compared with the value of 0.276 inch used in the original lighthouse design and in the electron

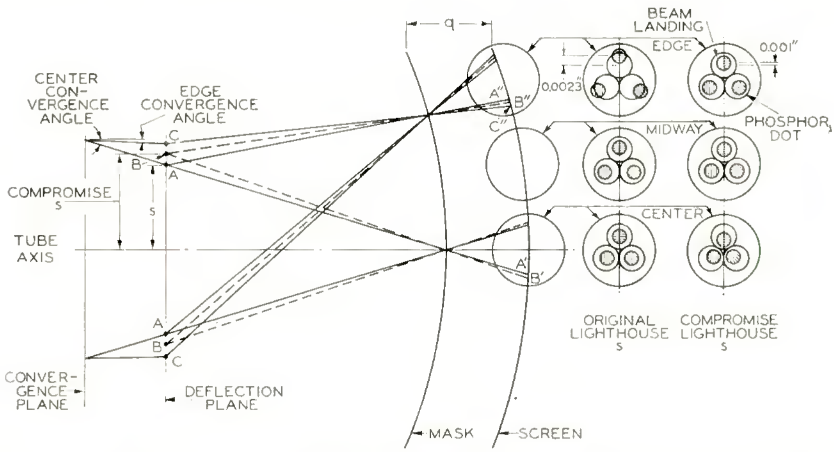

Fig. 22—Sketch illustrating effect of dynamic convergence on a tube with a compromise S valve.

gun assembly. The mask-to-screen spacing, *q*, has been decreased from 0.535 to 0.451 inch. As a result of these changes dynamic degrouping at the edge of the screen has been reduced from 0.0023 to less than **0.001 inch.**

Phosphor-Trio Asymmetry

In a planar-type shadow-mask tube the phosphor-dot trios form perfect equilateral triangles over the entire surface of the screen. In a formed-mask tube, however, the curvature of the mask and screen causes a radial compression of these trios which increases with deflection angle. This radial compression or "grouping" amounts to more than 0.001 inch at the edges and is particularly undesirable because it is in opposition to the dynamic *degrouping* of the beam spots.

Correction for Phosphor-Trio Asymmetry

This radial grouping of the phosphor dots can be minimized by shifting the center of the correction lens off the center line of the light source. Such a shift increases the refraction on one side of the center line and decreases it on the other, and thus redistributes the dot grouping in the same manner as the use of a compromise value of s redistributes the degrouping of the beams. A substantial reduction in phosphor trio grouping has been obtained by offsetting the center of the lens 0.075 inch beyond the center line of the light source. Figure 23 shows the present arrangement, using the compromise offset

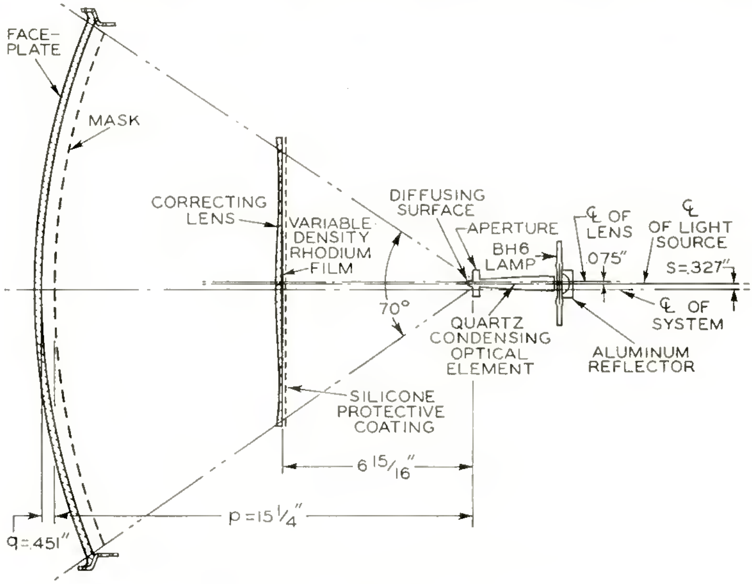

Fig. 23—Complete lighthouse geometry.

of 0.327 inch for the light source and an additional offset of 0.075 inch for the lens.

