

Feb. 12, 1952

W. D. LEWIS
DIRECTIVE ANTENNA SYSTEM

2,585,562

Filed Dec. 4, 1947

9 Sheets-Sheet 1

FIG. 1

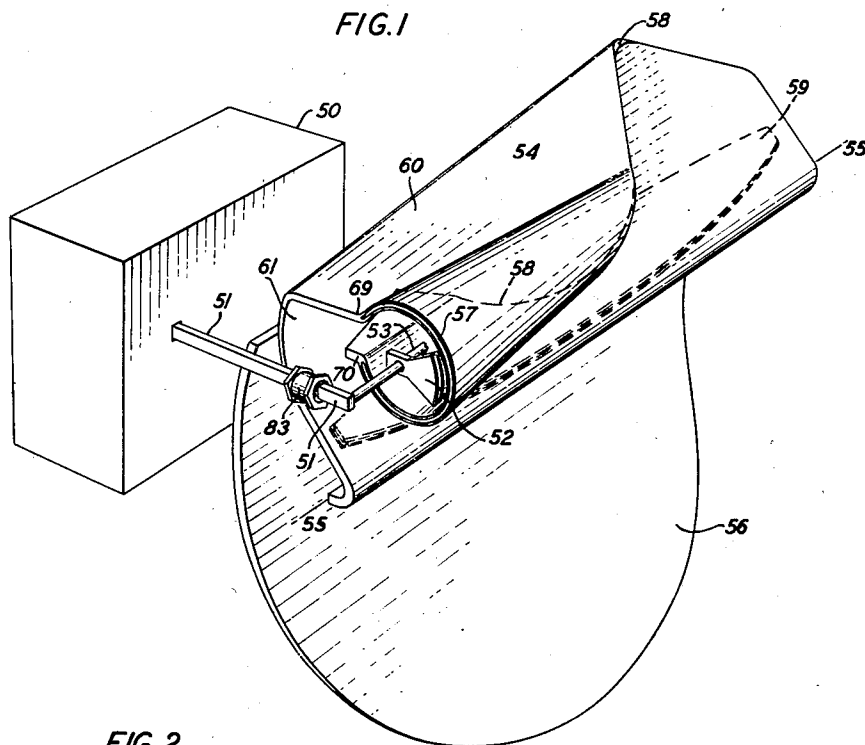
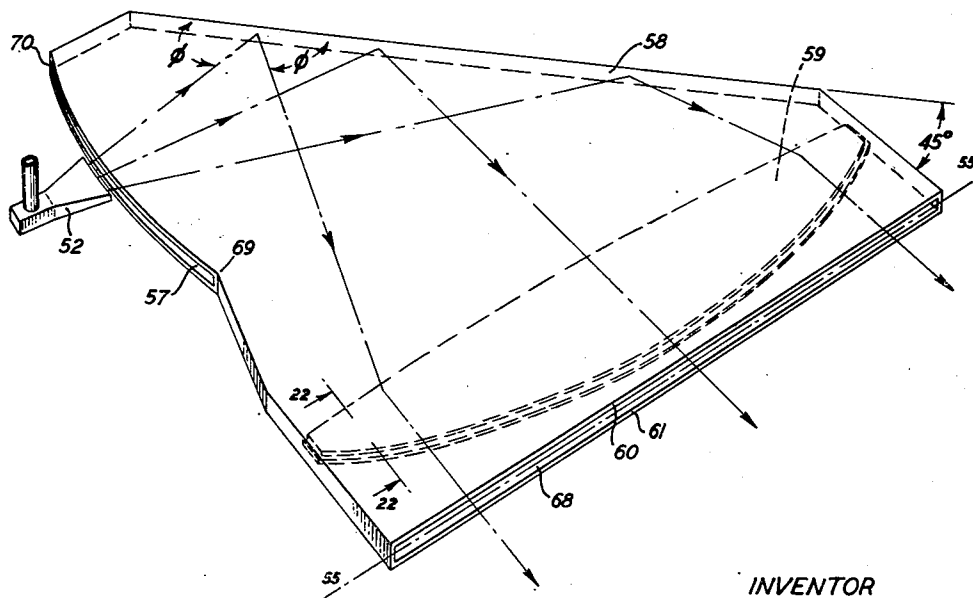


FIG. 2



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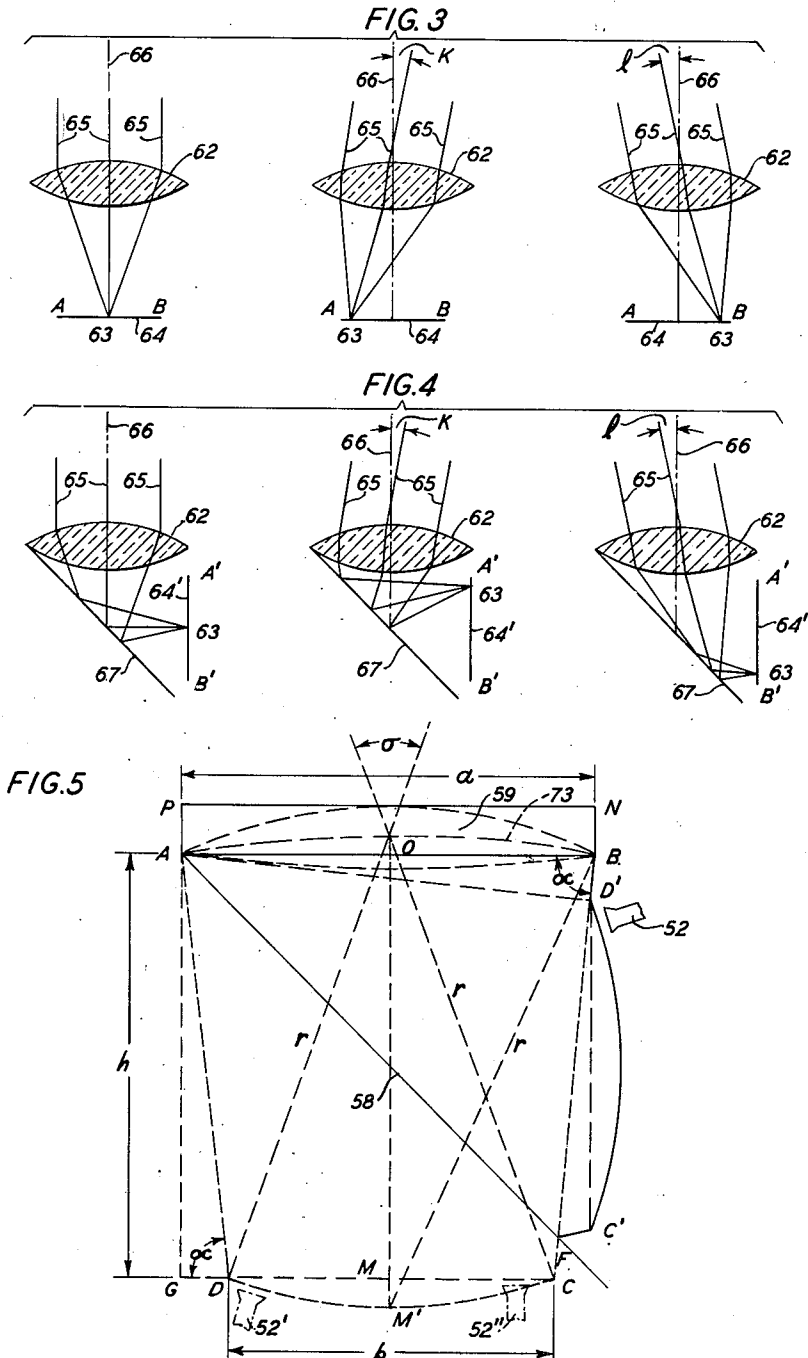
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9 Sheets-Sheet 2



