June 10, 1952 W. E. KOCK 2,599,763

DIRECTIVE ANTENNA SYSTEM

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FIG. 1
(PRIOR ART)

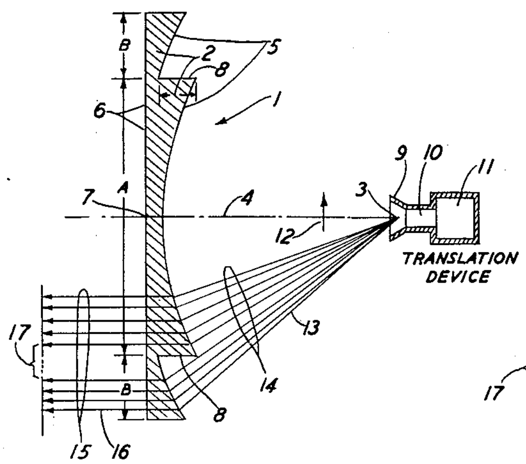

FIG. 2
(PRIOR ART)

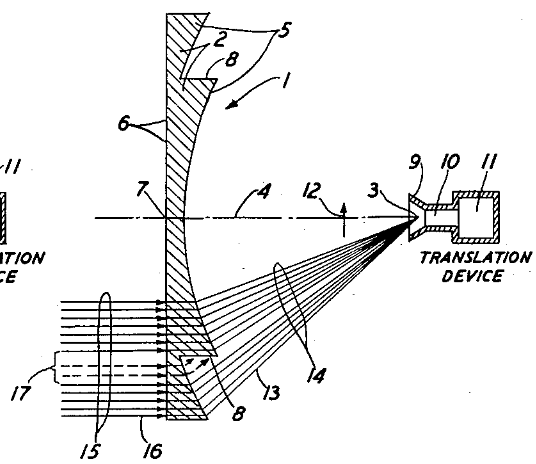

FIG. 5
H-PLANE DIRECTIVE PATTERN OF SYSTEM OF FIG. 3

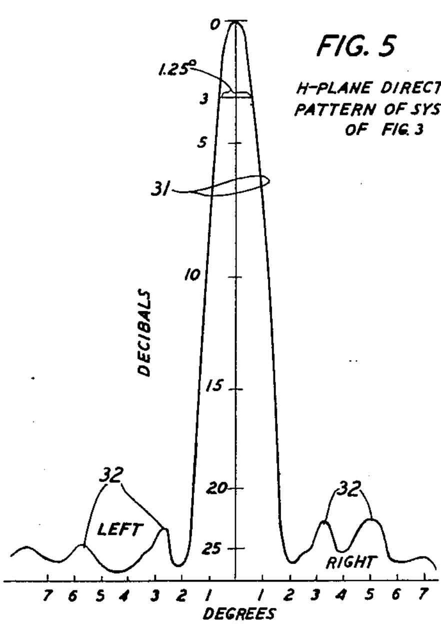

FIG. 6
E-PLANE DIRECTIVE PATTERN OF SYSTEM OF FIG. 3

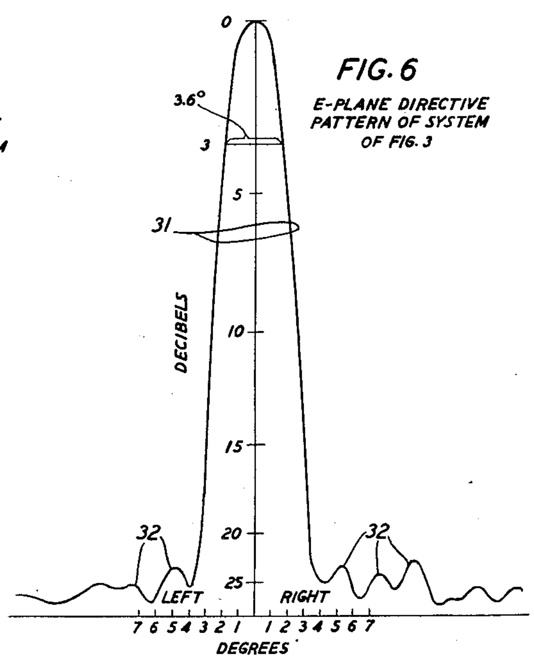

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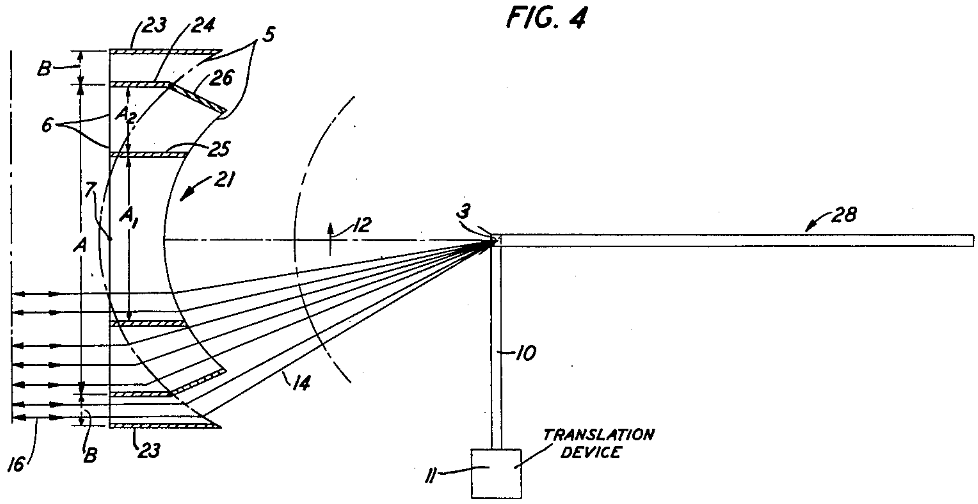
FIG. 4



