DEVELOPMENT OF A 21-INCH METAL-ENVELOPE COLOR KINESCOPE*

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Summary—*The major features of a 21-inch metal-envelope color kinescope are described, and considerations involved in the choice of the size and construction used are discussed. Basic operational principles of the tube are explained, and geometrical relations governing its design dimensions are given. A discussion of a number of factors affecting register is included.*

Introduction

THIS paper describes some of the main technical features of the recently announced 21AXP22 formed shadow-mask color kinescope. A photograph of the tube showing its round metal envelope appears in Figure 1. The picture size of 260 square inches is obtained with an over-all tube length of less than 25½ inches. This was made possible by the use of a short gun and a deflection angle of 70°. The spherical faceplate, upon which the phosphor screen is deposited, is of 77 per cent transmission gray glass for high contrast under ambient light operation.

A comparison of the physical dimensions of this tube with those of a conventional 21-inch black-and-white tube may be of interest. Table I gives the picture and over-all tube dimensions of the 21ZP4-B and the 21AXP22. The color tube has a somewhat greater picture size. The height of the round tube is, of course, greater than that of the rectangular 21ZP4-B; however, its diameter falls between the horizontal and diagonal dimensions of the black-and-white tube. The two-inch difference in over-all length is taken up entirely in the neck portion. The longer neck of the color tube is necessitated not by gun length, which is about equal in the two tubes, but by the space requirements of circuit components used on the neck of the tube.

A cross section of the tube is shown diagrammatically in Figure 2. The chrome-iron shell is made in two pieces having matching flanges which are joined by inert-gas welding in the final bulb-sealing operation. The "top cap" consists of the faceplate sealed to the rim portion, within which is mounted a light frame supporting the formed shadow

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* Decimal Classification: R138.31.

mask. The lower, conical section of the envelope is sealed at its small end to a glass funnel-neck assembly.

The round tube shape was chosen in preference to a rectangular shape for greater stability of both envelope and internal parts, and for the lower cost of the simpler structure. The decision as to tube size was based on the popularity of 21-inch tubes for black-and-white television, which combine a picture size adequate for most homes with moderate deflection angle and over-all tube length. The use of metal rather than glass for the envelope contributes to ease of handling the tube, which is at least 10 pounds lighter than a comparable glass tube. In addition, the metal envelope provided more flexibility for design and development.

Fig. 1—Photograph of 21AXP22 color kinescope.

Table 1

	BLACK-AND WHITE KINESCOPE 21ZP4-B	COLOR KINESCOPE 21AXP22
Picture Dimensions (Min.)		
Area	245 sq. in.	260 sq. in.
Width	19-1/8 in.	19-5/16 in.
Height	14-3/16 in.	15-1/4 in.
Tube Dimensions		
Width	20-3/8 in.	—
Height	15-11/16 in.	—
Diagonal or Diameter	21-11/32 in.	20-11/16 in.
Over-all Length	23-13/32 in.	25-3/8 in.
Deflection Angle (Diagonal)	70°	70°
Weight	24 lbs.	28 lbs.

Placement of the phosphor screen on the inner surface of the tube face puts the color picture on the same basis as black-and-white so far as the ratio of picture size to bulb size is concerned. The same freedom from raster distortion shown by white-screen tubes is obtained.

Operating Principles

As a basis for explaining some of the advances made in the art of color-tube design and fabrication, a brief review of the principles of shadow-mask[1] operation may be in order. In the three-beam type of tube, exemplified by the 21AXP22, each electron beam is used to excite one of three interlaced phosphor-dot arrays forming the screen. Because each of the dot arrays emits one of the three primary colors,

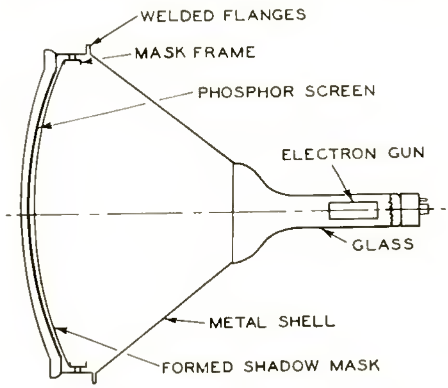

Fig. 2—Schematic diagram of 21-inch color kinescope.

red, green, or blue, control of the relative beam intensities permits mixing the primary colors as desired to produce any of a wide range of hues and chromas. The mechanism by which each beam is caused to strike the dots of only one array is based on the fact that electrons travelling in field-free space move in straight lines. Hence, a perforated shield or mask interposed in the path of a beam shadows portions of the screen from that beam, yet permits it to strike other portions. By the use of three beams so adjusted as to approach the mask and screen from different directions, i.e., from different apparent sources in the deflection plane, each beam may be caused to strike different, non-overlapping portions of the screen. Attainment of this condition requires proper dimensions and spacings of the tube parts. Furthermore, correct operation requires proper placement of the phosphor dots relative to the mask apertures.