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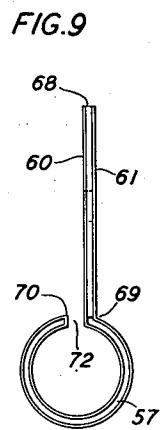
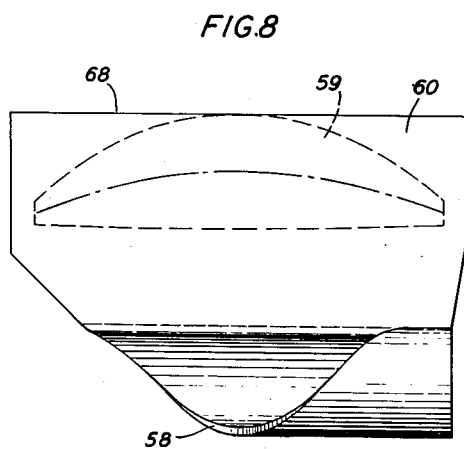
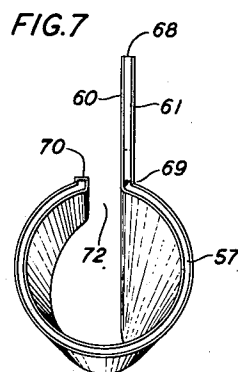
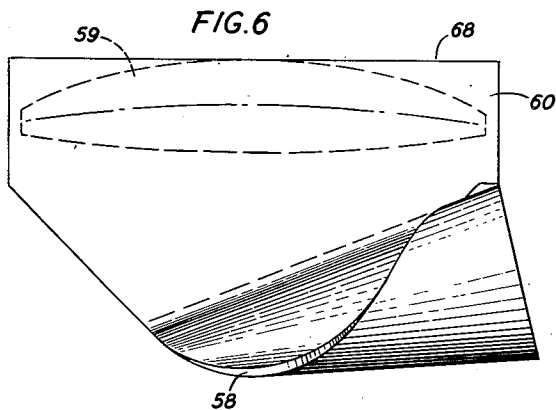
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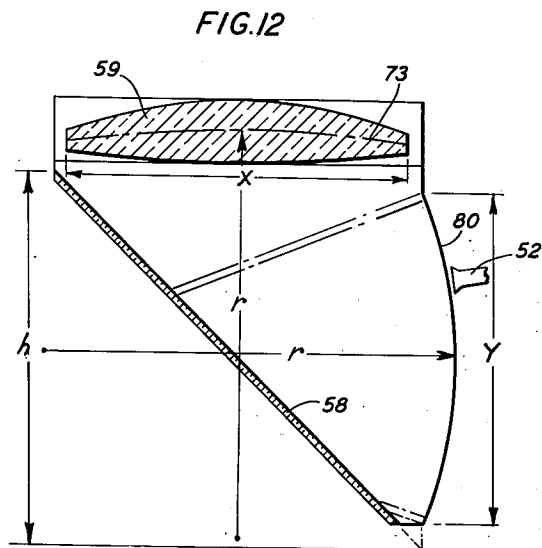
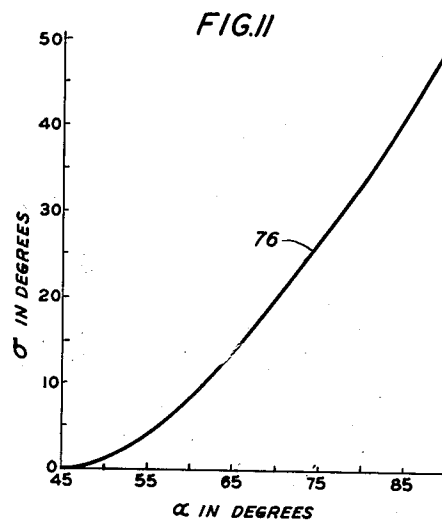
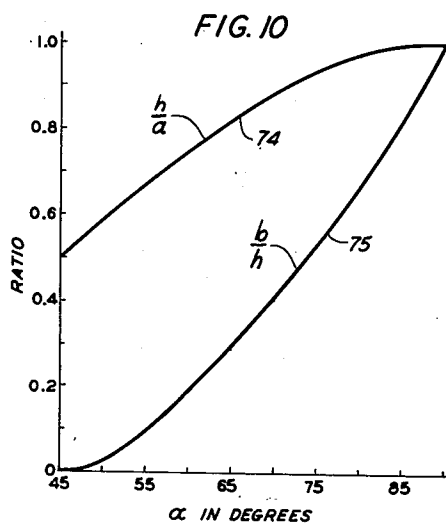
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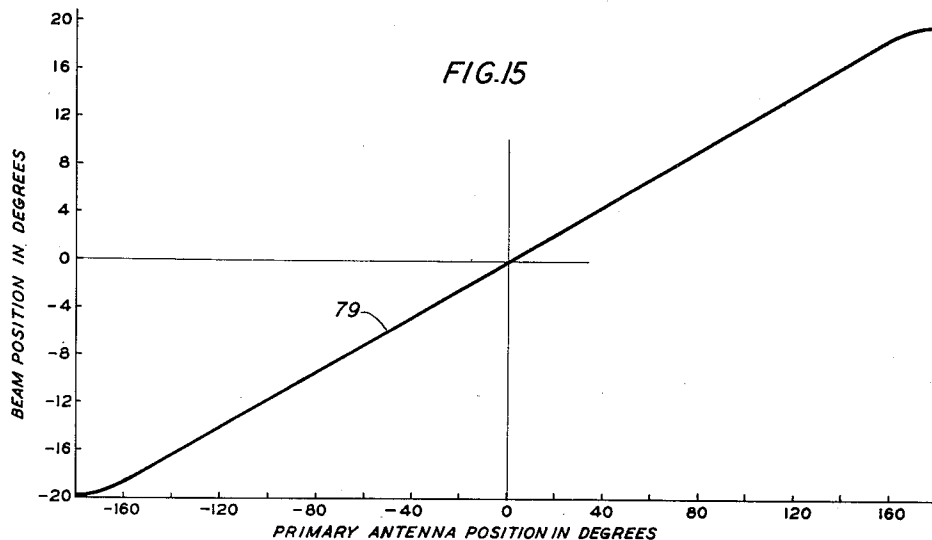
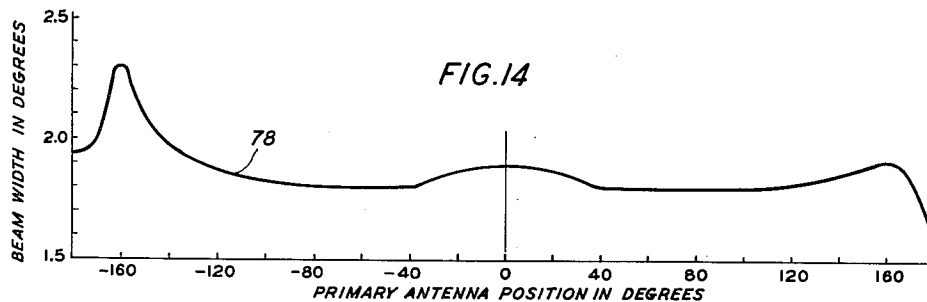
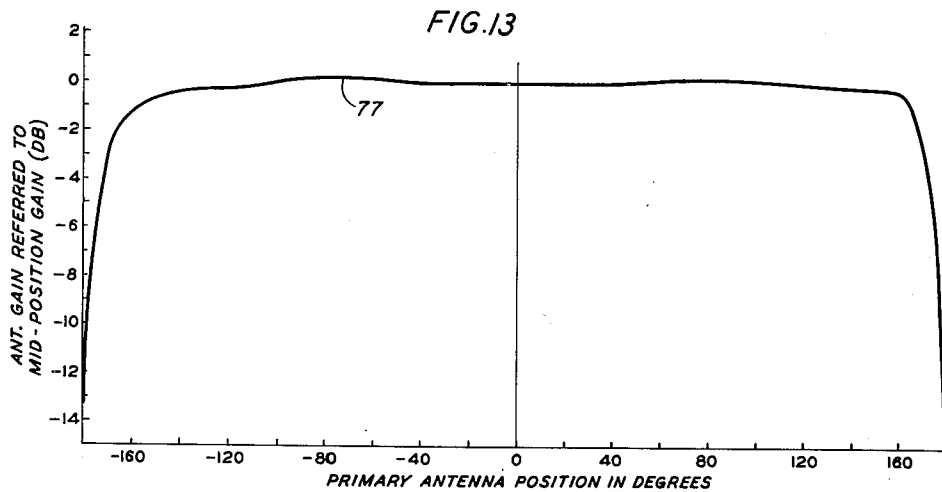
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DIRECTIVE ANTENNA SYSTEM

