February 17, 1947

PHILCO CORPORATION

Report on

Philco Projection Television Receiver

Model 47-2500

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INTRODUCTION

The Philco Model 47-2500 Projection Television Receiver produces a brilliant, high contrast, 15 inch by 20 inch picture.

The high brilliance of the picture results from the use of a high intensity cathode ray projection tube, a modified wide aperture Schmidt Optical System. and a highly developed reflective light directing viewing screen.

Excellent immunity to room light, and consequent high contrast of the viewed image, are achieved in a device having a compact cabinet by the combination of the special screen, tilted toward the viewer, and the skew projection system.

A. OPTICAL SYSTEM

A1. PROJECTION TUBE

The receiver uses a 4 inch Philco projection tube operating at about 20 kilovolts. This tube has a fluorescent screen, which is white in color. but only when operated at the correct anode voltage. Aluminum backing may be used. The grid characteristics are such that the tube has a cut-off of 100 volts (plus or minus 30 volts). The outer tube face has a radius of 5.75 inches and its thickness is .125 inch. The tube operates an average beam current of about 80 microamps and attains peaks of about 600 microamps in the highlights. It requires a swing of some 80 volts.

A2. PROJECTION SYSTEM

A2a. Wide Aperture Optics*

The main problem in developing an optical system for this television set was that of focussing large fields of light with high efficiency. If a conventional lens system were used, only a small part of the light emitted from the cathode ray tube would reach the screen. If the lens were enlarged to admit more light, aberrations would result and the rays would meet accurately at a single focus. A system was needed that was capable of using a large relative aperture to focus a large field with high efficiency.

In answer to this problem, a modified Schmidt System was adopted. It consists of a front face spherical mirror and a weak aspherical correcting lens located at the center of curvature of the mirror. The outstanding advantage of this system, as diagrammed in Figure 1, is its ability to focus a large field with a large relative aperture. This is possible because a spherical mirror with an aperture located at the center of curvature of the minor suffers from only two aberrations, spherical aberration which is uniform all over the field, and curvature of the field. This may be seen from Figure 2: where C is the center of curvature of the mirror and O_1, and O_2, are object points, located on the axis, and off the axis, respectively. Figure 2 shows the ray paths for these two object points with the aperture located at the center of curvature. It is seen that the image, or rather the circle of least confusion since spherical aberration is present, is practically of the same size and symmetry for both object points. As may be seen, the reason for this is that the principal ray, i.e., the ray passing through the object point and center of the aperture, also passes through the center of curvature of the mirror and is therefore also an axis of symmetry for the sphere. The only difference is that the circular aperture, mounted perpendicular to the principal axis, and therefore symmetrically located with respect to the principal axis, is non-symmetrically located with respect to the auxiliary axis. This causes some nonsymmetry in the light distribution of the circle of least confusion; however, this nonsymmetry becomes of importance only in the case of very large fields.

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*Note: The material for section A2a on Wide Aperture Optics was obtained from D. W. Epstein and L. G. Maloff in "Projection Television" from "Journal of the Society of Motion Picture Engineers". June, 1945.

The object of the correcting lens is to correct for the spherical aberration of the mirror without introducing any serious aberrations in itself. This is accomplished by making the correcting lens as weak as possible and locating it in the plane of the aperture at the center of curvature. In this way, the symmetry property of the mirror is least disturbed.

The spherical aberration of the mirror may be looked upon as focussing by means of zones, each zone having a different focal length. Thus, the correcting lens has to be such that each of its zones has a different focal length and just compensates for the various focal lengths of the mirror. The result is a focussing system, all zones of which have the same focal length.

Referring to Figure 3, the shape of the correcting plate must be such that all rays emanating from an object point (O) and reflected by the mirror, shall meet at the image point (I) located at a distance (S) from the correcting plate. Figure 3 shows three rays emanating from O and striking the mirror at different apertures. Without the presence of the correcting lens, the rays 1, 2, and 3 would intersect the axis at distances ql, q2, and q3 from the center of curvature. The slopes on the correcting lens have to be such that all 3 rays intersect at I, i.e., the correcting lens has a flat at the point where ray 2 passes, negative slope where ray 1 passes, and positive slope where ray 3 passes. Considered from the point of view of spherical aberration, if the zone where ray 2 strikes the mirror is taken as the reference, then the mirror has negative spherical aberration for smaller apertures and thus requires a positive lens for correction. Likewise, it has positive spherical aberration for larger apertures and thus requires a negative lens.

Since the mirror with an aperture at center of curvature has no extra axial aberration or chromatic aberrations, the aberrations which are present are caused by the correcting lens itself, i.e., the power or slopes on the correcting lens. From the stand-point of aberrations, therefore, that shape should be chosen whose maximum slope is the least. Thus, if the paraxial (central) focal length of the mirror is chosen as that of the system, then the central focal length of the correcting lens is infinite and the shape of the curve is concave. Alternately, if a zonal focal length of the mirror is chosen as that of the system, there will be a zonal focal length of the correcting lens which is infinite and the shape of the curve is convex at the center and concave outside this zone. If a peripheral focal length is chosen, the required correcting lens is convex.

The shape and size of the correcting lens depend up the throw or magnification for which the system is to be used. For a given focal length and relative aperture, the correcting lens aperture decreases as the magnification decreases. That this must be so may be surmised from the fact that for unity magnification, the lens aperture is O, since object and image coincide at the center of curvature. Since in a high relative aperture optical system correction can be made for only one position of object and image, a different correcting lens is required for each throw or magnification.

In order to obtain a flat image field, i.e., focus on a flat viewing screen, it is necessary that the object field or tube face be curved. Calculations show that, in general, the shape of the tube face depends on the throw – a sphere for infinite throw and an ellipsoid for finite throw. The eccentricity of the ellipsoid is sufficiently small, however, so that even for finite throw the tube face may be made spherical with a radius of curvature equal to about 0.53 times the radius of the spherical mirror. In this receiver the mirror has a radius of 11.00" and a diameter of 12". The correction plate has an effective diameter of 7.0". The radius of curvation of the tube face is 5.750" on the outside, 5.625" inside, and it has a thickness of .125". The throw for which the system is designed is 33.5" (from correction plate to screen). This distance may be varied about 10% with resulting variation in magnification. Variations of throw beyond this tolerance would lead to serious deterioration in image quality.

The projection efficiency will be defined as the fraction of total light flux (say, in lumens) emitted in a forward direction by an axial element of a non-directional source, such as the luminescent screen of a cathode ray tube, that the optical system accepts and focusses on the corresponding image element, assuming that the mirror reflects 100 percent and the lenses transmit 100 percent. The efficiency e_∞ as defined above, is given by $e = \sin^2 \mu$ where μ is the semi-apex angle. as shown in Figure 4.

Hence, to determine the efficiency of a lens for a perfectly diffusing source, it is merely necessary to know the angle that the lens (or entrance pupil) subtends at the source. As can be seen from Figure 4, the farther a given lens is from a source, i.e., the less the magnification, the lower the efficiency of the lens. This fact is important in the case of home projection where magnifications as low as 5 may be used. It is customary to rate a lens by its f/number for infinite magnification, i.e., object located at the focal point of the lens.

This is defined as f/number = $\dfrac{1}{2 \sin \mu} = \dfrac{1}{2\sqrt{e_\infty}}$ where e_∞ is the efficiency for infinite magnification.

Since the reflective optical systems under consideration are designed for a specific magnification and since the central part of the reflective system is masked to maintain contrast (this part being blocked by the cathode ray tube), it seems preferable to rate such systems by efficiencies. rather than by f/number which involves the focal length. Figure 5 shows the efficiency e_∞ of a lens as a function of f/number, enabling one to read off the equivalent f/number for any efficiency of a masked system.

In these systems the efficiency with no masking is about 40 percent, and the efficiency of the central part of the system that is masked is approximately 10 percent, so the efficiency of the system with masking will be about 30 percent, and hence, neglecting losses in the system, about 30 percent of the light admitted by an axial point will be focussed into an image point. This corresponds to the efficiency of a f/0.8 lens used at magnification of 6.7.

A2b. Rectilinear Projection and Keystone Projection

The Schmidt System described above and as used by other concerns employs conventional rectangular image projection. The Philco Projection Receiver, for reasons to be discussed later, employs a different system, namely, keystone projection.

Figure 6 is a diagram of an optical system with a single thin lens (L) employing conventional rectangular image projection. The center of the lens is the optical center through which all rays are assumed to pass undeviated. As is shown by side views of the object (O) and image (I), a rectangle is projected at the image by rays passing from the rectangular object (O) through the lens.