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

Phosphor-Dot Screen Fabrication

Accurate deposition of the dots is accomplished by a photographic exposure process carried out in an apparatus called a "lighthouse." The lighthouse contains a light source and top cap holder so arranged that the source may be moved successively to three positions. These positions or "color centers" correspond to the apparent electron sources in the deflection plane of the finished tube.

The procedure for fabrication of the phosphor-dot screen consists essentially of the following steps:

1. Coating the inner surface of the tube face with a uniform layer of one of the phosphors and a photoresist;
2. Exposing the photoresist through the mask apertures and developing the array of dots thus exposed;
3. Repeating these steps with each of the other two phosphors in turn; and
4. Applying an aluminum backing to the screen surface.

The phosphors used are:

for blue—a silver-activated zinc sulfide;
for green—a manganese-activated zinc orthosilicate or willemite;
for red—an improved manganese-activated zinc phosphate.

Red emitting phosphors, in general, exhibit relatively lower efficiencies than the other two primaries, and thus limit the light output of any tricolor tube. An improvement in efficiency of the red phosphor, therefore, shows up directly in the brightness capabilities of the tube. In the 21AXP22, a substantial increase in efficiency of the zinc phosphate has been obtained by improved techniques and controls in its manufacture. In addition, a loss of efficiency formerly suffered by the phosphate during application has been minimized. In contact with water, it had tended to hydrolyze, a decomposition which is now being prevented by use of an excess of zinc oxide in phosphor manufacture. Together these improvements raised the red light output by about 30 per cent over that obtained in earlier color tubes.

The successive phosphor coatings are deposited on the faceplate by a new method which gives improved quality at a considerable saving in time. The conventional process consisted of allowing the phosphor crystals to settle out of an aqueous suspension. After the phosphor was dried, a layer of photosensitive resist was spun over the surface and dried. The coating was then ready for exposure. As each of these operations is time-consuming, and as each of the three primaries must be applied in turn, the total time required for the fabrication of one complete screen amounted to about 4¾ hours. The new process consists of flowing a thin paste or slurry containing phosphor and photo-resist over the faceplate surface in such a manner as to provide a uniform coating. For this operation, a machine (Figure 3) is used which gives the top cap a rotating and tilting motion at suitable speeds and angles. The proper amount of slurry is poured onto the center of the face and motion of the machine spreads the mixture outward. Excess slurry is thrown to the edge, from which it is drained off. The total time required for the application of the entire screen by the slurry method is about 2¼ hours, a saving of 2½ hours per screen over the settling method.

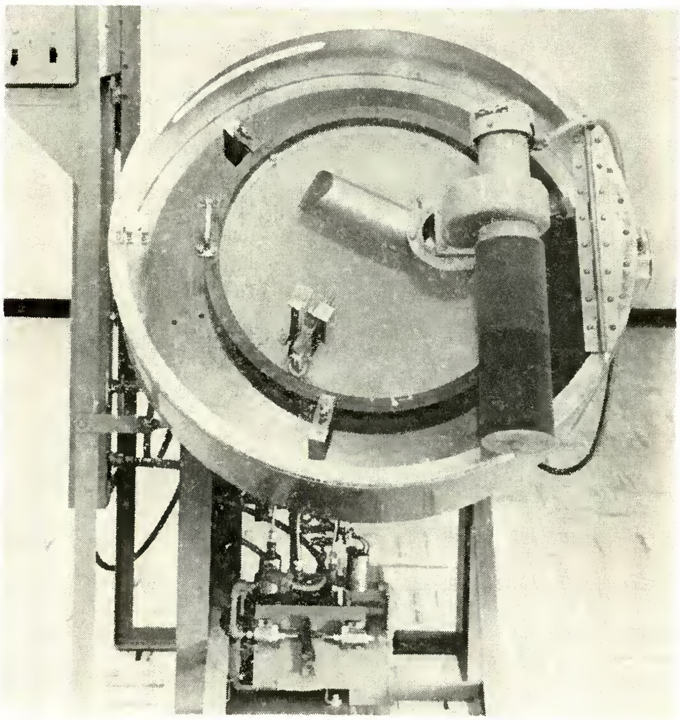

Fig. 3—Photograph of slurry equipment used for application of phosphors.

To aid in the exposure process, several recent improvements have been built into the lighthouse. They include alteration of mechanical features to increase accuracy and ease of use, and a complete redesign of the light assembly. The new assembly not only is more efficient, but also provides approximately uniform light distribution over the entire screen surface. The resulting printed dots are uniform in size. In tube operation this dot uniformity contributes importantly to equalization of the brightness of each color field and particularly to white uniformity in black-and-white reception.

Mask Design and Fabrication

The mask material is a cupro-nickel alloy, 95 per cent copper, 0.008 inch thick, which is highly satisfactory for etching. Inasmuch as the aperture array is fabricated by a photoengraving process, the latter characteristic is very important. Approximately 357,000 apertures 0.010 inch in diameter are etched within the useful area of each mask. The mask is formed from the flat etched sheet to the proper curvature edged by a short cylindrical section. This border fits closely around the light, C-section frame and is welded to it. Thus, the mask is supported by a light, rigid platform which is sufficiently rugged to hold the mask in shape during its repeated insertions into the top cap.