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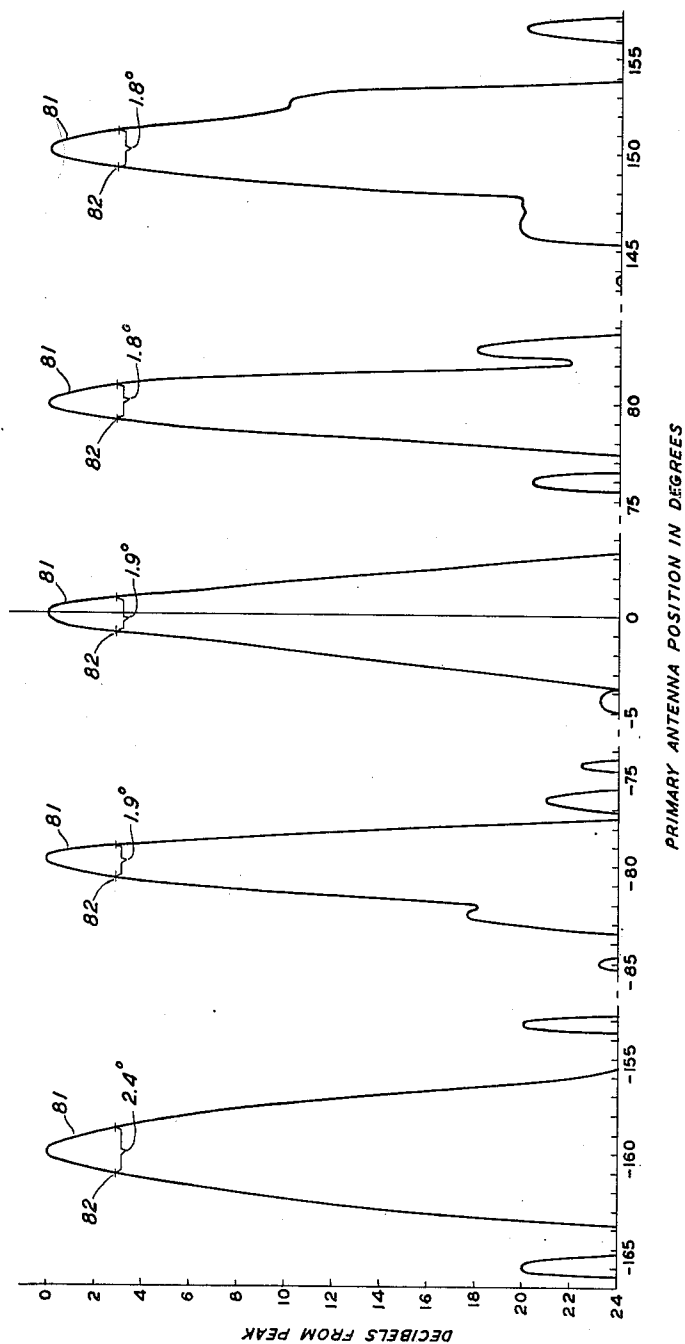
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FIG. 16



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FIG. 17

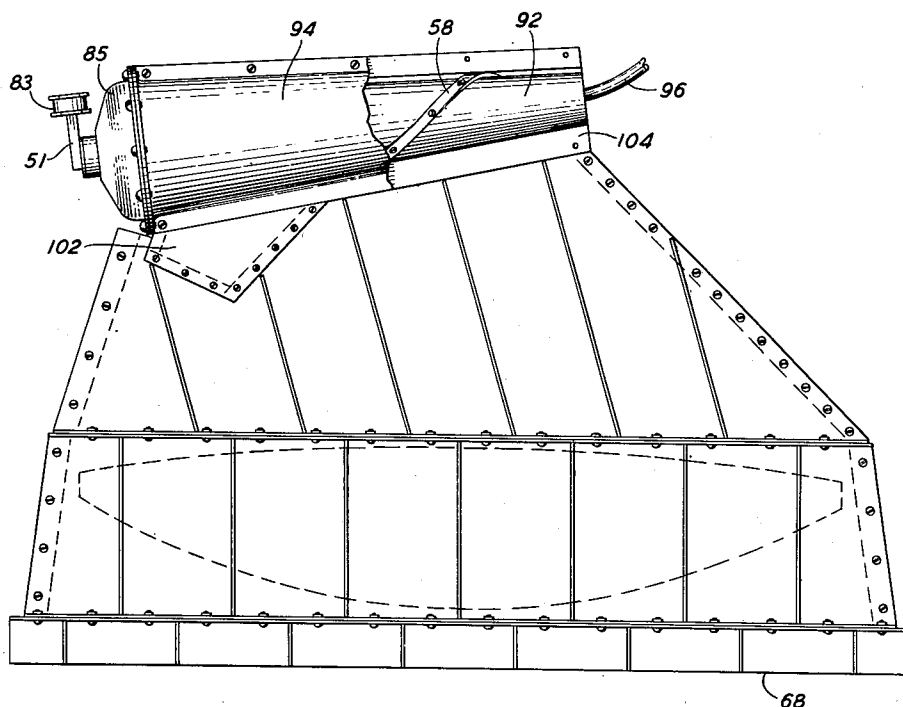
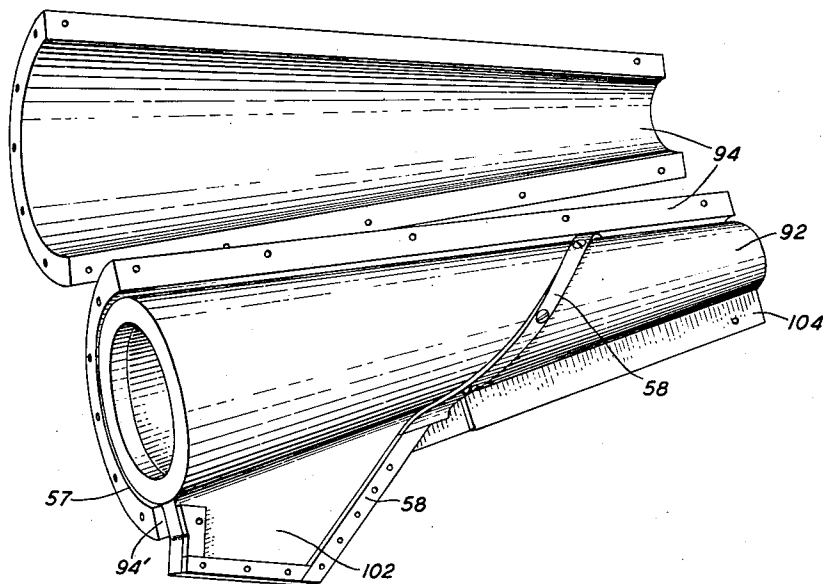