In the Philco Projection television receiver, the screen is on a slant and not perpendicular to the axis of the optical system. The system of projection in Fgure 6 would produce a trapezoid on the screen instead of a rectangle, and the correction for this lies in a system known as keystone projection.

The basic idea is that if a rectangle projects a trapezoid on the slanted screen, then the opposite would be true and a trapezoid would project the desired shape of a rectangle.

Figure 7 gives a diagram of the principles of keystone projection. From the object in the shape of a trapezoid, the rays pass through the lens (L) and project a rectangular image. The object screen and image screen are so placed in relation to each other that

$\tan B = m \tan \alpha$ where m is the reciprocal of the magnification = $\frac{l_2}{l_1}$ The dimensions of the rectangle are h_1 x w_1, and the object is of height ($h_2' + h_2''$) with the width varying from w_2' to w_2''.

The geometry of this system is specified by the following equations:

$$\tan \theta' = \frac{h_1 \cos a}{2l_1 + h_1 \sin a}$$

$$\tan \theta'' = \frac{h_1 \cos a}{2l_1 - h_1 \sin a}$$

$$h_2' = \frac{h_1 l_1 m \sqrt{\cos^2 a + m^2 \sin^2 a}}{2l_1 + h_1 (1 + m) \sin a}$$

$$h_2'' = \frac{h_1 l_1 m \sqrt{\cos^2 a + m^2 \sin^2 a}}{2l_1 - h_1 (1 + m) \sin a}$$

$$m = \frac{l_2}{l_1} = \frac{\tan B}{\tan a}$$

$$w_2' = \frac{2w_1 l_1 m}{2l_1 + h_1 (1 + m) \sin a}$$

$$w_2'' = \frac{2w_1 l_1 m}{2l_1 - h_1 (1 + m) \sin a}$$

A2c. Wide Aperture Keystone Projection

It will be seen from the above that keystone predistortion and correction involve the fulfillment of 3 conditions: (1) trapezoid predistortion of the primary image, (2) vertical linearity predistortion and, (3) focus correction involving the correct relationships between angles α and B.

Figure 8 shows keystone projection applied to the Schmidt System. In this combination, the primary image appears on the spherical face of the cathode ray tube. Our discussion of Keystone Projection, up to this point, has concerned projection from a flat face to a flat screen, but the same principles apply when projecting from a spherical face. The approximate size of the primary image in the Philco set is as follows: height – 2-1/16 inches, width at bottom – 2-9/16 inches, width at top – 2-31/32 inches.

Referring back to Figure 7, the geometric center of the rectangle is conveniently located by the point where the two diagonal cross, and of course, the center is equidistant from the top and bottom. In the trapezoid, the geometric center is also where the two diagonals cross, but in this case the center is farther from the top of the figure than from the bottom. Because of this linearity distortion, it is necessary to adjust the vertical linearity on the face of the tube so that rays coming from the center of the trapezoid will also coincide with the center of the rectangular projected picture.

As can be seen from Figure 8, the tube is placed at a small angle to the axis of the optical system. This is necessary in order to focus correctly and project a rectangle on the screen. The face of the tube is slanted such that $\tan B = m \tan a$ where m is the reciprocal of the magnification. In the Philco set, a is 24º 30', and m is 6.7, so B is 3º 54'.

B2c. Keystone Correction

As has been mentioned, it is necessary to obtain a trapezoidal primary image on the face of the cathode ray tube. Ordinarily, the electron beam going horizontally through the tube would scan a rectangle, but in order to project a rectangular picture on the final screen, there must be a trapezoid scanned on the face of the tube.

Actually, the electron beam is a very thin beam which scans a figure on the tube face in 1/60 of a second, but the results are the same if it is considered a solid rectangular pyramid as is illustrated in Figure 12. Now in figure 12, if a plane were passed obliquely through this solid rectangular pyramid cutting a section ABCD, this section would appear as the trapezoid A'B'C'D'. This leads to the fact that one method of obtaining a trapezoid on the face of the tube would be to deflect the beam from its horizontal course to strike the tube face obliquely.

Deflection of the electron beam is possible by producing a magnetic field at right angles to it. Two bar magnets are placed on the edge of the tube face, one on each side. Referring to Figure 13 the poles A of the magnets, then, produce a magnetic field at right angles to the electron beam. The action of this magnetic field results in deflection of the beam upwards to strike the tube face at an acute angle to achieve the same trapezoid as if the tube face had been passed through the horizontal electron beam obliquely.

There is one thing still to be corrected. The image is now too high on the face of the tube and in some way, the beam must be deflected so that the image will appear in the center of the tube face.

By deflecting the beam downward before it is deflected upward to the face of the tube, the image will be scanned in the center. In order to deflect the beam downward, another magnetic field, opposite in direction to the original field, is produced. Referring again to Figure 13. the bar magnets are attached to the tube face with tabs which are bent back toward each other in the same horizontal plane. The outside poles (B) of the two magnets, then, produce another magnetic field which is opposite in direction to the field produced by the poles (A) of the magnets. Through these two magnetic fields, then, the beam is deflected, first downward and then upward to scan a trapezoid on the face of the tube. The second field from poles A is necessarily stronger (since it must both straighten out the beam and force it upward) due to the fact that the poles A are closer together than are the magnet poles B forming the other field.

In Figure 13, a diagram is given of a pole piece, two of which are attached, next to the tube face, onto poles A of the magnet. This makes the corresponding field a uniform one consisting of nearly parallel lines. Pole pieces are unnecessary for the field produced by poles B.

By producing these to magnetic fields, a weaker one to deflect the beam downward followed by a stronger one to force it upward, the electron beam will scan a trapezoid in the center of the tube face.

It will be noted that the magnetic field nearer the gun is relatively weak and has curved flux paths, while the field nearer the tube face is relatively strong and has straighter flux paths. Each field introduces a certain amount of keystoning, displacement, and curvature of the horizontal lines. The opposed fields are so disposed as to cancel out the curvature, and most of the displacement, while leaving a substantial amount of keystoning. (A-1638)

In order to permit adjusting the cathode ray tube to its correct position relative to the other optical elements, it is mounted in a frame which provides for adjustments axially, for focussing, and rotationally about two axes, each perpendicular to the optical axis. These adjustments are entirely independent of each other. (A-1737)

B. SCREEN

B1. GENERAL CONSIDERATIONS

The general requirements for screens are that they give a bright picture of substantially uniform intensity that is visible over a large part of the room. Furthermore, screens should be smooth in texture in order to produce good resolution and they should render good contrast and pleasing color. The simplest type of screen is a sheet of paper or linen, such as is used in some movie theaters. Such a screen is unsatisfactory for television, however, as it does not reflect nearly enough light. On the other hand, the movie screen gives perfectly uniform re-diffusion visible all over the viewing room, or throughout a hemisphere whose center may be considered as coinciding with the center of the screen. For this reason, such a screen is called a Perfect Diffuser and the brightness characteristic of the screen is shown in the Rousseau diagram, Figure 9a. This characteristic applies to any angle in the azimuth and a screen of this type is assumed to have a "gain" of unity. This is another way of saying that the screen will produce an apparent brightness of one foot-lambert for an incident illumination of one foot-candle.

B2. HIGH GAIN SCREENS

The problem is how to increase the apparent brightness in foot-lamberts without increasing the incident illumination in foot-candles, or to put it more compactly, how to produce a screen having a high "gain" (greater than unity).

Gains greater than unity can be achieved by a process of controlled directionality. Suppose a screen were built which would direct the incident illumination falling upon it into a concentrated sector of the hemisphere. Then the reduction in area from the hemisphere to this sector would determine the "gain" in brightness of the screen and the "gain" would vary inversely with the reduction in area. This is visualized by comparing Figure 9b with

Figure 10b. It is apparent from these diagrams that ideal directional screens should have perfectly sharp cut-offs, or in other words, that the picture should be quite invisible outside the predetermined viewing sector.

B3. VIEWING SECTOR

We have studied the anatomical factors which affect the choice of a suitable viewing sector to be used when viewing television receivers of the projection type in the home. There is a considerable body of literature available on an allied subject based on the research of Professor Hooton of Harvard (carried out in conjunction with Army Air Force, Wright Field) and dealing with anatomical statistics for pilots (both male and female, of different sizes) in pursuit planes. Correlating this information with tests of our own concerning optimum height of the viewing screen above the floor, we have come to the conclusion that viewing space in the average living room can be compressed into a sector subtending a total vertical angle of 20º and a total horizontal angle of 60º. Referring again to Figures 9 and 10, it will be evident that the area of a 20º by 60º sector is 1/17.2 of the area of a hemisphere; therefore, a screen designed for a 20º by 60º sector will have a gain of 17.2.