Light Source Nonuniformity

The phosphor dots produced on the screen during the lighthouse exposure are, in the ideal case, demagnified images of the light source used to produce them. However, the characteristics of the photoresist are such that the sizes of the phosphor dots vary considerably with light intensity and exposure time. The optical system used in early lighthouses was designed to pick up radiation throughout a wide-angle cone, and to pass the condensed radiation through a circular aperture of about 0.160 inch diameter to a hemispherical diffusing surface. In these lighthouses, the variation in light intensity from center to edge was approximately 35 per cent, and resulted in a corresponding variation in phosphor dot size, the smallest dots occurring at the edge of the screen. Consequently when tubes produced on these lighthouses were operated, even small amounts of misregister caused the beams to miss the phosphor dots at the edge of the screen. As a result, there was considerable variation in light output and color purity in these regions. It was possible to obtain more nearly uniform dot size over the screen by increasing the exposure time so that the edge received adequate exposure. When this was done, however, the center portion

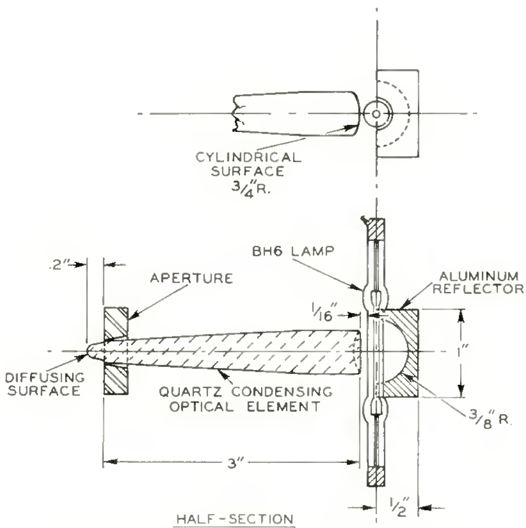

Fig. 24—Improved lighthouse optics.

of the screen, where the radiation intensity was highest, was overexposed.

IMPROVED LIGHTHOUSE OPTICS

The optics of the new and more efficient lighthouse assembly mentioned by Seelen[1] are shown in Figure 24. The light source is a 1-kilowatt high-pressure capillary mercury-arc lamp, selected as the brightest source of ultraviolet and blue radiation in the region 3,400 to 5,000 angstroms commercially available, and for its good stability and life. The reflector is a spherical mirror having a highly polished aluminum surface.

The light-collecting end of the quartz condensing optic has been made cylindrical, with a radius of curvature of about 0.75 inch. This configuration provides maximum light collection in the direction perpendicular to the axis of the lamp when the optic is mounted with the axis of its cylindrical end parallel to the lamp axis.

The optimum shape for the diffusing surface was found to be parabolic rather than hemispherical, the optimum diameter 0.220 inch, and the optimum extension beyond the defining aperture 0.200 inch (see Figure 25). These changes reduced the maximum variation in light intensity across the screen from 35 to 25 per cent. However, with proper exposure at the center of the screen there was still considerable variation in dot size across the screen.

Analysis of the radiation intensity over the screen surface showed that the equal-intensity contours were approximately elliptical, with their long axes parallel to the axis of the lamp. It was determined that the variation in radiation intensity over the screen could be reduced

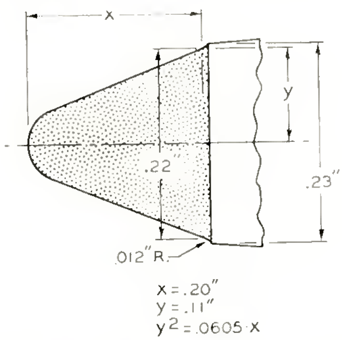

Fig. 25—Optimum lightsource diffusing surface.

to about 15 per cent by the application of a metal film of varying density to the flat surface of the lens. Rhodium was selected as a suitable material for this film because of its stability in air and relative ease of evaporation. The rhodium was evaporated from a plated tungsten filament, shaped and positioned so as to produce a film having an essentially elliptical density distribution and gradients equivalent to those of the radiation intensity. The thickness of the film was controlled so as to obtain white-light transmission of approximately 75 per cent at the center, and of almost 100 per cent at the two edge points perpendicular to the axis of the lamp.

These new features have made it possible to achieve a uniformity of dot size within 0.002 inch over the entire screen area, and have permitted a 40 per cent reduction in exposure time over the older system. Work is being directed toward even further improvement.

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