Mask Mounting

Satisfactory mounting of the frame within the top cap has been the subject of considerable developmental effort. To appreciate the logic behind the present mounting design, one should bear in mind certain facts concerning tube construction and processing. In the first place, the mask, frame, and envelope are of different metals having different coefficients of expansion, and these assembled parts must be heated to about 400°C during the exhaust process. In the second place, any net displacement of mask apertures which results from this processing causes a shift of the electron beams from their proper landing positions on the phosphor screen, a condition of misregister which produces color dilution. From the beginning of color tube work, it was clearly understood that some means was required to permit differential expansion of parts during tube processing and simultaneously to prevent any permanent change in the shape and position of the parts.

In the shadow-mask tubes having flat masks and screens, this problem was met by a system of three pins whose heads fitted into radial grooves in the phosphor plate. The pins, mounted from the heavy mask frame, could slide in the grooves as required during heating and cooling. This system with its rigid frame automatically brought the mask back to its initial position upon return to room temperature.

In the 21AXP22, however, it was desired to avoid loss of any picture area which would be required by a mounting device on the faceplate surface. The frame supports were therefore attached to the metal rim of the top cap. A set of posts or studs, projection welded to the metal, proved to be a sturdy, satisfactory form of support.

The next consideration was how best to mount the mask frame from these studs. Previous experience with a three-point radial sliding mechanism suggested a modification of this method for the new construction. It was found, however, that friction between the metal parts, particularly after exhaust treatment, resulted in binding, or at best erratic slipping, of one part against another. A spring mounting method completely free of the vagaries of friction coefficients was then tried. Figure 4 shows the highly satisfactory spring mounting used in the 21AXP22. Because of the stability of the mask frame, three leaf springs have proved adequate for its support. These springs are fastened to the inside of the frame, each with a hole near one end which seats on the tapered head of the corresponding stud. The combination of the taper on the stud with the flexing of the spring provides the necessary self-aligning or indexing feature of this device. As will be covered more fully in the following discussion of misregister, the

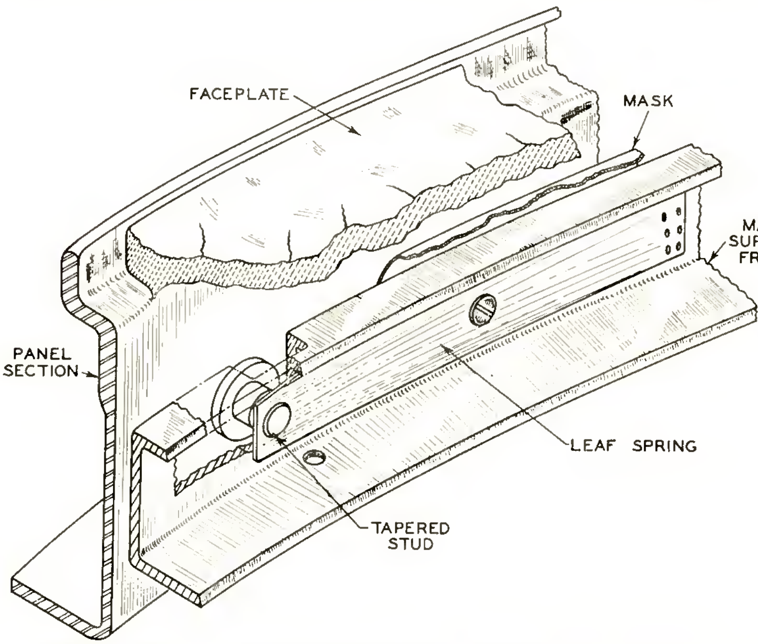

Fig. 4—Detail of spring mounting for shadow-mask support frame.

frictionless frame mounting consistently permits the mask assembly to return after exhaust bakeout to its initial position relative to the phosphor screen.

Electron-Gun Assembly

The short triple-beam gun assembly used in the 21AXP22 (Figure 5) is an improved version of the internal pole piece gun developed in 1952-1953 and demonstrated in January 1954. The gun assembly incorporates electrostatic focus and combined mechanical and magnetic convergence. The three electron guns, each including a heater, cathode, control grid, accelerating grid, focusing grid, and high-voltage grid, are inclined at a small angle to the axis of the assembly to converge the beams at the center of the mask. Cathodes, control grids, and accelerating grids are all electrically isolated to permit cathode and/or grid modulation and adjustment of drive characteristics to fit receiver requirements. The new gun assembly is so designed as to economize on neck length and at the same time produce a narrow, high-current-density beam. The focusing grid structure has been designed in relation to the accelerator grid to form a small crossover at high voltage for sharp focus. The "prefocusing" action between these electrodes, together with the shortness of the focusing