It will be noted from the above figures that the ideal viewing sector of a high gain screen is rotationally asymmetrical. This consideration, then eliminates immediately the use of conventional screens having rotationally symmetrical characteristics, such as ground glass, glass beaded screens, etc.

There is a second advantage to be gained from the use of rotationally asymmetrical screens and that is a great reduction in susceptibility to the stray light which comes from sources lying outside the viewing sector. This enormously improves the contrast of the image when there is random illumination present in the viewing room and, in effect, psychologically it still further improves the apparent "gain" of the screen when used under average living room conditions with stray light.

Referring again to Figures 10a and 10b, it is possible to build screens having directional characteristics of the type indicated (perfectly sharp cut-off). Such screens, however, are extremely difficult and expensive to make, since they involve the use of some 12 million precise lenticular screen elements.

B3a. Philco High Gain Screen

We at Philco have investigated and built small samples of ideal directional screens of the type referred to. In view of their complexity, we decided to develop a new and special type of screen which, although quite cheap and extremely simple, gives a close approximation to the results obtainable with an ideal screen, both as regards gain, and freedom from susceptibility to stray light. The characteristics of the Philco screen are shown in Figures 11a and 11b.

The screen itself consists of a reflecting member with strong asymmetrical characteristics. The reflecting member of the screen is a reflecting sheet or body containing a large number of vertical grooves. These grooves are shaped and spaced at random while the average shape of the grooves has certain general characteristics approximating those of the circular form. These vertical grooves are provided for the purpose of introducing broad but controlled horizontal light distribution over a sector of say, 50º to 80º in subtense. The screen member is cylindrically concave (with respect to the viewer), the axis of the cylinder being horizontal and at right angles to the grooves. The radius of curvature is determined as twice the product of the projection throw and the viewing distance divided by the sum of these distances.

A screen of this kind is not, however, altogether satisfactory for general use. If a refractive lens of available aperture were used in conjunction with it, then the space over which the image may be viewed would be greatly confined in height. On the other hand, when a reflective high aperture optical system, such as the Schmidt System, is used, there is a less confined viewing space height but there are other defects such as shadows on both sides of the screen caused by excessive vignetting due to the great projected area of the projection tube intercepted by skew rays.

The screen above described has been modified to overcome these defects, particularly when used with a Schmidt Optical System. The Modification consists in applying, to the screen, a thin coating of discrete particles of a material which does not abosrb light. The material should be such that each particle will be lenticular, and the particle density must be such that no area of appreciable size is uncoated, while only a small proportion of the particles coalesce with each other. (A-1623) In practice, the coating is applied in the form of a lacquer spray, and satisfactory coverage without undue particle coalescence is dependably achieved by the application of several coatings, each of which is insufficient in density to give sufficient coverage, each being allowed to dry before the next coat is applied, to inhibit coalescence, (A-1623-2)

When used with an optical system having a large aperture, rays from all parts of the aperture will focus on the variously sloped regions of each particle, and the overall effect is that the light falling on each point on the screen is diffused to a moderate extent. The amount of diffusion is enough to overcome the deficient vertical light distribution properties of the uncoated cylindrical screen. (A-1607)

This effect is particularly marked when the operation of this screen is studied in its application to a Schmidt System. The central vignetting due to the C.R.T. and the focussing and deflecting apparatus results in a marked reduction of the apparent illumination of portions of the uncoated screen, and the consequent comparative increases in illumination of other portions. However, when the sprayed screen is used, the light from all portions of the toroidal aperture is evenly diffused from the central part of the screen, while the outer portions of the screen, which are illuminated to a reduced extent by the more remote portions of the aperture, diffuse the light from the closer portions of the aperture in the most effective manner to illuminate the viewing space.

The extent of the horizontal diffusion provided by the coating is so much smaller than that provided by the vertical grooves that it does not change the horizontal light distribution pattern appreciably.

In the vertical plane then, the use of the coating serves to increase the vertical viewing space while maintaining strong resistance to overhead lights. It also serves to smooth out the previously mentioned shadow effects by a process of light integration. The loss due to omnidirectional diffusion is small enough to be negligible.

The overall brightness was measured at 20 kv and it was found to be up to about 80 foot-lamberts. Measurements indicated that the brightness of the primary image on the cathode ray tube is about 15 times as great as the image on the screen.

C. CABINET

The cabinet is adapted to house the electrical apparatus and the optical system illustarted in Figure 8. The total overall length from the concave mirror to the screen dictates a folded optical system. The requirements of the front projection screen furthermore dictate that the light hit this screen from below the horizon. This, in turn, means that in order to direct the light that is reflected or directed from the screen across the room approximately horizontally, then the screen itself must be tilted slightly forward. This is of particular advantage in preventing lights at eye level from reflecting from the screen to the receiver, and thus degrading the picture.

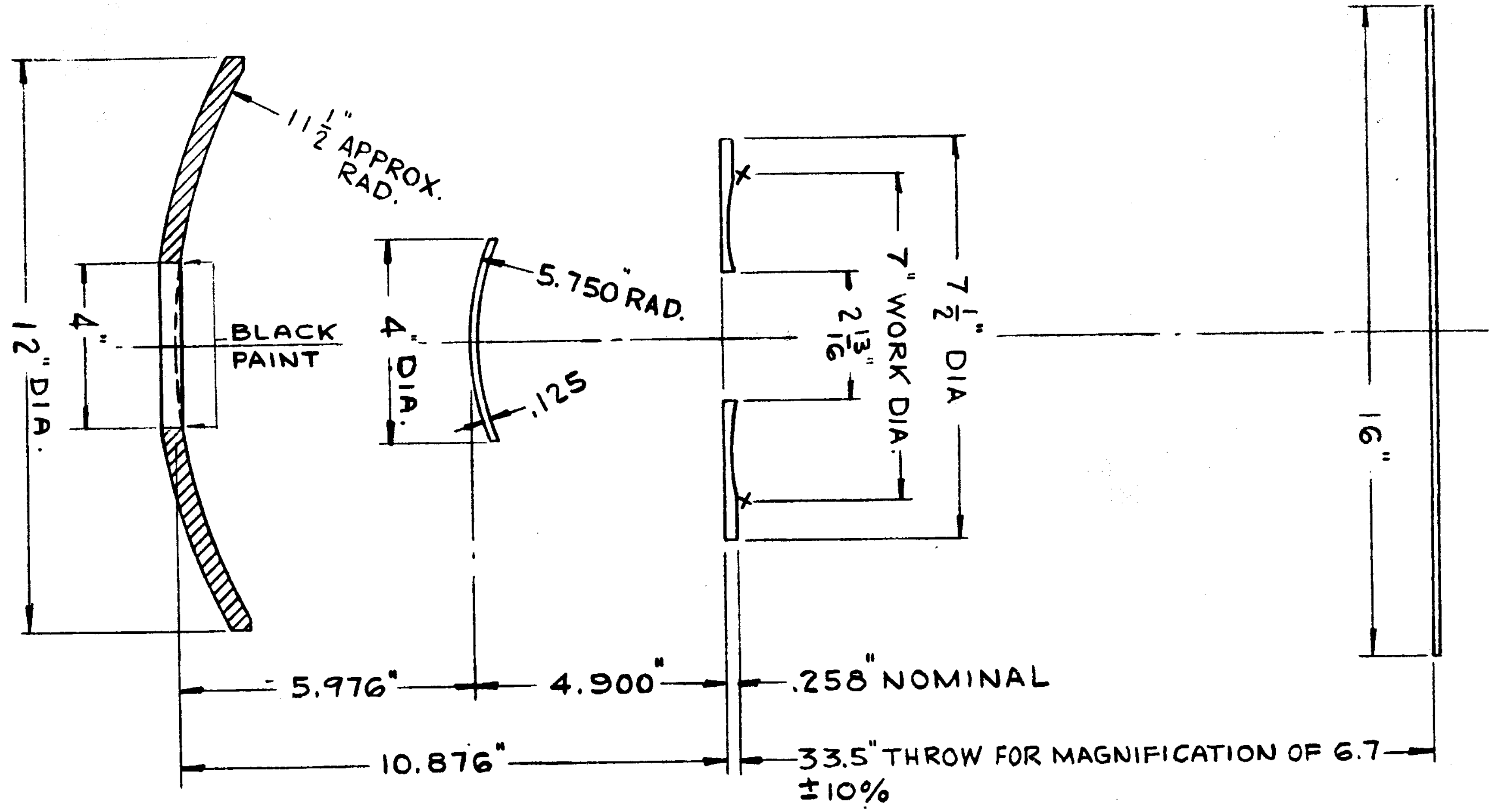
The lay-out and cabinet of the receiver are shown in Figure 14. The screen is attached to the inside of the lid which is hinged along the rear edge of the cabinet. When the receiver is not in use, the lid can be closed.