FIG. 18



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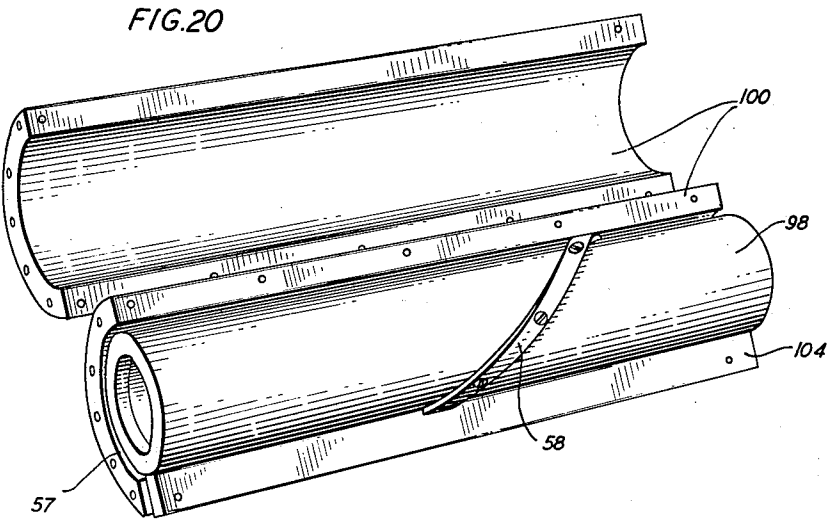
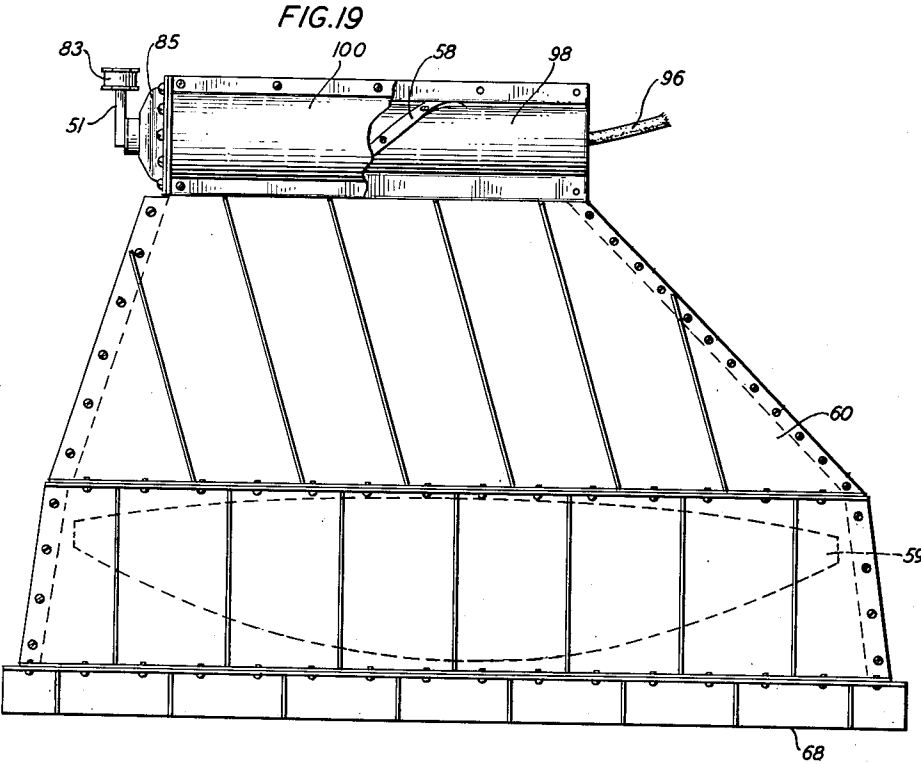
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FIG. 24

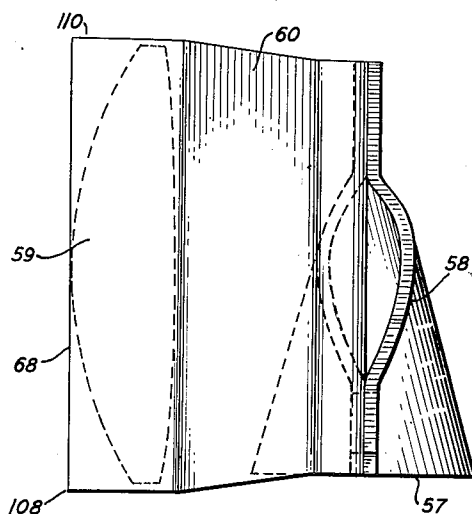


FIG. 25

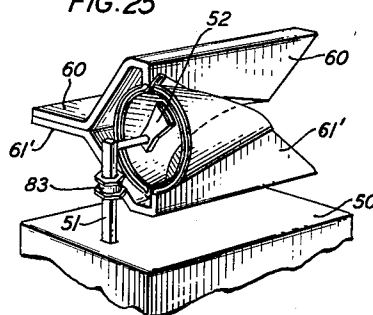


FIG. 23

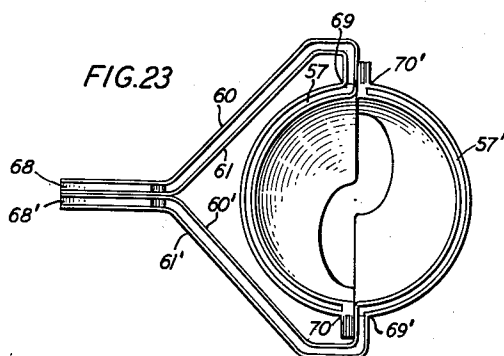


FIG. 22

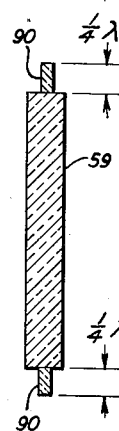
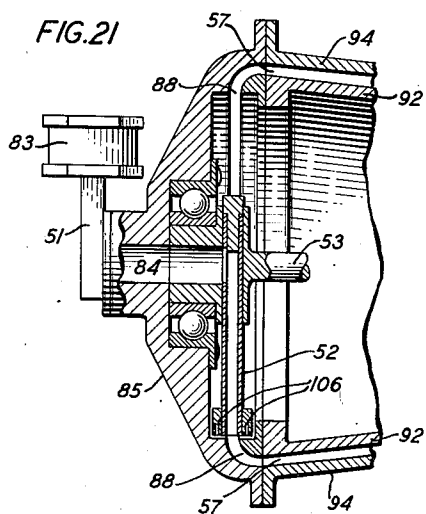


FIG. 21



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UNITED STATES PATENT OFFICE

2,585,562

DIRECTIVE ANTENNA SYSTEM

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Application December 4, 1947, Serial No. 789,602

8 Claims. (Cl. 250—33.63)

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This invention relates to directive antenna systems and particularly to radar scanning antenna systems and particularly to radar scanning antennas for securing a line scan.

As is known, in radio sector scanning systems of the single plane or "line" scan type, an oscillatory scan or a non-oscillatory scan is ordinarily utilized; and various systems have been proposed for producing these two kinds of scan. Thus, the copending application of W. E. Kock, Serial No. 590,562, filed April 27, 1945, now Patent No. 2,521,524, issued September 5, 1950, and my copending application Serial No. 547,396, filed July 31, 1944, disclose oscillatory line scanning systems; and the copending application of C. B. H. Feldman, Serial No. 641,844, filed January 17, 1946, Patent 2,419,205, granted on April 22, 1947, to C. B. H. Feldman and Fig. 60 of the article "Radar" by E. G. Schneider published in the proceedings of the Institute of Radio Engineers, August 1946, disclose non-oscillatory scanning systems. In general, the non-oscillatory type of scanning action is preferred over the oscillatory type of scanning action since, in the former type, the radio beam or lobe moves over the angular scanning sector with linear uniform motion and, considering any single sweep or scan, the scanning action is constant over the sector whereas, in the latter type of action, the beam moves with linear simple harmonic motion and, considering any complete oscillatory scan, the action undeniably varies over the sector.

In the systems mentioned above, other than the system of the Schneider article, the scanning action is produced by oscillating or rotating a relatively heavy structure, such as the entire antenna system including a large parabolic reflector, a primary feed horn of appreciable size, a set of wave guide phase changers, or a slotted circular wave guide and associated wave guide phase changers; and the maximum scanning rate ordinarily realized in practice is relatively low, say 10 scans per second. In the Schneider system the scanning action is obtained by utilizing a sectoral trapezoidal horn having its neck portion rolled so that its throat orifice is annular, and by rotating a small light-weight horn around the throat orifice. While a high scanning rate, say 30 scans per second, is obtainable in this system, the rolled horn comprises surfaces of complex curvature, and hence the system is not completely

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satisfactory or practicable from a construction and manufacturing standpoint. Accordingly, it now appears highly desirable to obtain an antenna system of the non-oscillatory rapid scan line type which is devoid of the disadvantages inherent in the above-mentioned and other prior art oscillatory and non-oscillatory line scan antenna systems and, in addition, possesses distinct attributes not found in the systems heretofore utilized.

It is one object of this invention to obtain, in a line scanning radar antenna system, an exceedingly high scanning rate.

It is another object of this invention to obtain an electromagnetic scanning beam having a rapid linear uniform non-oscillatory motion.

It is another object of this invention to obtain a non-oscillatory line scanning antenna system which, as compared to systems of this type heretofore utilized, is simple and easily manufactured.

The parallel plate antenna member described herein and forming part of the invention, in a sense, resembles a sectoral horn and terms applicable to a horn are employed in the following description. As used herein, the terms "mouth orifice" and "far-end opening" have the same significance, and the terms "throat" and "near-end opening" have the same significance. Also, as used herein, the term "focus" is generic to "focal line" and "focal path" and the term "focal path orifice" denotes the near-end opening framed by the wide and narrow walls of the parallel plate antenna member, the plane of which opening roughly corresponds to the throat orifice of a sectoral horn. The focus and focal line or path lie in the plane of this opening.