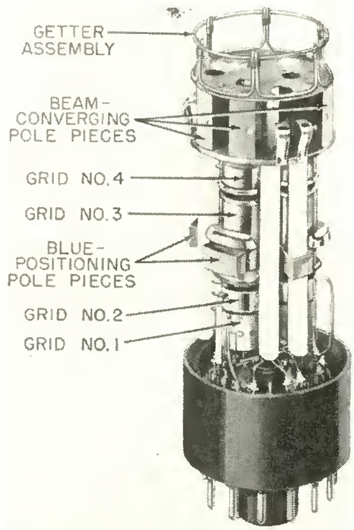

Fig. 5—Photograph of electron-gun assembly.

grid, provides a narrow beam in the focusing and deflection regions, a characteristic which has triple usefulness. A narrow beam leads to high gun efficiency, reduced aberration in the focusing lens, and improved screen tolerance in respect to color purity. This increased tolerance results from the fact that the diameter of the fluorescent dot in a shadow-mask tube is a function of the beam diameter in the deflection field. Thus, a narrow beam provides greater tolerance in landing position of the electrons with respect to the phosphor dot. The short gun has a further advantage in that alignment of its parts is less critical.

In addition to the mechanical convergence built into the gun, which superimposes the beams only at the center of the mask, dynamic convergence is needed in synchronism with the scanning to maintain

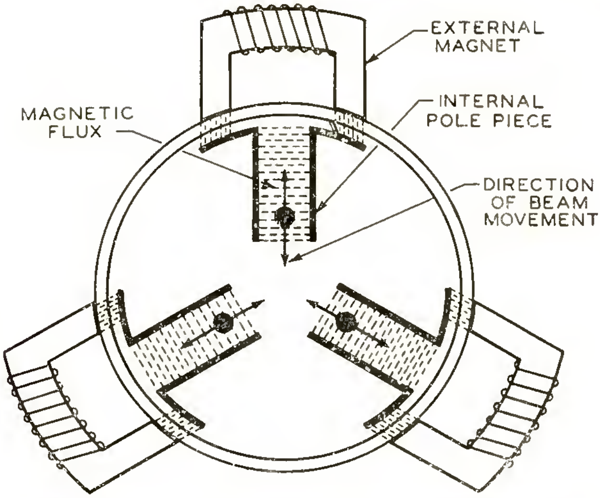

Fig. 6—Schematic of beam-converging pole pieces.

convergence over the entire mask. The beam angle variations needed for this purpose are produced by a separate magnetic field acting on each beam. To form these fields three pairs of radial pole pieces, located at the top of the gun (Figure 6), are excited by three external electromagnets. Thus an appropriate field variation may be applied to each beam individually as required by the geometry and electron optics of the system. Any inaccuracy of mechanical convergence may be corrected by application of direct current fields, as needed, to the three radial pairs of pole pieces and an additional tangential pair located further back on the "blue" gun (Figure 7). These blue posi-

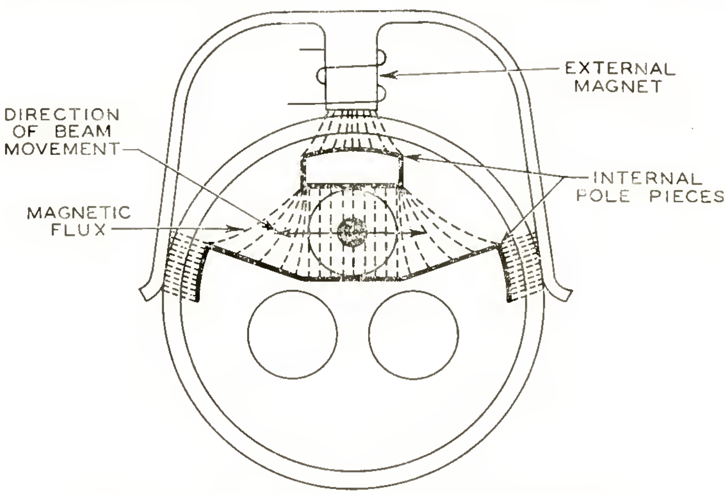

Fig. 7—Schematic of blue-positioning pole pieces.

tioning pole pieces are shown in Figure 5. The combined mechanical and magnetic convergence incorporated in this gun design offers a number of distinct advantages over earlier convergence methods. The maximum voltage brought through the base is that of the focusing electrode, nominally 4500 volts. This low voltage, together with a new base design, eliminates serious leakage troubles. As the pole-piece structure and neck coating operate at the same potential, a number of getters may be placed at the top of the gun and flashed to produce a large active area. Mechanical convergence of the beams provides good stability of convergence regardless of voltage fluctuations. Finally, the application of a magnetic field to each of the three beams separately provides the flexibility needed to obtain accurate dynamic convergence over the entire picture area, even at the relatively wide deflection angle used. All of these factors add up to the production of a high fidelity, high definition, stable picture devoid of color fringing and color shading.

Geometrical Considerations

The basic design dimensions of a shadow-mask tube are determined by straightforward geometry. When the mask and screen are curved, the geometry becomes a little more complex than in the case of a flat screen assembly because of the additional variables introduced, namely, the curvatures of face and mask. The geometry of a tube having a curved structure is worked out by first assuming a suitable radius for the faceplate and then determining the coordinate mask radius needed to provide constant magnification.