The fact that the picture appears on a slightly forward tilted screen (about 22º) in itself tends to introduce a slight perspective distortion in the form of vertical compression. A special form of compensation is used in the Philco receiver whereby the physical height of the screen is elongated by a suitable factor which makes the image appear undistorted to the eye of the viewer. It is for this reason that in Figure 14 the physical height of the screen is actually 16" whereas, when tilted forward at the correct angle, it appears to be only 15" high to the viewer. It will be seen from the accompanying drawing and photographs that if the screen is made integral with a lid hinged to the rear of the cabinet, then the maximum depth of the cabinet is determined by the picture height. This depth will, in fact, be equal to the picture height plus a small constant (about 2 inches) for the frame or border around the screen.

The correct choice of tilt angle of the screen and the position of the Schmidt unit within the cabinet and the folding of the optical system in general use are matters of very considerable complexity for designers, because there are so many considerations that have to to be fulfilled simultaneously and so many interplays between these considerations. For instance, the optical system should, if possible, not project outside the rear line of the cabinet which line may be defined as a perpendicular dropped from the hinge of the lid. Also, the neck of the tube must be a reasonable distance away from the plane mirror attached to the front of the cabinet and the neck should preferably obstruct as little as possible of the cone of light. The plane mirror again must be so situated as to intercept all the light emanating from the correction plate and to redirect it suitably on to the screen. The top of this mirror must be low enough so as not to obstruct the bottom of the screen from the viewer. This mirror need not, of course, be absolutely vertical, as in Figure 14, but could be a slight forward or rearward angle. However, minimum depth considerations and the convenience of mounting make a vertical mirror desirable. The above points are mentioned merely for the sake of illustrating some of the conflicting considerations with which the designer is faced.

The lay-out and arrangement of the optical system is self-evident from Figure 14, which shows the method of folding the light path and various angles involved in the system. One further point should be noted here, namely, that the angle of tilt of the screen has been so arranged as to give a slight upward slant of 1º to 2º to the principal direction of the light coming from the screen. This feature enables viewers sitting close to the screen (10 feet) to see the picture under optimum illumination conditions when sitting down and at an eye level of 45-50 inches. Also, viewers standing up at the back of the room (20 feet) will see the picture equally well at an eye level of 60-70 inches.

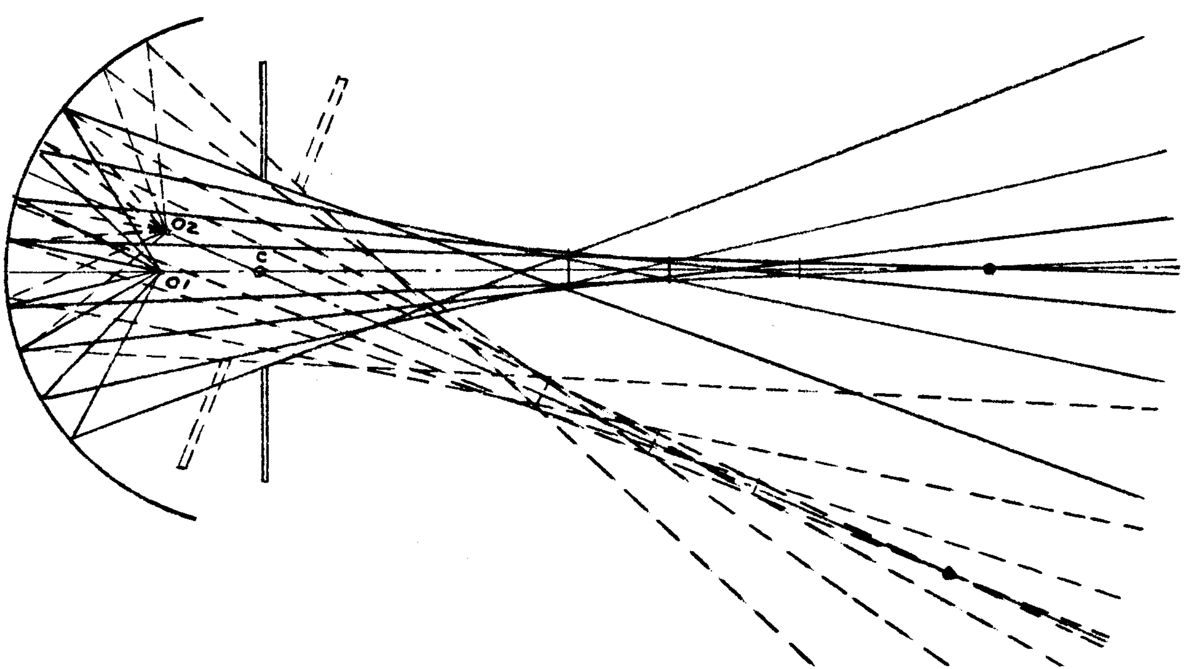
One of the many advantages of this type of lay-out is that the distance between the screen and the eye of one adjusting the controls is the maximum possible in a completely self-contained receiver because the controls and the screen are separated by the maximum amount with the screen at the rear and the controls at the front. This allows for the greatest possible viewing distance when operating the controls at arms length, which is an important consideration particularly when adjusting pictures of 15 by 20 inches in size.



SCHMIDT OPTICAL SYSTEM

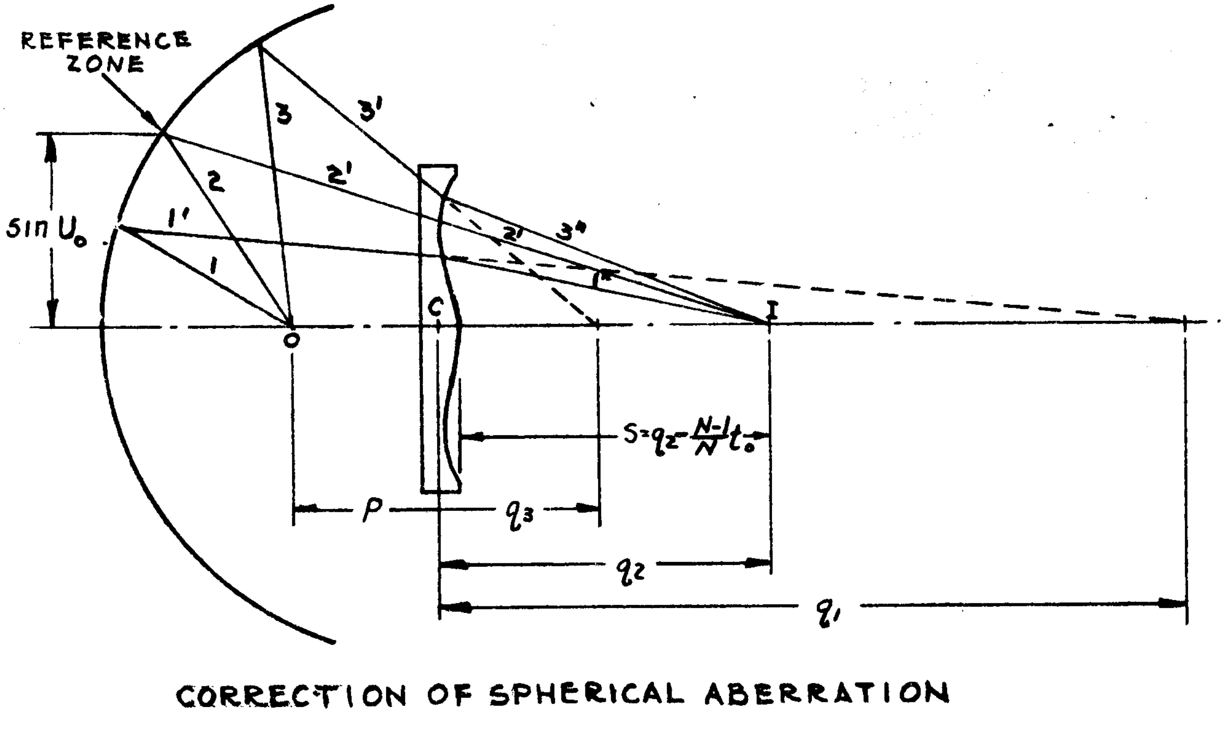
FIGURE 1

A508Y-7



IMAGING PROPERTIES OF SYSTEM CONSISTING OF SPHERICAL MIRROR AND APERTURE LOCATED AT CENTER OF CURVATURE

FIGURE 2.



CORRECTION OF SPHERICAL ABERRATION BY CORRECTING LENS —

FIGURE 3.