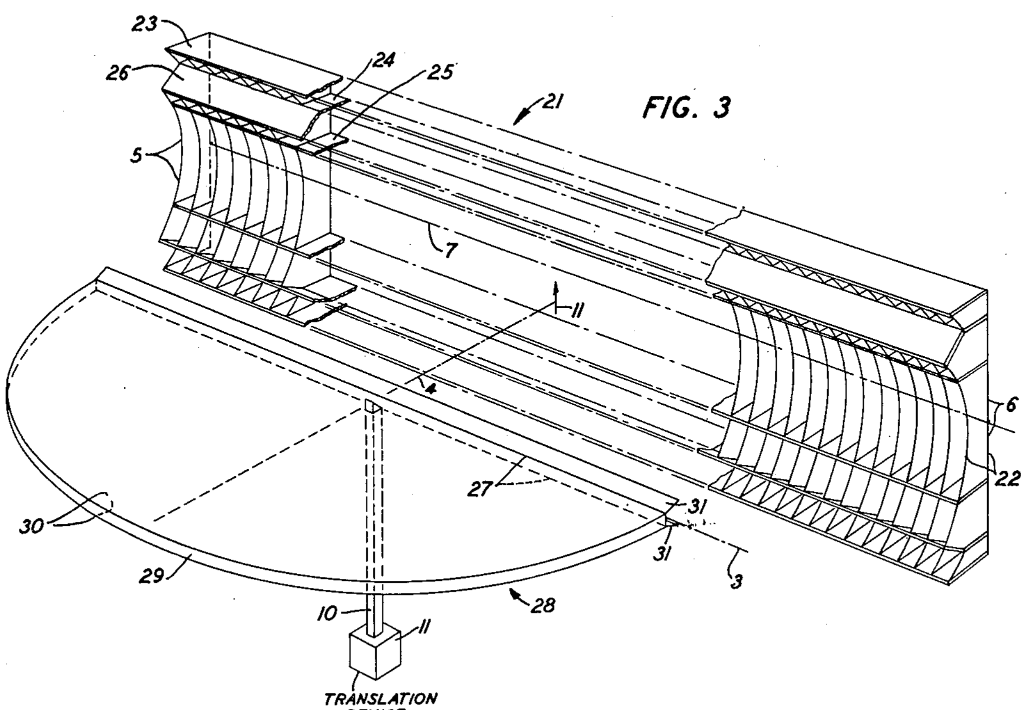


FIG. 3