The term "constant magnification" may best be illustrated by consideration of a planar assembly[1] (Figure 8). The flat mask and phosphor plate are shown parallel to each other, spaced at distances p and L, respectively, from the source, O, which is a distance S from the axis of the assembly. The center-to-center spacing of the apertures in the mask is a and the center-to-center spacing of the phosphor dots is D.

In the phosphor-screen application process and later during tube operation, the mask pattern is projected onto the phosphor plate, forming an image having dimensions D/a times the corresponding mask dimensions. This ratio D/a, which is equal to L/p, is termed the magnification.

The magnification in this planar structure is constant, regardless of the angle at which the rays strike the mask. Consequently, if the mask-hole spacing is uniform, as indicated by the dimension a, the phosphor-dot spacing in each array, D, is likewise uniform. By the same reasoning, the dot size and the dot-to-dot spacing within each

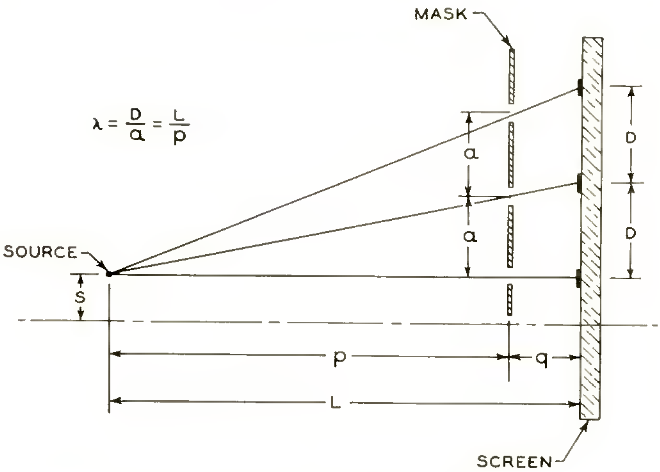

Fig. 8—Geometry of planar system.

triad are also uniform and each triad of dots is a replica of every other triad. The desirability of constant magnification stems from this uniformity of picture element spacing, and, in this planar case, the resultant optimum utilization of the screen area.

Although the spherically curved system does not permit attainment of precisely constant magnification, the slight deviations required turn out to be negligible. In Figure 9 the source, O, again lies a distance S from the axis and a distance L along the axis from the phosphor

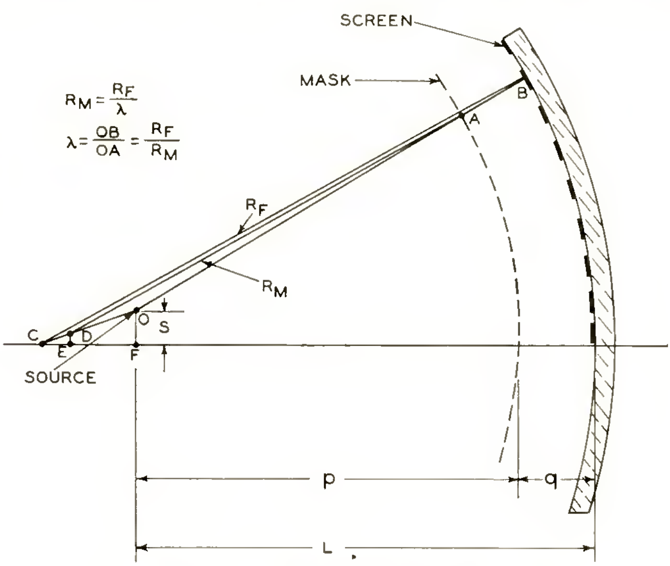

Fig. 9—Geometry of spherical system.

screen. B is any point on the screen, and A is the point where the line OB intersects the mask. If a constant magnification, λ, is required throughout the screen, then $\frac{OB}{OA}$ must be equal to λ. To meet this condition, first make the mask radius, R_m, equal to $\frac{1}{\lambda}$ times the face radius, R_f. The center of curvature of the face is at point C on the axis. Lay R_m parallel to R_f, terminating at point A. The center of curvature of the mask then falls at point D on the line connecting C and O. Since $\frac{OB}{OA}$ and $\frac{R_f}{R_m}$ both equal λ, triangles OAD and OBC are similar and $\frac{CO}{DO}$ also equals λ. It follows that $\frac{DE}{OF}$ is equal to $\left(1 - \frac{1}{\lambda}\right)$, from which is obtained $DE = S\left(1 - \frac{1}{\lambda}\right)$.

Thus far only one of the three sources has been considered. Because these sources are symmetrically disposed about the axis, it is desirable to shift the center of curvature of the mask from the point D, as shown, to point E on the axis, a distance $S\left(1 - \frac{1}{\lambda}\right)$. In the 21AXP22, $S = 0.274$ inch and $\lambda = 1.04$, so that $DE = 0.011$ inch. It may be shown that such a compromise results in a deviation from constant magnification of a negligible 0.1 per cent.