RM-10-10-45 A508Y-3

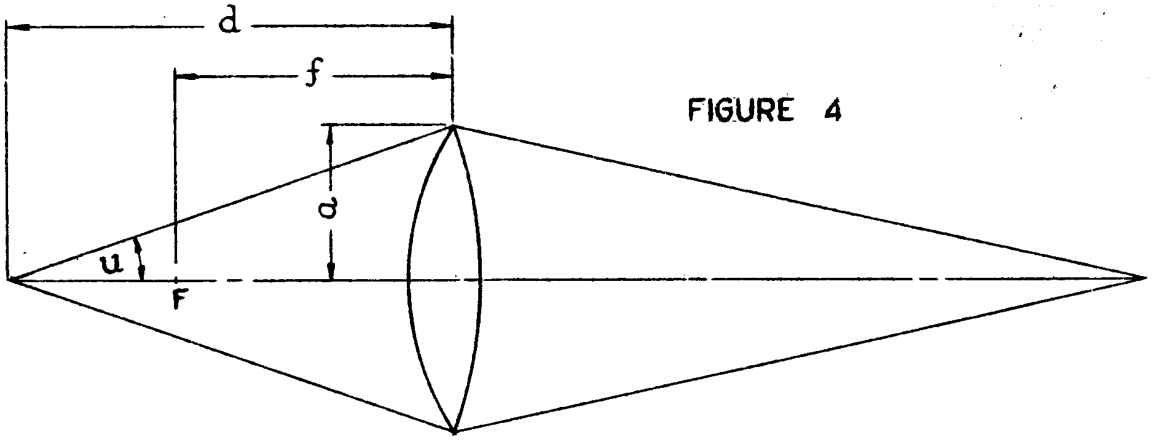


FIGURE 4

$e = \sin^2 u$

$F\text{: number} = \frac{1}{2\sin u} = \frac{1}{2\sqrt{e_\infty}}$

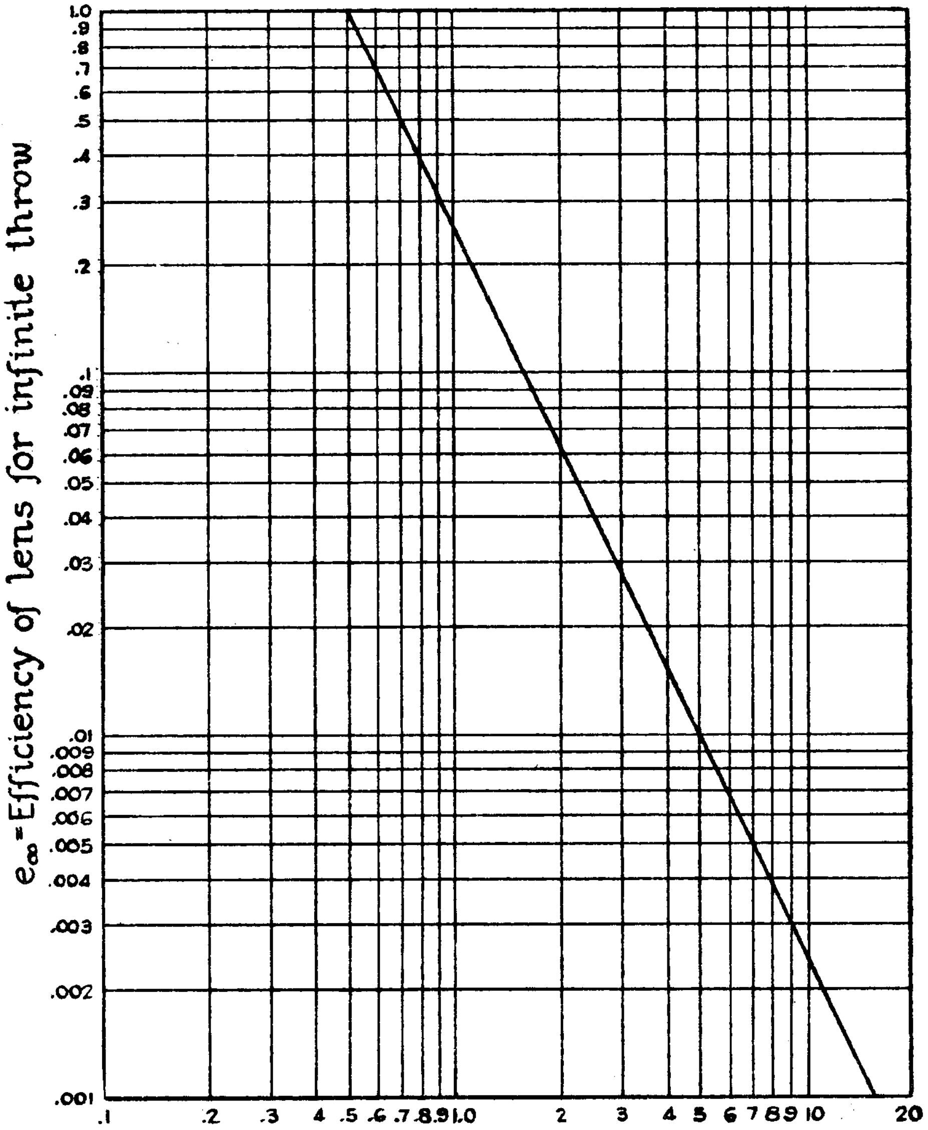
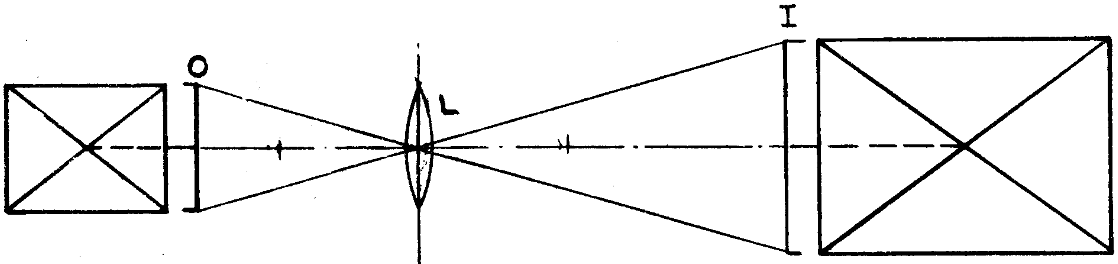
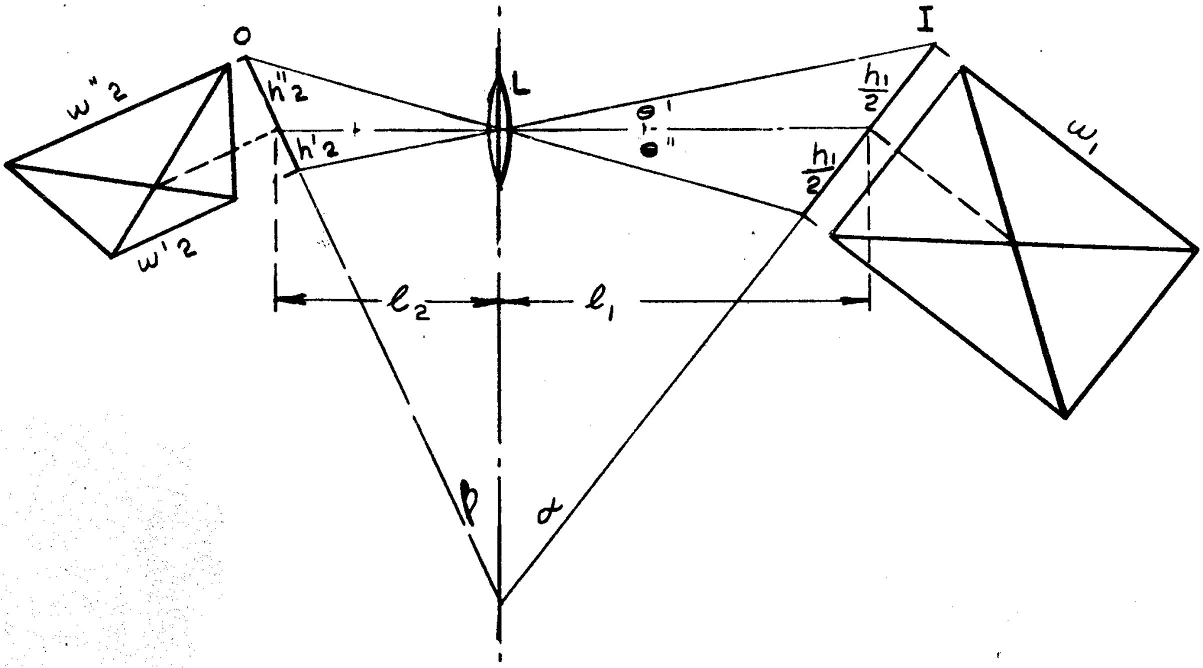