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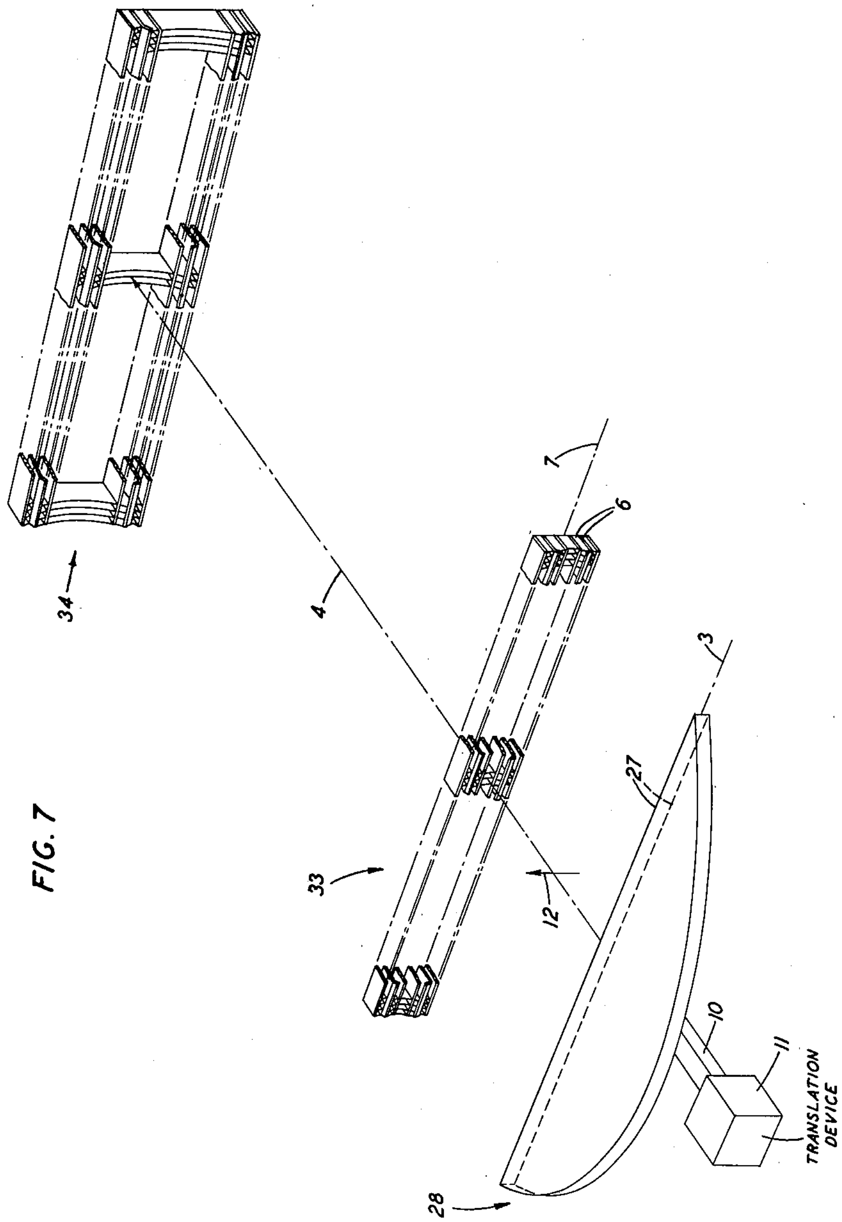