In accordance with one embodiment of the invention a scanning antenna system comprises a parallel plate type or quasi-sectoral horn antenna member having a near-end focal path orifice and a far-end mouth orifice. The portion of the parallel plate structure adjacent the near-end orifice is in effect folded more or less diagonally and rolled into a conical section so that the focal path opening assumes an annular shape. It should be noted and understood that the "effective fold" can be made at any of a large number of angles provided that the "folded" portion at the focal line aperture end is sufficiently long that with the angle of "fold" selected, the complete focal path opening projects beyond the edge

of the sectoral horn opposite the line of the fold. This will be readily perceived if a soft paper model of the plan view of a conventional sectoral horn having a focal line aperture is made and folded at random so as to position the focal path opening (horn input aperture) beyond the edge of the sectoral horn opposite the fold. The fold angle of 45 degrees has no especial merit other than that of causing the plane of the focal path opening to be substantially perpendicular to the plane of the far end opening (horn output aperture) of the "folded" sectoral horn. Where the throat portion of the quasi-sectoral horn is to be rolled as in the several illustrative embodiments described in detail hereinafter, a fold angle in the neighborhood of 45 degrees will, however, in most instances provide convenient and adequate space for the positioning and mounting of the rotary wave guide feed arrangement, as will become apparent during the detailed description of illustrative structures given hereinafter. The focal path is arcuate, and its plane and the plane of the mouth orifice form an acute dihedral angle. A portion of one of the narrow walls of the rolled parallel plate structure constitutes a linear reflecting member extending inside the parallel member at an angle of 45 degrees to the longitudinal axis of the plate member and symmetrically facing the mouth orifice and the focal path opening. By virtue of the roll in the parallel plate structure the linear reflecting member assumes the form of a conical helix or a flat spirally curved surface. A small movable primary horn antenna is positioned so as to rotate along the ring focal path orifice of the parallel plate member. The circumference of the annular focal path opening is large compared to the width, measured along the aforementioned circumference, of the small movable primary antenna member, so that in operation, assuming transmission, the radio beam from the primary horn member appears to emanate at a point in the focal path opening. As this primary antenna member rotates in a clockwise direction completely around the annular focal path opening, the lobe axis or mean ray of the beam swings about the center point of the mouth orifice from side to side, say right to left, and single-line scanning is secured. A convexo-convex dielectric lens is positioned between the wide parallel plates in the mouth orifice to secure a fairly linear wave front, coincident with the aforesaid longitudinal dimension, and hence to secure a cylindrical wave front suitable for illuminating a cylindrically symmetrical lens or a cylindrical parabolic reflector. The longitudinal mean surface of the lens is equidistant at all points from the mid-point of the focal path orifice, whereby wide angle scanning with minimum aberration is obtained.

In a different embodiment of the invention the parallel plate structure is folded and rolled into a cylindrical section so that the plane of the resulting annular focal path is perpendicular, substantially, to the plane of the mouth orifice and the focal path is in effect linear rather than curvilinear. In still another embodiment a single conical section is associated with a pair of flat parallel plate sections and alternate, that is, a double successive line scan is produced.

The invention will be more readily understood from the following specification taken in conjunction with the drawing on which like reference characters denote elements of similar function and on which:

Fig. 1 is a perspective view of a scanning an-

tenna system constructed in accordance with the invention and comprising a parallel plate member having a conical roll;

Fig. 2 is a perspective developed view of the parallel plate member included in the embodiment of Fig. 1;

Figs. 3, 4 and 5 are explanatory diagrams used in explaining certain features of the invention;

Figs. 6 and 7 are, respectively, explanatory plan and end views of a parallel plate member having a conical roll;

Figs. 8 and 9 are, respectively, explanatory plan and end views of a parallel plate member having a cylindrical roll;

Figs. 10 and 11 are curves illustrating the dimensional relations of the parallel plate member;

Fig. 12 is an explanatory diagram of a tested embodiment of the invention;

Figs. 13, 14, 15 and 16 are curves illustrating measured characteristics of an antenna system constructed in accordance with the invention;

Fig. 17 is a plan view of a scanning antenna system comprising concentric conical elements;

Fig. 18 is a perspective view of the concentric conical elements included in the embodiment of Fig. 17.

Fig. 19 is a plan view of a scanning antenna system comprising concentric cylindrical elements;

Fig. 20 is a perspective view of the concentric cylindrical elements included in the embodiment of Fig. 19;

Fig. 21 is a detail sectional view of the primary rotating antenna member included in the embodiment of Fig. 17;

Fig. 22 is a sectional view of the dielectric lens used in the embodiments of Figs. 17 and 19;

Figs. 23, 24 and 25 are end, plan and perspective views of an alternate line scanning antenna constructed in accordance with the invention.

Referring to Fig. 1, a translation device 50 is connected through a wave guide 51 to a primary antenna member 52. The member 52 is mounted for rotation on shaft 53. The parallel plate antenna member 54 has a linear mouth orifice, the longitudinal dimension 55 of which is substantially coincident with the focal line of the cylindrical parabolic reflector 56. The near end of this parallel plate antenna member is rolled into a conical shape such that the focal path opening forms an annular opening 57. Radio frequency energy from the translation devices 50 is supplied to the rotational member 52, and by it emitted in a beam having a directional characteristic such that an axis of maximum action is clearly defined. This radio frequency energy is directed into the wave guide channel which is defined by the parallel plates, and which terminates at its near end in the focal path 57. One of the narrow walls 58 of the parallel plate member forms a flat reflecting surface, indicated by the dotted lines, such that incident energy is reflected by it from the focal path opening 57 to the mouth orifice 68. In the mouth orifice a dielectric lens 59 is located between the wide parallel plates to convert the emerging radio frequency energy wave into a wave front that is relatively flat along the longitudinal dimension 55. As the rotating member 52 describes a clockwise movement around the annular opening 57 it emits a beam of radio frequency energy, the mean ray of which impinges upon the reflecting member 58 at different points along its longitudinal dimension. This energy is then reflected through the dielec-

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tric lens 59 to form an energy lobe that has an axis of maximum action that passes through the center of the lens. As the primary member 52 continues its rotational cycle it so distributes its radio energy along the longitudinal dimension of the reflector 58 that this axis of maximum response pivots about the center point of the lens 59. By this pivoting action the energy lobe sweeps, or scans, an angular sector to the right and left of the center line, or axis of the system. This sweeping, or scanning, radio energy lobe may be used directly, or may be used to illuminate a suitable reflecting member such as the cylindrical reflector 56.

The scanning action of this system may be best visualized with reference to Figs. 3 and 4 which show a simple optical system containing a convex lens 62 having a geometrical axis 66. When a point source of light 63 is placed at the center of the focal line 64, the light will pass through the lens 62 and will emerge from the front of the lens as a beam having parallel rays 65 directed straight ahead. If the source 63 is moved to the left along the focal line 64, to point A, the light will again emerge from the front of the lens 62 as a series of parallel rays 65, the mean ray of which is directed at an angle k to the right of the axis 66. Conversely, moving the source 63 to the right along the focal line 64, to point B, will cause the light beam to emerge from the front of the lens 62 with the mean ray at an angle l with the axis 66. In the absence of distortion, a linear relationship may exist between the angular displacement of the beam and the movement of the light source 63 along the focal line 64. It is therefore possible to cause the rays 65 to continuously scan a sector, equal to the angles k plus l , to the left and right of the geometrical axis 66, by moving the source 63 continuously between points A and B along the focal line 64. If the movement of this source is unidirectional from left to right the scanning action will be unidirectional from right to left. The same result may be obtained by placing a reflecting mirror 67 (Fig. 4) at some angle behind the lens 62, and projecting the focal line 64 to one side of the lens instead of directly behind it, as in the previous example. In its reflected position, this focal line 64' has points A' and B' situated along its length and corresponding to points A and B respectively of Fig. 3. As in the previous example, movement of the light source 63 along the reflected focal line 64' produces a scanning action of the light beam in front of the lens 62. By inspection it is apparent that this reflected focal line 64' must lie outside of the optical path to insure uniform illumination of the lens 62.