FIGURE 5

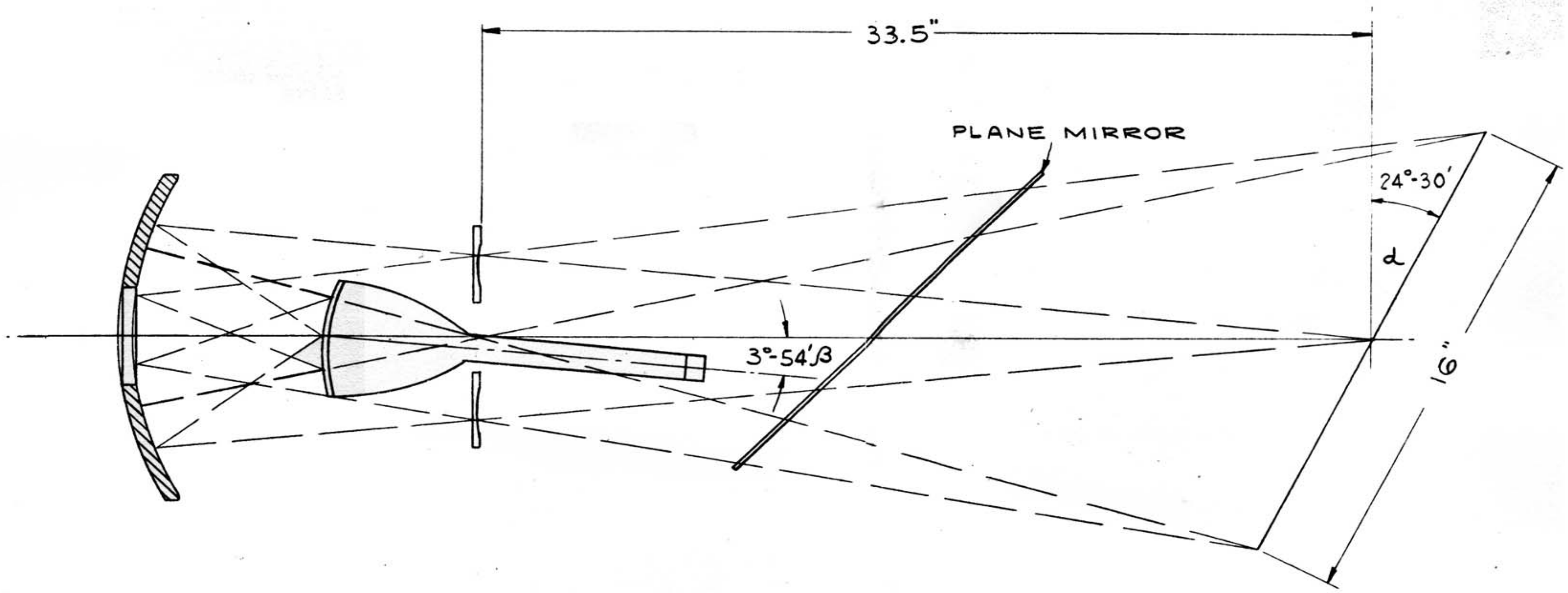
FIGURE 6





KEYSTONE PROJECTION
FIGURE 7

A508Y-8
9-27-45. F.K



SCHMIDT- KEYSTONE PROJECTION

FIGURE 8

B-508Y-9
9-27-45 R.M.

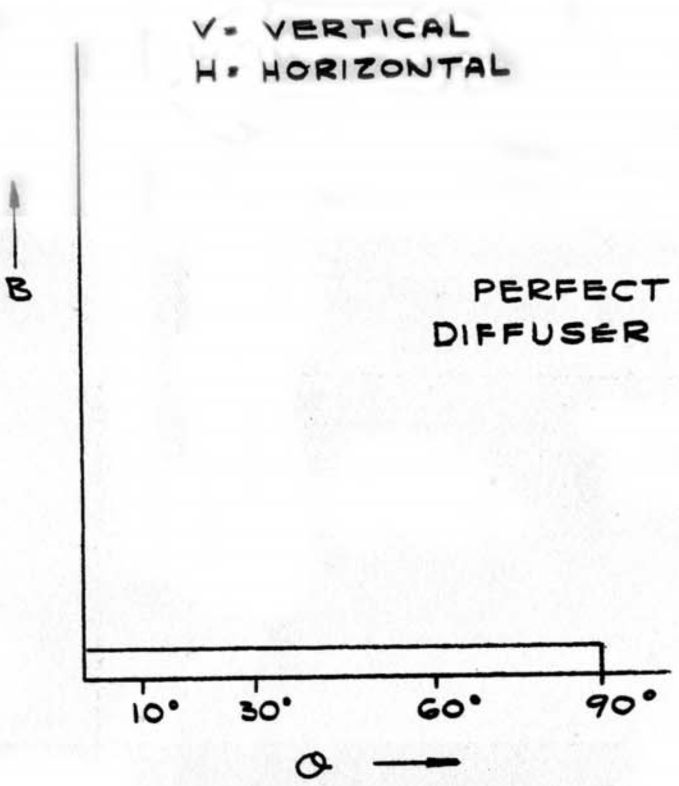


FIGURE 9a

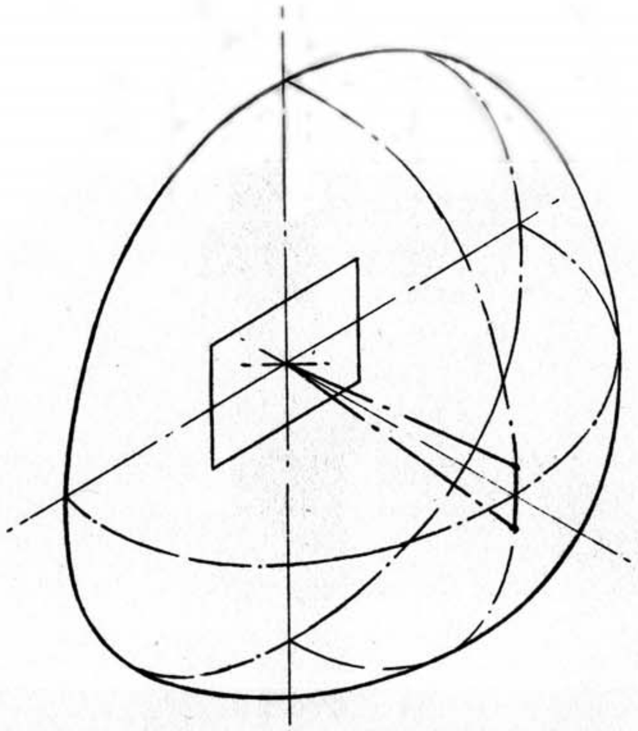


FIGURE 9b

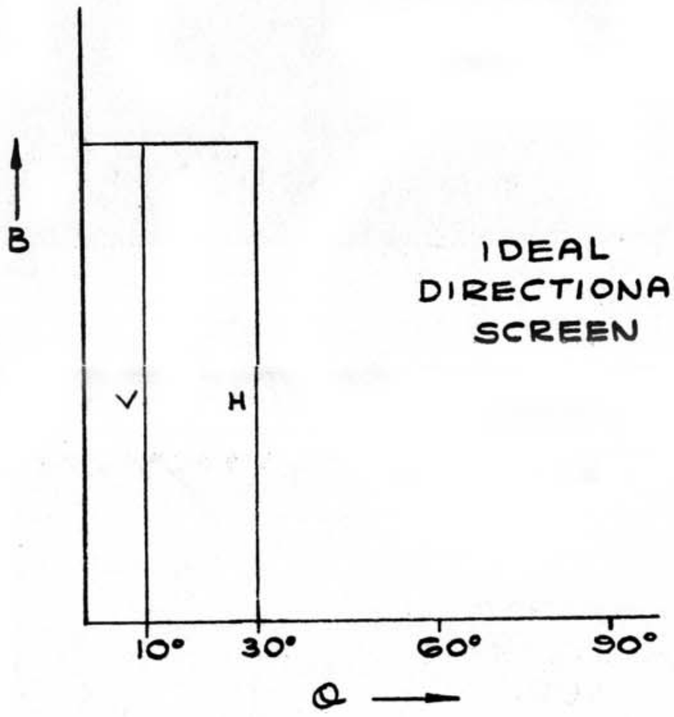


FIGURE 10a.