FIG. 7

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FIG. 8

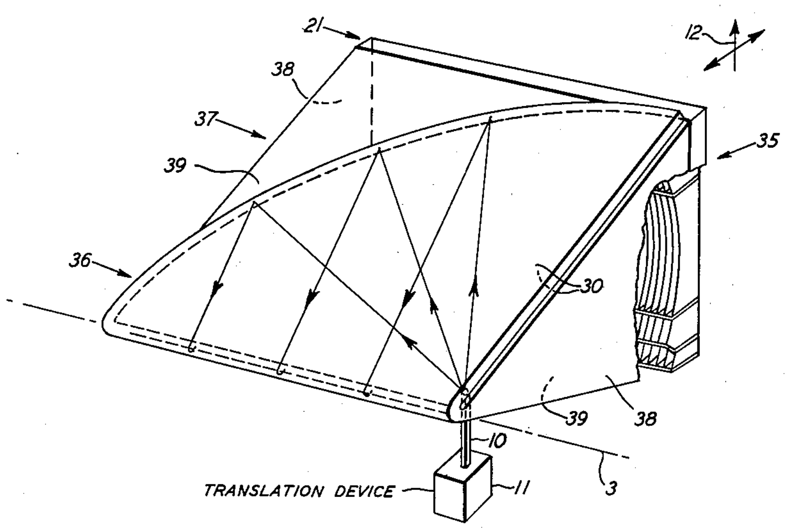


FIG. 9

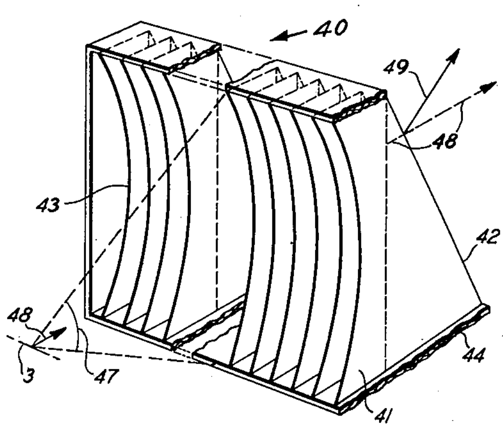


FIG. 10

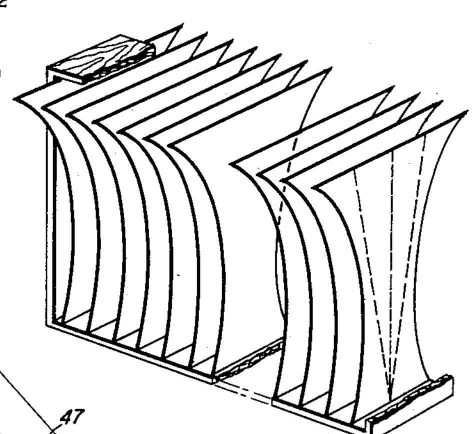
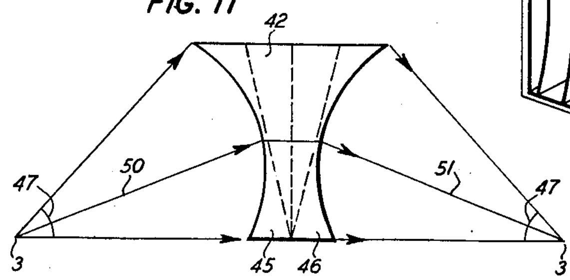


FIG. 11



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Patented June 10, 1952

2,599,763

UNITED STATES PATENT OFFICE

2,599,763

DIRECTIVE ANTENNA SYSTEM

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Application December 31, 1948, Serial No. 68,542

8 Claims. (Cl. 250—33.63)

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This invention relates to directive antenna systems and particularly to metallic refractors of the wave guide type for use in such systems.

This application is a continuation-in-part of my copending application for "Radio Relay Systems," Serial No. 5,952, filed February 3, 1948, which matured into United States Patent 2,530,826, granted November 21, 1950.