Referring now to Fig. 2, in which is shown a perspective developed view of the conically rolled parallel plate member of Fig. 1, the primary antenna member 52 is analogous to the light source 63, and the linear reflecting member 58 replaces the mirror 67. Radio frequency energy emanating from the primary antenna member 52, indicated by the directional lines, enters the wave guide channel enclosed by the wide parallel plates 60, 61. Here, it encounters the reflecting surface 58, and is reflected to the dielectric lens 59, in the mouth orifice 52. Since the angle of incidence θ is equal to the angle of reflection Φ at the point of incidence on the reflecting member 58, it is apparent that as the primary antenna member 52 is moved along the focal path opening 57 from point 69 toward point 70,

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the axis of maximum radio frequency action will pivot about the center point of the lens, and scan an angular sector in front of the lens in the previously described manner. In order to achieve rapid uniform unidirectional scanning action, the throat end of the parallel plate member containing the focal path opening 57 may be optionally formed into a conical or a cylindrical roll with the end 70 being brought near to, but not contiguous, with the point 69, as shown in Figs. 7 and 9. This configuration results in a dead space 72 which is approximately of the same extent as the wide dimension of the rotating primary antenna member 52. Figs. 6 and 7, respectively indicate the plan and end views of a conically rolled parallel plate member. Figs. 8 and 9 show corresponding views of a member where the parallel plates have been formed into concentric cylinders. From the preceding, it is apparent that as the primary antenna member 52 is rotated in a clockwise direction from point 69 on the focal path opening to point 70 of this opening, the axis of maximum radio frequency action will pivot in the mouth orifice 68 (Fig. 2) in such a manner that it will sweep an angular sector from left to right, as viewed in Fig. 2. As the primary member moves from point 70 across the dead space 72 (Figs. 7 and 9) to reappear at point 69, the axis of maximum radio frequency action leaves its angular position at the right of the center axis to suddenly reappear at its extreme left angular position, ready to repeat its scan toward the right.

In the preceding discussion, the principal reference has been to a scanning antenna system employing a parallel plate member in which the plates have been rolled into concentric conical structures. This structure is a preferred embodiment of the invention, however, if desired, the parallel plates may, for example, be formed into concentric cylindrical formations. This latter type of construction presents simplified manufacturing considerations, and may prove to be desirable if the intended use of the structure does not involve beam width and scanning requirements that are too rigorous. For reasons that will be later discussed, a scanning member in which the parallel plates are conically rolled appears capable of providing more desirable energy lobe conformation and scanning action at wide scanning angles, than does one in which the cylindrical conformation has been used.

The considerations accompanying a choice of the optimum size and shape of a parallel plate member, for use under a given set of service conditions, may best be visualized by reference to Fig. 5. The geometric configuration here shown is intended by way of explanation only as an aid in visualizing the various factors controlling the design of such a member. The area PNBD'C'FA represents the mean developed surface of a conically rolled parallel plate member. In this area the rectangle APNB represents the area between the parallel plates that functions as a housing for the dielectric lens 59. This lens has a mean center line, indicated by the dotted line 73, which is approximately coincident with the arc of a circle of radius r about the point M'. The linear reflector 58 is represented by the line AF, and the arc D'C' represents the focal path edge of the near end or throat opening 57 which is energized by the rotating primary antenna member 52. In passing, it might be well to note that the edge of this opening would assume the form of the straight dotted line D'C' if the parallel

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plates were formed into concentric cylinders instead of concentric cones.

The area bounded by the straight lines ABCMD represents an isosceles trapezoid that is substantially equivalent to the mean developed surface of the parallel plate member. This area differs from that of the mean developed surface by the area bounded by the dotted line CMD and the arc CM'D, which in turn corresponds to the difference between the conical and cylindrical forms of constructions. As previously stated, the conical form may be expected to give slightly superior results. However, for purposes of explaining the procedural steps in the design of such a member the equivalent trapezoid convention is useful.

By inspection, the area AD'C'F is the reflection of area AFCD, and if a source along C'D' is to be reflected without interference toward the far end or mouth opening, indicated by the line PN, the near end opening line C'D' must lie entirely outside of the equivalent trapezoid ABCD. Assume now the limiting conditions of a scanning angle, and a beam width each of zero degrees. For this condition the smallest optical region (equivalent trapezoid ABCD) that may be folded and rolled into a parallel plate member having a mean developed surface as shown, may by the relations $h = a \sin^2 \alpha$ and $h = b/(\cot \alpha - 1)^2$, be determined to be one in which the angle α is 45 degrees. It is also one in which the diagonal AF is at an angle of 45 degrees with the base lines AB and CD.

These relationships may be more evident upon the following consideration. Considering first the angular position of the linear reflector 58, or line AF, the triangle AGD is constructed such that the angle AGD equals 90 degrees. Bases AB and CD are parallel, therefore the angle GAB also equals 90 degrees. The angle ADG equals α degrees and angle DAG equals 90 minus α degrees. The complementary angle D'BA is equal to α and as angle BD'A is 90 degrees, the angle D'AB is equal to 90 minus α degrees. Angle BD'A is 90 degrees since by definition dimension AD' is the reflection of AD, and point D' must be as close to but outside of the trapezoid as is possible. For this condition, point D' coincides with the point where the arc of a circle of radius AD about point A is tangent to side BC, and line AD' is perpendicular to BC'. Angle D'AF is the image of angle DAF, and angle GAF equals 90 minus α degrees plus angle DAF, and equals angle BAF. The combined angles GAF and BAF equal 90 degrees, and each equals 45 degrees.

That $h = a \sin^2 \alpha$ may be seen from the following relations. The height h of the trapezoid is equal to the length of side AG of the right triangle AGD, and $AG = AD \sin \alpha$.

From triangle ABD' side $AD' = AB \sin \alpha$ where $AB = a$. As $AD = AD'$ it follows $AD = a \sin \alpha$. Substituting this expression in the previous equation for AG, we find $AG = h = a \sin^2 \alpha$.

The relation

$$h = \frac{b}{(\cot \alpha - 1)^2}$$

derives from the following considerations: From triangle ADG, side $DG = AD \cos \alpha$. The trapezoid base $CM'D = b$, and $b/2 = MD$. Base $AB = a$, and

$$\frac{a}{2} = \frac{b}{2} \text{ plus } DG$$

or

$$b/2 = \frac{a}{2} - AD \cos \alpha$$

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$$\begin{aligned} b &= a - 2AD \cos \alpha \\ &= a - 2a \sin \alpha \cos \alpha \\ &= a - a \sin 2\alpha \\ &= a(1 - \sin 2\alpha) \\ &= \frac{(1 - \sin 2\alpha)h}{\sin^2 \alpha} \\ &= h(\csc^2 \alpha - 2 \cot \alpha) \\ &= h(1 - \cot \alpha)^2 \\ h &= b/(\cot \alpha - 1)^2 \end{aligned}$$

Graphical representations of these relations; i. e., $h = a \sin^2 \alpha$ and

$$h = \frac{b}{(\cot \alpha - 1)^2}$$

are shown by curves 74, 75 of Fig. 10, for various values of the angle α .

One more factor; namely the effective scanning angle, requires determination. If it is assumed that the channel medium between the parallel plates is air, and only a single optical element, such as dielectric lens 59, is to be placed as near to the far end base AB as is practicable, the mean line 73 of lens 59 should approximate the curve of a circle about the axial focal point M'. Its focal length will correspond to the radius r of the circle, and will have an approximate minimum value of

$$r = \sqrt{(a/2)^2 + h^2}$$

which for the cylindrical roll is the distance from the mid-point M of the focal line CD to points B or A. For the conically rolled structure the radius r will exceed this value by the slight axial distance separating points M and M'. The total scanning angle σ , exceeds the effective scanning angle by about twice the width of the parallel plate members energy beam, as measured between its half power points. This difference arises from the finite time required by the rotating primary member 52 to pass over the "dead space" 72 (Fig. 7).

The total scanning angle

$$\sigma = 2 \tan^{-1} \frac{b}{2r}$$

from triangle MBO,

$$r = \sqrt{h^2 + \left(\frac{a}{2}\right)^2}$$

$$\begin{aligned} \sigma &= 2 \tan^{-1} 2 \frac{b}{\sqrt{h^2 + \left(\frac{a}{2}\right)^2}} \\ &= 2 \tan^{-1} \frac{h(\cot \alpha - 1)^2}{2h \sqrt{1 + \frac{1}{4 \sin^4 \alpha}}} \\ &= 2 \tan^{-1} \frac{\sin^2 \alpha (\cot \alpha - 1)^2}{\sqrt{1 + 4 \sin^4 \alpha}} \\ &= 2 \tan^{-1} \frac{\cos^2 \alpha (1 - \tan \alpha)^2}{\sqrt{1 + 4 \sin^4 \alpha}} \end{aligned}$$

A graphical representation of this value for σ is shown by curve 76 (Fig. 11) for values of α ranging from its limiting value of 45 degrees up to 90 degrees.