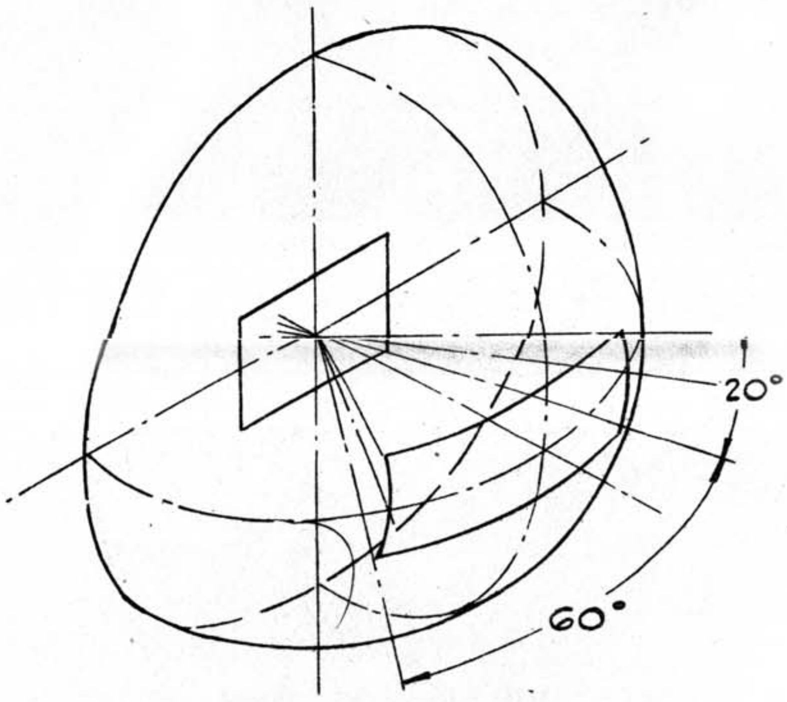


FIGURE 10b

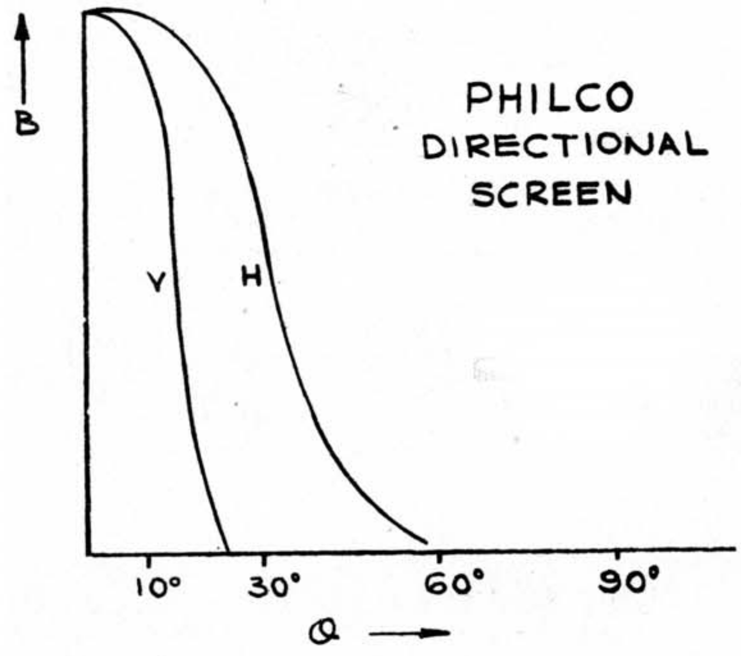


FIGURE 11a.
ROUSSEAU DIAGRAM

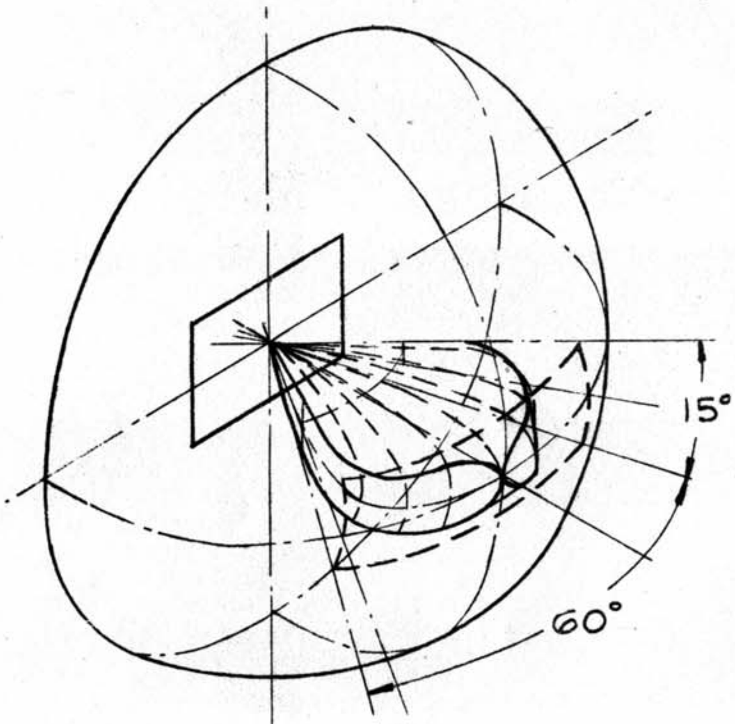
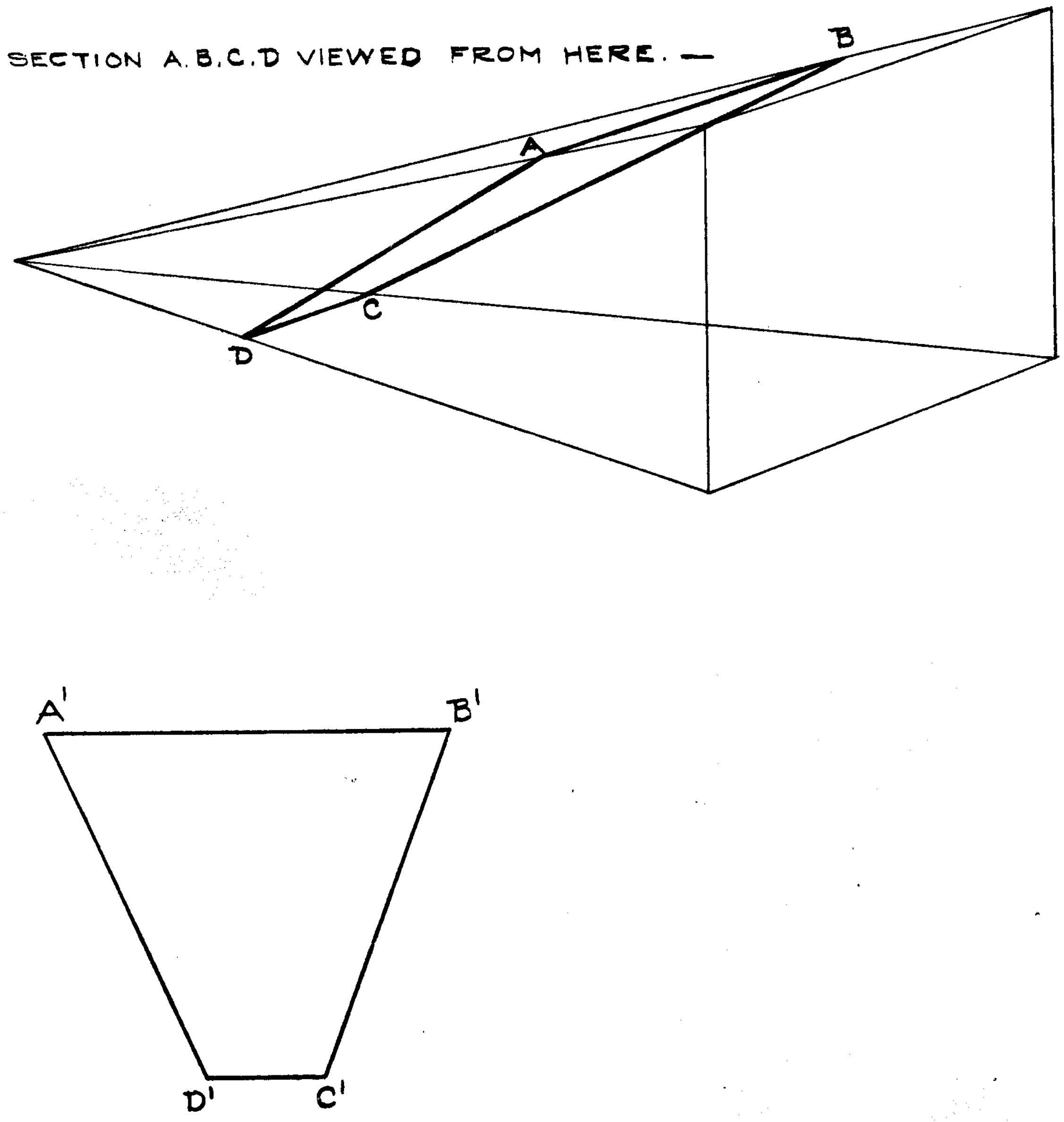