As is known radio lenses having one or more stepped zones, such as the solid dielectric lenses disclosed in Patent 2,283,935 to A. P. King and in the copending application of A. M. Skellett, Serial No. 717,214, filed December 19, 1946, now United States Patent 2,547,416 issued April 3, 1951, and the metallic lenses disclosed in my copending application, Serial No. 642,723, filed January 22, 1946, have been suggested for use in directive antenna systems. Also, radio reflectors having one or more zones, such as the reflectors disclosed in Patent 1,906,546 to R. H. Darbord have been proposed for use in such systems. In certain of the aforesaid lens systems heretofore utilized the directive action is sometimes impaired by reason of the so-called shadow effect and the diffraction effect at the steps, or zone peripheries, of the lens. The shadow effect, if pronounced, is especially detrimental since it may cause the establishment of large undesired minor lobes. While, as explained on page 26 of my above-mentioned application, Serial No. 642,723, the shadow and diffraction effects of the steps may be reduced somewhat by utilizing intermediate stepping, rather than high or low stepping, it now appears desirable to eliminate the shadow effect in multiple zone lenses of both the circularly symmetrical and cylindrically symmetrical types, in a more complete manner, than heretofore accomplished.

It is one object of this invention to obtain, in a lens antenna, a directive pattern having negligible minor lobes.

It is another object of this invention to eliminate shadow effects in a stepped cylindrically symmetrical metallic lens.

It is another object to obtain, as a manufacture, a compact, easily constructed compound radio refractor comprising a metallic lens and a metallic prism.

In accordance with one embodiment of the invention the first or central zone and the zone adjacent thereto, of a multiple zone cylindrically symmetrical metallic lens, such as that illustrated by Fig. 21 of my above-mentioned application, Serial No. 642,723, are separated by a narrow flat metallic plate extending parallel to

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the optical axis of the lens. An inclined metallic plate is attached to the narrow plate and forms with the narrow plate an obtuse dihedral angle. The inclined plate is included, substantially, in a plane containing the focal line of the lens. Also, a wide flat metallic plate is positioned between the narrow plate and the longitudinal axis of the front face of the lens. The three plates extend perpendicular to, and intersect, the spaced metallic members forming the lens. In operation, the intermediate lens section included between the wide plate and the two attached plates functions as a sectoral horn, and substantially no shadow effect is produced.

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

Figs. 1 and 2 are explanatory side views of a metallic lens in which prior art low stepping is utilized;

Figs. 3 and 4 are respectively perspective and side views of a directive antenna system comprising a metallic lens constructed in accordance with the invention;

Figs. 5 and 6 are respectively H-plane and E-plane directive patterns for the system of Fig. 3;

Fig. 7 is a perspective view of another directive antenna system comprising a pair of lenses each similar to the lens included in the system of Fig. 3;

Fig. 8 is a perspective view of still another directive antenna system comprising a single lens similar to the lens included in the system of Fig. 3;

Fig. 9 is a perspective view of a compound metallic refractor constructed in accordance with the invention and comprising a focussing section and a non-focussing section; and

Figs. 10 and 11 are respectively perspective views and side views of another compound metallic refractor constructed in accordance with the invention.

Referring to Figs. 1 and 2, the cylindrical symmetrical plano-concave metallic lens **1** comprises a plurality of spaced stepped metallic members or walls, such as the typical wall **2** shown in cross-section. The lens has two zones A and B, a focal line **3**, an optical or electromagnet axis **4**, an elliptically concave back face **5** and a plane front face **6**. Reference numeral **7** denotes the longitudinal axis, which intersects the optical axis **4**, of the plane front face **6**. The step **8** between zones A and B is a "full wave length" and is of the flat or low type extending parallel to the optical axis. Except for the number of zones and the type of stepping, the lens 1 is the same as that illustrated by Fig. 21 of my copending application, Serial No. 642,723. Numeral 9 denotes a line type antenna, or more specifically, a sectoral horn which is connected by a wave guide 10 to a translation device 11 which may be a transceiver, a transmiter or a receiver. The throat aperture of the sectoral horn 9 is aligned with the focal line 3 of the metallic lens 1.

In operation, Fig. 1 assuming the device 11 is a transmitter and that the electric polarization 12 of the wavelets is parallel to the walls 2, the rays 13, emitted by the horn 9 along the radial directions and forming a diverging beam 14, are refracted by the lens 1 so as to form a beam 15 of parallel rays 16. As is apparent from Fig. 1, the step 8 is positioned between the focal line 3 and a portion of the concave face of zone B, that is, the step 8 shadows a part of zone B so that the outgoing parallel beam 15 contains a "hole" or null portion 17. As a result, the transmitting E-plane directive pattern may contain a null and hence a pronounced minor lobe. Similarly, in reception, Fig. 2, the parallel rays 16 in the portion 17 of the incoming beam 15, after passing through zone B, are intercepted by the step 8 and hence do not reach the focal line 3 and horn 9, so that the incoming converging beam 14 does not contain the intercepted energy. This loss in received energy results in objectionable minor lobes.