An additional design dimension, the axial distance between mask and screen, is given by $q = R_f - R_m - CE$. Since $\frac{CE}{CF} = \left(1 - \frac{1}{\lambda}\right)$ and $CF = R_f - L$, the expression for q becomes $L\left(1 - \frac{1}{\lambda}\right)$.

The geometry of the spherical system, in contrast to that of the planar system, is such as to produce asymmetrical instead of equilateral triads toward the edge of the screen. Because of this asymmetry, the basic design criterion of constant magnification may be modified slightly to provide optimum phosphor dot coverage of the screen area.

Factors Affecting Register

The preceding geometrical criteria are basic in the design of the tube. However, consideration must also be given to probable deviations from the assumed mechanical dimensions and operational characteristics. From the printing industry the term *register* has been borrowed to convey the idea of the accurate landing required of the electron beams on the appropriate phosphor dots. Perfect register, then, indicates that the center of each fluorescent spot coincides with the center of the corresponding phosphor dot. Naturally, the chief concern is with *mis*register which generally results in impure or even incorrect colors appearing in parts of the picture.

After the tube has been designed as indicated in the discussion of its geometry, and the screen photographically deposited according to this geometry, it is well to consider what factors can cause misregister in the picture produced by the completed tube. The causes are either mechanical or electrical. Mechanical effects will be considered first.

Processing Deformations

The tube and its parts are subjected to various mechanical stresses between the time of screen application and the completion of the tube. The top cap must be baked in air, and then welded to the lower cone. The tube must then be exhausted and baked while under vacuum. Thus, the tube parts may suffer a deformation due to thermal effects and to mechanical stresses on the envelope, including atmospheric pressure. Extensive tests on the 21AXP22 have indicated that resulting deformations occur, but are rather small. They are composed almost entirely of a radial component of misregister with respect to the tube axis, due principally to a minute flattening of the faceplate from atmospheric pressure. In effect, the mask is mechanically isolated from its environment by the frictionless, spring-type mounting, which permits one or more of the springs to absorb distortion of the envelope without transmitting this motion to the frame and mask.

Inaccuracies of Parts Assembly

Another potential source of mechanical misregister is misalignment between gun and screen. As already indicated, it is necessary for proper operation that the electron beams reaching the screen appear to originate at the color centers previously set by the light source during screen fabrication. This alignment is achieved by using a set of reference points repeatedly during tube manufacture. The reference points consist of three dimples approximately 120° apart stamped in the top cap flange. The dimples mate with three V-grooves in the lighthouse and thus position the top cap uniquely with respect to the light source. The flange of the lower cone is likewise stamped with a set of V-grooves, with reference to which the neck and gun seals may be made. Finally, after screen fabrication and mask insertion, the dimples and V-grooves in the flanges are mated to position the top cap uniquely with respect to the lower cone, and the final weld is made. This procedure of referencing parts positions always from the same set of three dimple-and-groove locations reduces misalignment between gun and screen to a small value. As will be indicated later, compensation may readily be applied for this small residual error.

Mask Expansion

Motion of the mask apertures results from heating under electron bombardment. The mask's shadowing function of course requires that it intercept a large fraction of the total electron current — about 85 per cent. If heating effects are such as to move an aperture a short distance *along* the path of the beam which passes through it, the change cannot be noticed. However, if the aperture moves *transversely* to the beam path, the fluorescent spot moves about the same distance and misregister ensues.

Therefore, since mask heating and resultant expansion are unavoidable, the desirable condition is that the whole mask move a small distance toward the screen as it expands. If it were restrained at the edge, it would bow toward the screen and the apertures in a wide zone between center and edge would have an undesirable component of lateral motion. On the other hand, if it were unrestrained at the edge but fixed as to distance from the screen, the lateral aperture displacement would increase from zero at the center to a high value at the edge.

To prevent restraint at the edge and provide the desired motion toward the screen, a series of holes is punched around the border of the array (Figure 10) leaving a set of tabs or hinges connecting the array and the frame. These hinges are formed at about 45° to the side of the frame so that the tangential thrust of the mask expanding with respect to the frame causes the hinges to rise away from the frame and lessen the distance from mask to screen.

The electrical factors in misregister may be of several sorts.

Yoke Effects

As has been known for many years, the effective center of deflection of a yoke moves toward the screen as the deflection angle is increased. This motion appears whether a modern deflecting yoke having a flared "front end" and extensive fringe fields, or a hypothetical simplified yoke having "flat" fields and no fringes is considered. Its magnitude is a function of yoke length and beam deflection angle. Figure 11 illustrates this point. Starting with a very small deflection angle, for which the apparent center of deflection is at the midplane of the yoke, O, the deflection is increased to A'. The apparent deflection center for this ray is point A, while the center from which ray B' appears to come is point B. Now, because of this motion and the fact that the phosphor dots were exposed simultaneously from a stationary source of light, the electron paths are dissimilar from those of the light rays. The resulting error is radial with respect to the tube axis. Figure 12