The optimum size of the equivalent trapezoid ABCD (Fig. 5) may be readily computed from the foregoing relations for h and σ , when the operating frequency, the desired effective scanning angle and the beam width are known. As stated by H. T. Friis and W. D. Lewis at page 250 of The

Bell System Technical Journal, April 1947, the beam width in degrees is approximately expressed by the relation

$$65 \frac{\lambda}{a}$$

where λ is equal to the wavelength and " a " is the aperture dimension, corresponding to AB of Fig. 5. From curve 76 (Fig. 11) α , the angle between base CD and either side, may be determined since σ = effective scan angle plus 2 beam widths.

With α known, the relations shown by curves 74 and 75 (Fig. 10) may be used to determine the ratios between the trapezoid height and its bases, and from the value of " a " determined from

$$65 \frac{\lambda}{a}$$

these ratios may be converted into suitable linear dimensions.

As previously stated, the foregoing relations determine the optimum size of the parallel plate member that may be folded and rolled into an interference free linear reflecting member in accordance with the invention. For these conditions, the linear reflecting member 58 will be inclined at an angle of 45 degrees with respect to the plane of the far end, or mouth orifice 68. If desirable, the parallel plate member may be made larger than this optimum size without deterioration of the scanning results. In addition, the circumstances surrounding the intended use of the scanning member may permit the choice of either the concentric conical, or concentric cylindrical configurations of the parallel plates. The principal difference between these types of construction, aside from mechanical considerations, arises from the way in which the energy emanating from the rotating primary member 52 illuminates, or impinges upon, the lens 59.

Consider first the conical construction, a plan and end view of which is indicated in Figs. 6 and 7, and which is diagrammatically illustrated in Fig. 5. As the rotating primary member 52 sweeps from point 69 to point 70 along the annular focal path, indicated by the arc D'C', its mean energy ray effectively maintains a perpendicular relation to the arc. This mean energy ray may be considered as impinging upon the linear reflector 58, with its angles of incidence and reflection progressively changing during the rotational cycle, in such manner that it is always reflected to the axial portion of the lens 59. This condition would correspond to the movement of the imaginary primary member 52' from point D to C along the focal arc DM'C at the base of the equivalent trapezoid, in such manner that its mean energy ray is at all times directed toward the intersection of the lens axis and its mean center line 73. For this condition the maximum energy is at all times directed toward the axial portion of the lens, with the energy distribution progressively decreasing from this point toward each extremity of the lens. When it is so illuminated, or energized, the lens transmits a clearly defined lobe of energy that has highly desirable characteristics.

Conversely, if the cylindrical construction, as shown in Figs. 8 and 9, is used the focal path will lie in an annular opening corresponding to the dotted line D'C' of the mean developed surface of Fig. 5, or its corresponding equivalent trapezoid base CMD. In this case the mean ray of energy from the rotating primary member 52

remains perpendicular to the straight line D'C', and is reflected by the linear member 58 to successively different points along the lens 59. This would correspond to the movement of the imaginary primary member 52 along the base line CMD and results in a shifting pattern of illumination, or energy distribution, on the surface of the lens 59. When the primary member 52 is centered between D'C', corresponding to point M on line CD the lens 59 is illuminated, or energized, such that the incident energy uniformly decreases from its mid-point toward its ends. Although the shape and intensity of the energy lobe created by the cylindrical construction may, in some cases, be not as desirable as that obtained by the conically rolled member, particularly at large angles of scan, the relatively fewer manufacturing considerations involved in its production may form a desirable advantage.

An earlier reference was made to the shape of the dielectric lens 59. The choice of conical or cylindrical construction of the parallel plate member will control the dimension of its focal length and its contour. As previously explained, the parallel plate member's beam scanning action is secured by moving the primary antenna member 52 along the focal path. For highly satisfactory wide angle scanning, the beam components that are created by the various parts of the lens 59 must add, or reinforce, along the axis of maximum radio action to form the final beam. Stated otherwise, each of the individual beam components must shift by an equal angular amount when the position of the primary member 52 is changed. Or, the relation, $S=T/Z$ should express a constant value for any given value of T where:

S=angular shift of individual beam component,
T=displacement of the primary member along the focal path, and
Z=distance from focus of lens portion responsible for individual beam component.

This condition will exist only when the various lens portions are the same distance from the focus. It is closely approximated when the mean center surface 73 of the lens 59, having a focal length r , coincides with the arc of a circle of radius r about the focus. Theoretically, this focus will coincide with points M or M' (Fig. 5) respectively, for the concentric cylindrical or concentric conical configurations. It is believed that for most conditions the difference in the curvature of the lens will be of a minor order for the two types of construction.

In this connection, applicant wishes to point out that his copending application, Serial No. 547,396, filed July 31, 1944, discloses and claims a multiple zone antenna system comprising a plurality of passive members, such as reflective or refractive elements, spaced along the circumference of a circle for the purpose of minimizing coma aberration effects. With reference to the foregoing explanation, it should be noted that in accordance with one feature of the present invention, the mean center line 73 of an unstepped lens comprising, for example, a single solid dielectric member 59, is aligned with the circumference of a circle for the purpose of minimizing these coma aberration effects.

Fig. 12 shows the mean developed surface of a parallel plate antenna member, that was constructed in accordance with the principles of this invention. In this embodiment the dimension x of the mouth aperture and the height h of the

equivalent trapezoid were each 48 inches, the linear length y of the focal arc 80 was 43 inches and the radius r of the focal arc, and of the mean lines 73 of the lens 59, was 63 inches. Figs. 13 through 16 show performance data for this antenna member, when used in a radio frequency scanning system operating at a frequency corresponding to approximately 3 centimeter wavelengths. Referring to Fig. 13 curve 77 indicates the variation in the gain of this antenna system as the primary antenna member 52 is shifted from the mid-position of the arcuate path 80 (Fig. 12). From this curve it will be noted that the variation in antenna gain is less than two decibels as the primary member 52 is shifted through an arc of approximately 320 degrees. Referring to Fig. 14 curve 78 indicates the variations in the parallel plate member's beam width at the half power points for varying positions of the primary antenna member 52. In this case the measured beam width was 1.9 degrees or less for positions of the primary antenna member 52 through an arc of about 290 degrees. Fig. 15 indicates the linear relation existing between the shift in the axis of maximum response of the beam and the movement of the primary antenna member 52. This relation is expressed by curve 79 from which it may be seen that a substantially linear relation exists over an arc of about 320 degrees of movement of the primary member 52.

In Fig. 16 curves 81 indicate the energy distribution pattern of the parallel plate antenna member for various positions of the primary antenna member 52. It will be noted that at the half power point 82, 3 decibels below the peak power point, the beam width is maintained at approximately 1.9 degrees for all except the most extreme position of the primary member 52. In all positions the minor lobes were well suppressed.

With reference to Figs. 17 and 18 there is indicated one easily constructed embodiment of the invention in which the parallel plates 60 and 61 are fashioned into concentric conical elements 92, 94 and are associated with the interposed flat spirally curved reflecting surface 58. On the nearly correct assumption that the transverse electromagnetic wave travels around a band so that its velocity at the mean surface is equal to the velocity of light, an appropriate mean surface may be chosen in accordance with the previously detailed data. This surface then may be resolved into segments of cones 92, 94 as indicated by Figs. 17 and 19. In Fig. 17 the end plate 85 covers the focal path opening 57 and the primary antenna member 52. The focal path opening 57 (Fig. 18) gives access to the wave guide channel enclosed between the outer surface of the inner concentric cone 92 and the inner surface of the outer concentric cone 94, and which terminates in the mouth aperture 68. It will be noted that the area 102 of Fig. 18 does not contain any portion of the focal path, however, it must be retained since a portion of the linear reflector 58 occupies that space, and is accordingly folded back out of the conical curve. Reference numeral 104 indicates a solid metal insert which is keyed into the surface of the inner cone 92 and forms a mounting member for the upper (removed) half of the outer cone 94, from the right end of the structure up to the point where the linear reflector 58 leaves the conical surface. The underneath side of this insert 104 and the edge 94' of the bottom half of the outer conical element 94 are spaced apart

to form a rectangular slot through the wall of the conical element 94. The wave guide channel enclosed between the conical surfaces terminates in this rectangular opening at its one end, and in the focal path opening 57 at its other end. The flat parallel plate section is attached to the bottom side of this insert 104 in such manner that its enclosed wave guide channel is aligned with this rectangular opening and serves to extend the wave channel from the focal path opening 57 to the mouth orifice 68, in which is located the dielectric lens 59. The flat spirally curved reflector 58 extends from the region 102 across the surface of the inner cone 94 to emerge between the bottom side of the insert 104 and the upper edge of the bottom half of the concentric outer cylinder 94 as one of the narrow end plates of the parallel plate member.