FIGURE 11b
ISOMETRIC POLAR DIAGRAM

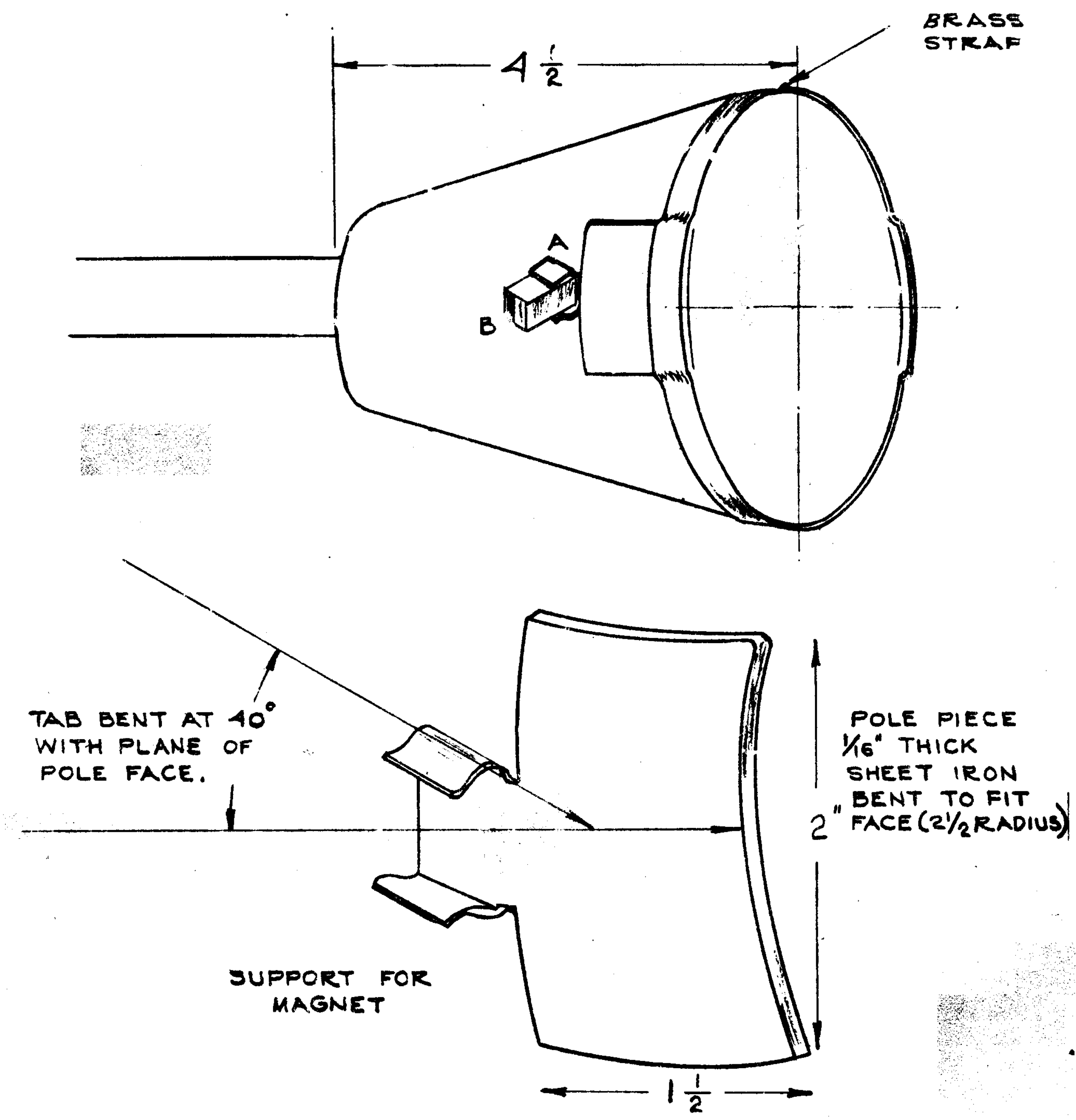
B508Y-10



APPEARS AS TRAPEZOID A'B'C'D'

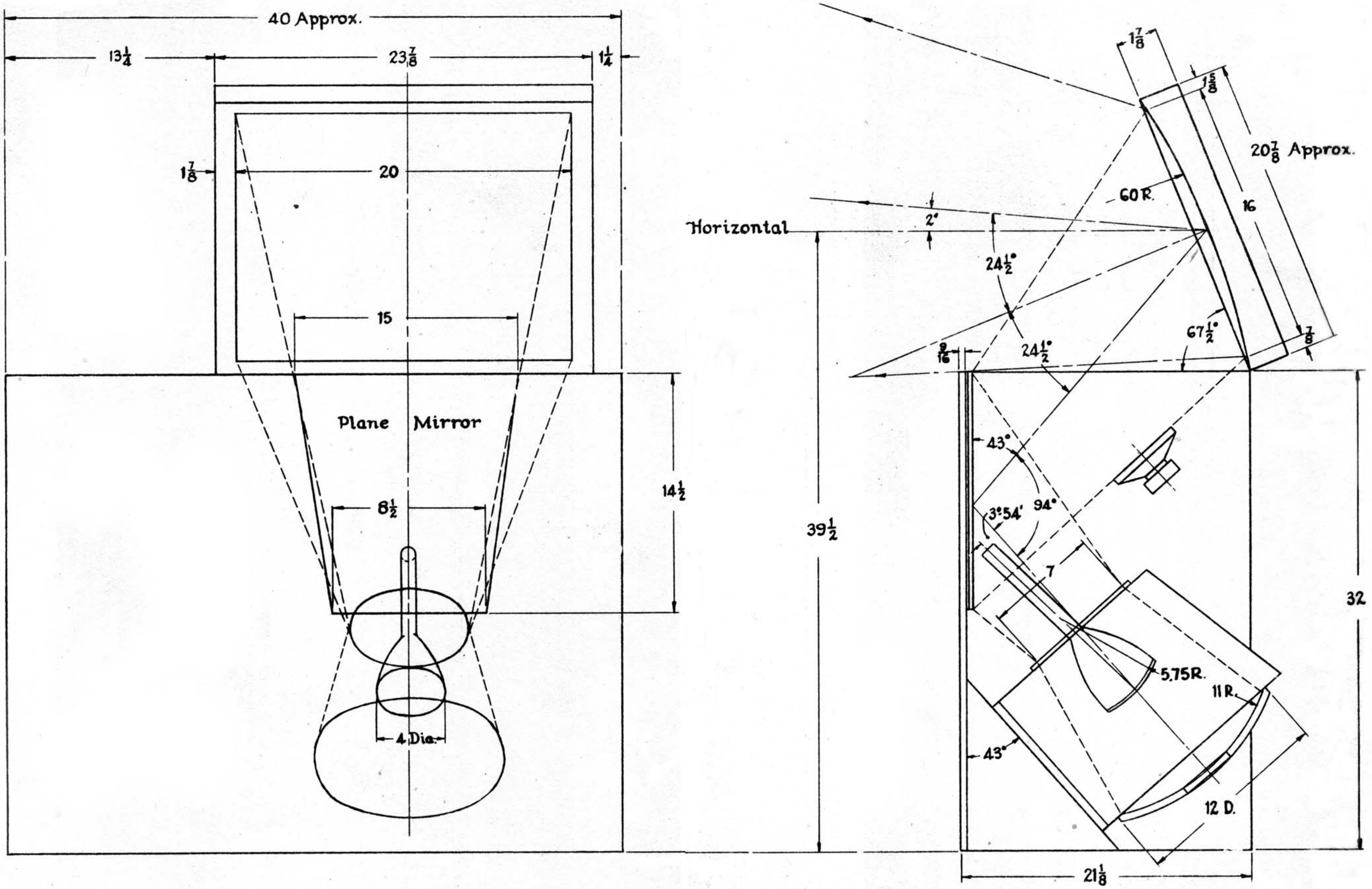
FIGURE 12

A508Y-6
9-27-45. F.K.



MAGNETS AND SUPPORTS
FIGURE 13

A508Y-5
9-27-45. F.K.



Front View

Side View

CABINET LAYOUT
Figure-