Referring to Figs. 3 and 4, the cylindrically symmetrical metallic plano-concave lens 21 comprises a plurality of flat metallic members or walls 22 extending parallel to the electric polarization 12 and spaced apart at least one half of the operating wavelength. The lens has a central zone A and an outer zone B, the stepping between zones being substantially a wavelength and the curvature of the concave surface of each zone being elliptical, as explained in my copending application Serial No. 642,723. The lens 21 is equipped with flat metallic top and bottom plates 23 extending parallel to the longitudinal axis 7 of the front face 6 and the electromagnetic axis 4 of the lens; and each of these plates intersects the extremities of the metallic wall members 22. Numeral 24 denotes a flat narrow metallic plate separating zones A and B and numeral 25 designates a flat wide metallic plate positioned in zone A between the narrow plate 24 and the longitudinal axis 7 of the front face 6 of lens 21. A flat inclined metallic plate 26 is attached to the back edge of the narrow plate 24 and forms therewith an obtuse angle. The inclined plate is included in a plane containing the focal line 3 of lens 21. All three plates intersect at right angles the plano-concave plates 22 constituting the lens 21 and extend parallel to the longitudinal axis 7 of the front face 6. As is apparent from Fig. 4, the lens section A2 formed by the wide plate 25 and the two plates 24 and 26, taken together, constitutes in effect a horn section flared in the plane of electric polarization or E-plane 12 and not flared in the plane of magnetic polarization or H-plane.

The focal line 3 of the cylindrical lens 21 is aligned with the axis of the substantially linear orifice 27 of a conventional line type "pill-box" ("parallel plate") feed antenna 28. The feed antenna 28 comprises a short cylindrical parabolic reflector 29, the flat parallel end plates 30 and the flares 31, the flares 31 being attached to the longitudinal edges of the antenna orifice 27. The guide 10 has an open end facing, and positioned at or near, the short focal line of the parabolic reflector 29.

In transmission, energy supplied by device 11 over guide 10 to the open end of guide 10 is reflected by the parabolic reflector 28 and a cylindrical wave front having a cylindrical axis coincident with the long focal line 3 is emitted by the parallel plate antenna 28. By reason of the parabolic curvature of the reflector 29 in the H plane the emitted beam is exceedingly narrow in this plane. The cylindrical wave front emanating from the line antenna 28 is converted to a plane front by the lens 21 and, by reason of the refractive effect in the E plane 12 of the lens 21, the beam outgoing from the system 28, 21 is exceedingly narrow in the E plane. In reception, the converse operation is obtained by reason of the theorem of reciprocity.

In more detail, zone B and section A_1, Fig. 4, of zone A function as conventional phase-advance lens sections and section A_2 of zone A functions as a phase-advance lens and also as a horn, that is, the wave front in section A_2 gradually expands. By reason of the presence and orientation of the metallic plates or separators 24 and 26, and the horn action of section A_2, diffraction and shadow effects are substantially eliminated. As shown in Fig. 4, all of the diverging or converging rays 14 and all of the parallel rays 16 pass through the lens 21, and no portion of either zone A or B is shadowed by the zone stepping.

It should be pointed out here that, in accordance with the invention, metallic separators corresponding to flat plate 26 may be included between the zones of a circularly symmetrical lens having a point focus, for the purpose of preventing shadow effects. In the case of a circularly symmetrical lens the inclined plate, corresponding to the plate 26, has a conical shape.