Electrical cable 96 provides electric power connection for the motivating mechanism (not shown) for the rotatable primary antenna member 52. This mechanism may be housed inside of the inner cone 92, and connected to the primary member 52 through the drive shaft 53 (Fig. 21).

Figs. 19 and 20 show the construction of a parallel plate scanning antenna member in which the near end of the member has been formed into two cylindrical sections 98, 100. The inner cylinder 98 and the outer cylinder 100 are concentric, and have interposed between them the flat spirally curved linear reflecting surface 58. The wave guide channel is enclosed between the inner surface of the outer cylinder 100 and the outer surface of the inner cylinder 98, and terminates at its one end in the focal path opening 57 and at its other end in a rectangular slot in the wall of the outer cylinder 100. This channel is formed in the same manner as the channel of the previously described conical member of Figs. 17 and 18. As in that case, the wave channel, that is enclosed by the flat parallel plates, is aligned with this rectangular slot to extend the channel from the focal path opening 57 to the mouth aperture 68.

In order to facilitate the transfer of radio frequency energy from the rotating primary member 52 to the focal path opening 57 the arrangement of Fig. 21 may be adopted. The wave guide coupling member 83 serves to connect the wave guide 51 to the translation device 50 (Fig. 1). Any suitable rotary wave guide joint may be employed to connect the stationary wave guide member 51 to the rotating primary antenna member 52 through the rotating wave guide 84. Rotary motion is imparted to the primary antenna member 52 through the attached shaft 53 having at its far end (not shown) any suitable motivating mechanism the power for which is supplied by the electrical cable 96 (Fig. 19). To simplify the construction of the rotary primary antenna member 52 the focal path opening 57 of the wave guide channel enclosed between the outer and inner concentric conic sections may be converted from an annular opening to a cylindrical opening by means of the toroidal bend 38 which is secured through the addition of the end cap 85. In addition to extending and turning the focal path opening as indicated, the end cap 85 also provides support for the rotary member 52. In order to prevent the leakage of radio frequency energy around the edges of the rotary member 52, shorted quarter-wave slots 106 are provided to present a high impedance path for transmission in that direction.

In all of the previously described embodiments,

the dielectric lens 59, located between the parallel plates 60, 61 in the mouth aperture 68 of the parallel plate member may be provided with a quarter-wave matching ridge 99 at each of its two boundaries, as indicated in Fig. 22. This quarter-wave ridge acts as a matching transformer to reduce the discontinuity existing at the points where the dielectric lens meets the dielectric medium contacting its two faces.

With reference to Figs. 23 to 25 there is shown one preferred embodiment of the invention in a scanning antenna member such as would be suitable for alternate line scanning or for a lobe switching system. In this embodiment, two parallel plate reflecting antenna members, such as have been previously described, are so folded and conjoined that a single primary member 52 will, in a complete revolution, cause a linear scanning action of the axis of maximum radio frequency response at twice the rate of the previously described single units. In such a system each parallel plate antenna member has its near end containing its focal path opening 57, 57' fashioned into either a cylindrical or conical roll in accordance with the previously described consideration. However, instead of rolling the focal path opening into a nearly complete circular or annular shape, this opening is fashioned into a semi-circular shape as indicated in Fig. 23 by the section included between the reference points 69 and 70. The curved portions of the parallel plate members are then positioned such that the extreme outer end of the focal path opening of one unit is adjacent to the inner end of the focal path opening of the other unit, that is, the point 69 of focal path opening 57 is adjacent to point 70' of focal path opening 57'. The parallel plate region comprising the wide parallel plates 60, 61 may then be bent in such manner that the mouth orifices 68, 68' lie one above the other and are parallel if alternate line scanning in one direction is desired. Referring for the moment to Fig. 2, it will be recalled that as the primary antenna member 52 is moved along the focal path opening 57 from point 69 to point 70, the axis of maximum response of the radio frequency energy sweeps a sector in front of the mouth aperture 68 in a left to right direction as viewed in that figure. It will be noted in Fig. 23 that the semicircularly curved focal path openings 57 and 57' may be so formed and united that for clockwise rotation of the primary member 52 (Fig. 25) the focal path openings are traversed in a direction from numeral 70 to numeral 69 instead of from numerals 69 to 70 as was previously the case. This motion corresponds to scanning action in the mouth orifice in a left to right direction from reference numerals 108 to 119 of Fig. 24. Therefore, for one complete revolution of the primary antenna member 52, starting at the end 70' of the focal path opening 57', the beam will sweep from left to right, in a direction from numerals 108 to 119 in the mouth orifice 68' as the primary member moves from point 70' to point 69'. As the primary member moves from point 69' to point 70, the beam will leave the mouth orifice 68' at its right extremity 110, and reappear in the upper mouth orifice 68 to repeat its left to right motion as the primary antenna member moves to point 69. As the member 52 moves from point 69 to point 70' the beam will leave the upper mouth orifice 68 to reappear at the left edge of the lower mouth orifice 68' to repeat the cycle. It is evident that the parallel plate region of the two parallel plate members may be so aligned that the beams will be parallel,

diverging or converging as may be desired. It is also apparent that alternate line scanning in opposite directions may be accomplished by suitably positioning the parallel plate members one with the other.

Fig. 25 indicates the manner in which the rotatable primary antenna member 52 is associated with the combined parallel plate member to form the alternate line scanning system previously described. The focal path openings 57, 57' may be converted from semicircular to cylindrical openings through the use of a single end cap 85 containing the toroidal band 88 (Fig. 21). As in the previously described embodiment, numeral 50 indicates any suitable radio frequency energy translation device coupled to the alternate line scanning system by means of the wave guide 51 and wave guide coupling unit 83 as indicated.

Although this invention has been described with reference to single and double line scanning members employing concentrically disposed conical and cylindrical elements, it should be appreciated that it should not be considered as limited thereto, since other applications thereof, not departing from the spirit and scope of the invention will readily occur to those skilled in the art.

What is claimed is:

1. An electromagnetic wave guiding structure comprising a pair of like substantially quasi-triangular conductive plates, said plates being positioned in parallel relation to each other with their corresponding edges in alignment with each other, two of the edges of each of said plates being at an angle of approximately 90 degrees with respect to each other, the third edge of each of said plates making substantially equal angles with respect to each of the first-mentioned two edges of each of said plates, a first orifice constituting an output orifice and comprising the space between one pair of said first two edges of said plates, a second orifice constituting an input orifice and comprising the major portion of the space between the other pair of said first two edges of said plates and a conductive reflecting strip member joining the said third edge of each of said pair of parallel conductive plates, whereby energy introduced into any point along said second orifice will be reflected by said strip member to said first orifice.

2. The structure of claim 1, in which a portion thereof is of curved shape to impart to said second orifice an annular shape and a rotating feed member adapted to progress by rotation along the annularly shaped orifice.

3. The structure of claim 2, in which said curved portion is conical.

4. The structure of claim 2, in which said curved portion is cylindrical.

5. A high frequency electromagnetic waveguide horn having an input orifice and an output orifice, said orifices lying in planes which are substantially perpendicular to each other, a reflecting side member, the plane of which side member makes substantially equal angles with said planes of said orifices, and enclosing members defining a wave-guide channel of constant depth interconnecting said input orifice and said reflecting member and said output orifice, a portion of said horn including said input orifice being curved to impart an annular shape to said input orifice.

6. The structure of claim 5, in which the curved portion has the form of a right circular cylinder.

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7. The structure of claim 5, in which the curved portion is of conical shape.

8. The structure of claim 5, and a rotatable feed member positioned adjacent said annular input orifice and arranged to inject electromagnetic wave energy into said orifice at successive points therealong as said feed member is rotated.

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