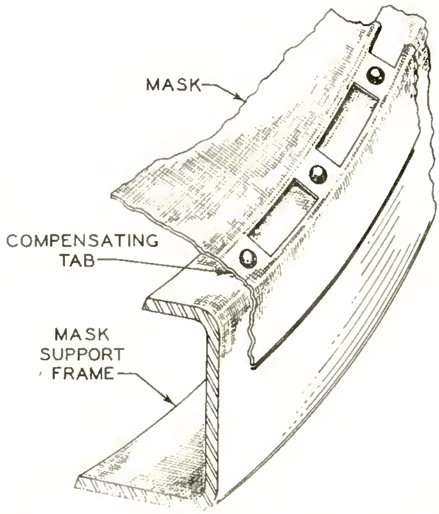

Fig. 10—Detail of shadow mask showing thermal compensating tabs.

indicates measured values of this radial component of misregister as a function of distance from the tube axis. The ordinate R is the magnitude of the radial component, with R positive when the beam is displaced toward the tube axis from its proper landing position. Adjustment of yoke position shifts the error as indicated by curves 1, 2, and 3. Thus the error may be compromised between different zones in the screen (curve 2), with results as shown in Figure 13. In this figure, the light rays which exposed the screen are indicated by dashed lines, emanating from a small source at E, while D, E, and F represent

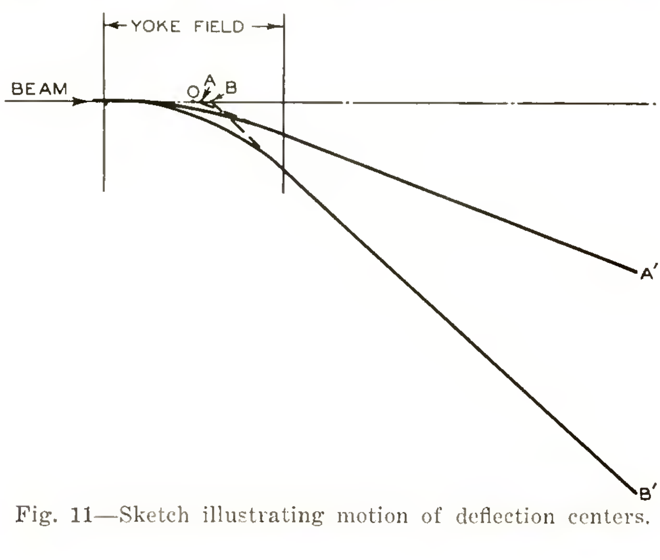

Fig. 11—Sketch illustrating motion of deflection centers.

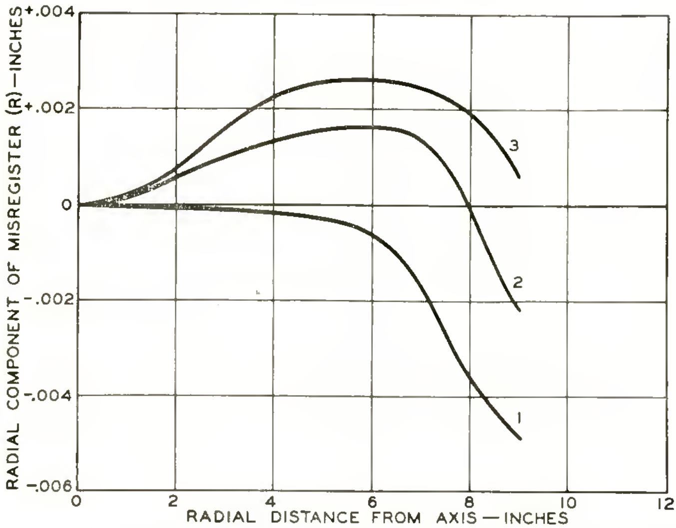

Fig. 12—Radial component of misregister as a function of distance from tube axis.

successive deflection centers as the electron beam is deflected to wider and wider angles during tube operation. The axis of the electron beam leaving deflection center *E* (in this case the original light source position) lands precisely on the center of phosphor dot *B*, while the wide-angle electron ray from *F* falls radially outside the center of dot *A* and the narrow-angle ray from *D* falls inside the center of dot *C*. To remove this error, precompensation may be built into the tube by suitable correction during tube fabrication. Thus the radial error due not only to the yoke, but also to the mechanical deformation mentioned previously, is eliminated.

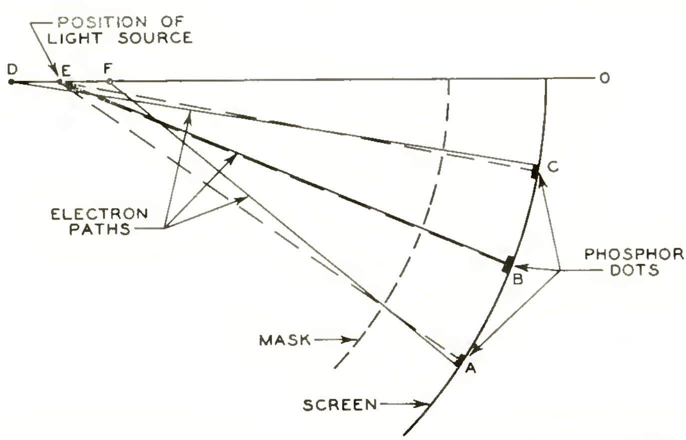

Fig. 13—Sketch illustrating radial error with yoke in compromise position.