Figs. 5 and 6 illustrate respectively the measured H-plane and E-plane directive patterns of a system constructed in accordance with Figs. 3 and 4. As shown on the drawing the major lobes 31 of the H-plane and E-plane patterns are relatively narrow, the widths, taken at the half-power of three-decibel point, of the H-plane major lobe and the E-plane major lobe being respectively 1.25 and 3.6 degrees. Also, by reason of the fact that the separators 24, 25 and 26 function to eliminate diffraction and shadow effects, the patterns of Figs. 5 and 6 do not include a large "shadow" minor lobe, and the actual minor lobes 32 of each pattern are more than twenty decibels below the major lobe and therefore negligible.

Fig. 7 illustrates a double lens system for securing an E-plane major lobe half power width which is smaller than that shown in the pattern of Fig. 6 and comparable to the H-plane major lobe half power width shown in the pattern of Fig. 5. In the system of Fig. 7 the focal line 3 of a small cylindrically symmetrical lens 33 constructed in accordance with the invention is aligned with the longitudinal axis of the linear orifice 27 of the pill-box antenna 28. The focal line of the large cylindrically symmetrical lens 34, also constructed in accordance with the invention, is aligned with longitudinal axis 7 of the front face 6 of the small lens 33. In the H plane, parallel to the focal line 3, the directive pattern for the system 28, 33 and 34 is essentially the same as that of the system of Fig. 3. In the

E plane containing the polarization 12, the small lens 33 converts the circular wave front emanating from the orifice 27 to a linear front. This linear front, however, appears to be circular rather than linear at a point remote from lens 33, such as the location of lens 34. The lens 34 changes this circular front to a linear front, whereby the directive action in the E plane is enhanced. In reception, in the E plane the large lens 34 focusses the waves on the axis 7 of the small lens 33 and the small lens 33 refocusses the waves on the longitudinal axis of the orifices 27 of the feed antenna 28.

The antenna system 35 of Fig. 8 comprises a cylindrical lens 21 constructed in accordance with the invention, a half pill-box feed antenna 36, and a horn 37 connecting the lens 21 and the orifice of the half pill-box 36. The horn 37 is flared in the E plane and comprises the flared metallic side members 38 and the non-flared metallic side members 39. As shown on the drawing, one of the two parallel plate members 30 of the pill-box antenna 36 extends around the edge of the other parallel plate member and the half pill-box is positioned on, or folded back upon, one of the wide horn walls 39, whereby the orifice of the half pill-box faces the lens 21 and the pill-box extends towards the lens 21. As in the systems of Figs. 3 and 7, the open end of guide 10 is positioned at the focal line of the short parabolic reflector included in the half pill-box. As is believed to be apparent from the description of Fig. 3, in operation, the system 35 produces a major lobe having a narrow width in the E plane and a narrow width in the H plane, the minor lobes in both planes being insignificant. The shields or horn sides enhance the directive effect and also prevent interference from undesired waves.

Figs. 9 and 10 illustrate compound refractors which are especially suitable for use in relay systems such as that disclosed in my copending application of which the present application is a continuation in part. The refractor 40, Fig. 9, comprises a focussing section or plano-concave lens 41, such as that disclosed and claimed in my above-mentioned copending application Serial No. 642,723, and a non-focussing or prism section 42 such as that disclosed in my copending application Serial No. 642,722, filed January 22, 1946, now Patent No. 2,588,249, issued March 4, 1952. Each section comprises a plurality of spaced metallic plates 43 and each plate is common to both sections so that, while from an electrical or refractive standpoint, the two sections are distinct, the two sections are not distinct considered from a mechanical or physical standpoint. The plates are held in position by the wooden members 44. In the embodiment of Fig. 10, the prism section 42 is in a sense included between two thin plano-concave lenses 45 and 46, as more clearly shown in Fig. 11.

In operation, Fig. 9, the lens 41 functions to convert the cylindrical front 47 originating at the line focus 3 to a plane front having a propagation direction 48 and the prism section functions to change the direction of propagation from direction 48 to direction 49. Similarly, in the system of Figs. 10 and 11, the lens section 45 operates to convert the cylindrical wave front 47 originating at the left focal line 3 to a plane wave front and the right lens section changes the plane front to a cylindrical front converging on the right focal line 3. The intermediate prism section 42 changes the propagation direction from the mean direction 50 incoming to lens 45 to the mean direction 51 outgoing from lens 46.