Dynamic Convergence Effects

As mentioned previously, dynamic convergence involves variation of the relative angles of the three beams as they scan the screen in order to maintain convergence throughout the raster. Because the beam angles must be altered by a convergence means located in the gun some distance back of the yoke, the separation of the beams as they pass through the deflection plane changes simultaneously with the dynamic field. Figure 14 illustrates the process by showing for simplicity two beams in the plane of the axis. As the screen is scanned out to its edge, the convergence angle of the beams must be decreased, thus moving their deflection centers from A to A' and from B to B'. Now, the triad of fluorescent spots produced by the three beams passing through an aperture is, in effect, a demagnified image of the three

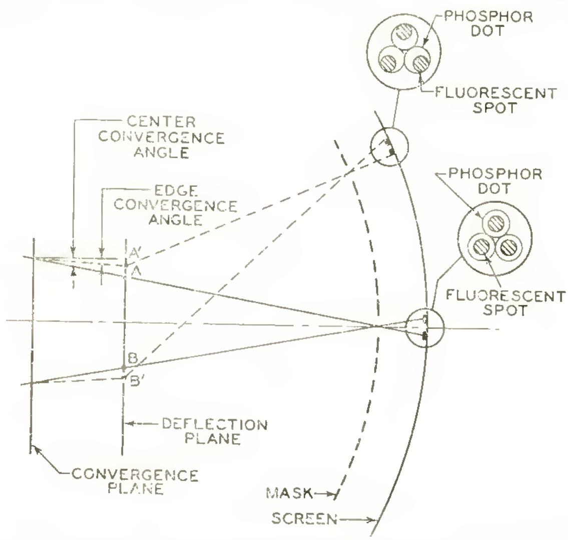

Fig. 14—Sketch illustrating effect of dynamic convergence.

beams as cut by the deflection plane. Thus, when dynamic convergence fields are applied, the object in the deflection plane AB is enlarged to $A'B'$ and its image, the fluorescent triad, is correspondingly increased in size. The phosphor screen was exposed from light sources at A and B, and the undeflected beams pass through these color centers. When deflection and dynamic convergence fields are applied, the fluorescent spots are "degrouped" with respect to the phosphor dot triads. Several promising approaches for elimination of this error are being investigated. In the interim, of course, the error may be minimized by splitting it between center and edge of the screen.

Effect of the Earth's Field

Although the earth's magnetic field is of small magnitude and the electrons travel at high velocity, the influence of the field on the beam direction and landing may be appreciable in terms of misregister. If the force on the beams were uniform throughout the tube, the effect could be compensated by a fairly simple shift. In the neck region, where it is nearly uniform, a transverse field is generally applied over the gun by the "purifying magnet," which serves simultaneously to correct for any slight misalignment between gun and screen. However, in the cone region the effect of the earth's field on the beam varies with the angle of deflection, so that the resulting misregister is far from uniform over the screen area. Furthermore, this misregister pattern changes with the orientation of the tube in the earth's field

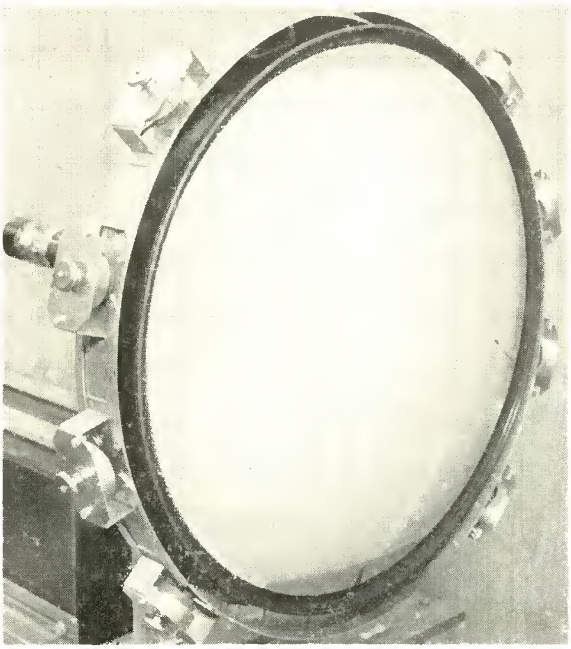

Fig. 15—Photograph of magnetic-field equalizer in position on the 21AXP22.

The metal envelope of the tube provides partial shielding and tends to redistribute the field. The resulting misregister is such as to be readily corrected by a magnetic field system placed around the front end of the tube. This "magnetic-field equalizer" (Figure 15) consists of eight small magnets, with associated pole pieces, which are adjustable as to strength and direction.

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