Although the invention has been explained in connection with certain specific embodiments it is to be understood that it is not to be limited to the described embodiments since other apparatus may be successfully employed in practicing the invention.

What is claimed is:

1. In an electromagnetic wave refractor comprising at least two stepped zones, a metallic plate shaped to conform to a zone contour line of said refractor, said plate being included between and completely separating two of said stepped zones.

2. An electromagnetic wave metallic lens for focussing waves having a given electric polarization, said lens comprising an assembly of a plurality of plane metallic walls extending parallel to said polarization and spaced apart uniformly in a direction perpendicular to said polarization one set of edges of said metallic walls being linear and being included in and defining a plane surface, said plane surface having a longitudinal axis, the opposite set of edges of said metallic walls being concave and stepped and being included in and defining a stepped cylindrically concave surface, the variation of the distance between said one set of edges and said opposite set of edges, in the direction of polarization, being proportioned to focus a plane wave, impinging perpendicularly upon said plane surface, along a focal line spaced from and on the concave side of said assembly, said stepped concave surface having a central zone and a stepped zone adjacent thereto, a flat metallic plate included between and completely separating said zones and intersecting said walls.

3. A lens in accordance with claim 2, and another flat metallic plate extending parallel to said first-mentioned plate, said other plate intersecting said metallic walls and positioned between said longitudinal axis and the first-mentioned flat metallic plate.

4. A lens, in accordance with claim 2, and another flat metallic plate attached to said first-mentioned plate and forming therewith an obtuse dihedral angle, said other plate being included in a plane containing said focal line, substantially.

5. A cylindrically symmetrical rectangular electromagnetic wave metallic lens for focusing waves having a given electric polarization, said lens having a focal line, said lens comprising a plurality of metallic walls extending parallel to said polarization and spaced apart uniformly in a direction perpendicular to said polarization one set of edges of said metallic walls being linear and being included in and defining a plane surface, said plane surface having a longitudinal axis, the opposite set of edges of said metallic walls being concave and stepped and being included in and defining a stepped cylindrically concave surface, said concave surface having a central zone and a stepped zone adjacent thereto, a first flat metallic plate included between and completely separating said zones and intersecting said walls, a second flat metallic plate extending parallel to said first plate, said second plate intersecting said metallic walls and positioned between said first plate and the longitudinal axis of said front plane surface, and a third flat metallic plate attached to the said first plate and forming therewith an obtuse di-

hedral angle, said third plate being included in a plane containing said focal line, substantially.

6. In combination, a lens in accordance with claim 5, and a cylindrical parabolic reflector having a focal line perpendicularly intersecting the focal line of said lens.

7. In combination, a lens in accordance with claim 5, a parallel plate line antenna comprising a cylindrical parabolic reflector and a pair of parallel plates attached to said reflector, said plates and reflector forming an elongated rectangular orifice, said orifice having a pair of short edges and a pair of long edges, the focal line of said lens being aligned with the longitudinal axis of said orifice, a horn comprising a pair of flared side members and a pair of non-flared side members, said pair of flared horn side members extending from the pair of short edges of said orifice, respectively, to the outermost left and right metallic walls of said lens, respectively, and said pair of non-flared horn side members extending from the upper and lower long edges of said orifice, respectively, to the upper and lower sets of ends of said plurality of metallic walls, respectively, of said lens, whereby said lens is positioned at the mouth orifice of said horn.

8. In combination, a first and a second cylindrically symmetrical metallic lens each constructed in accordance with claim 5, a line antenna having a substantially linear orifice and comprising a cylindrical parabolic reflector having a focal line, a wave guide connected to a translation device and having an aperture at said focal line of said reflector, the first lens being positioned between the second lens and said line antenna, the front plane surfaces of both lenses facing away from said reflector, the focal line of the second lens being aligned with the longitudinal axis of the front plane surface of the first lens and the focal line of the first lens being aligned with the longitudinal axis of said linear orifice.

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