

**Nov. 30, 1954**

**W. D. LEWIS**

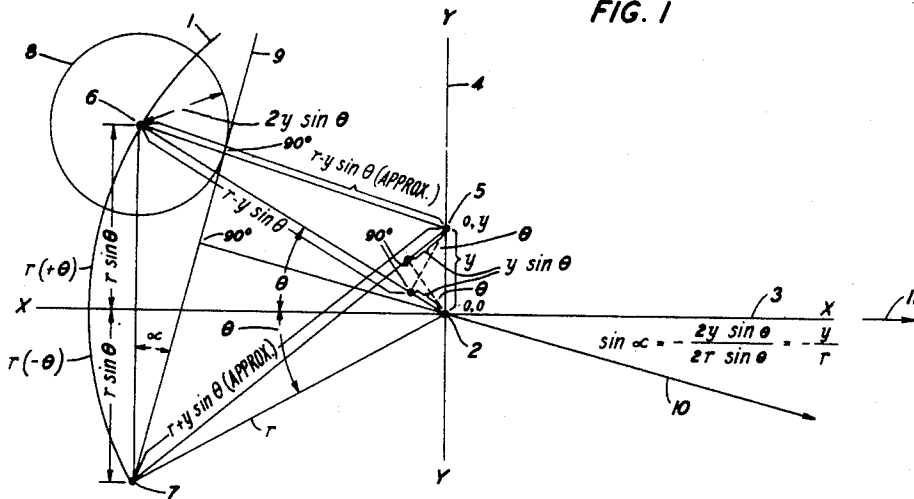
**2,695,958**

## DIRECTIVE ANTENNA SYSTEM

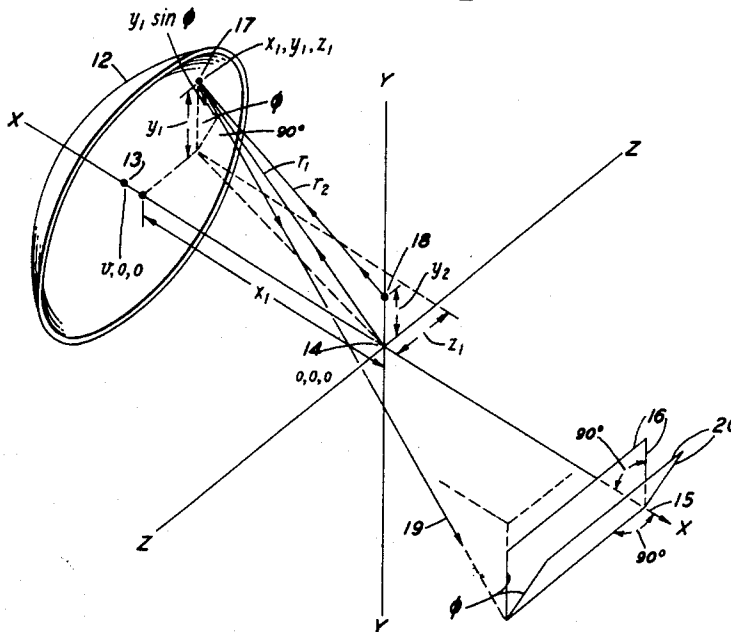
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5 Sheets-Sheet 1

**FIG. 1**



**FIG. 2**



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DIRECTIVE ANTENNA SYSTEM

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5 Sheets-Sheet 2

FIG. 3

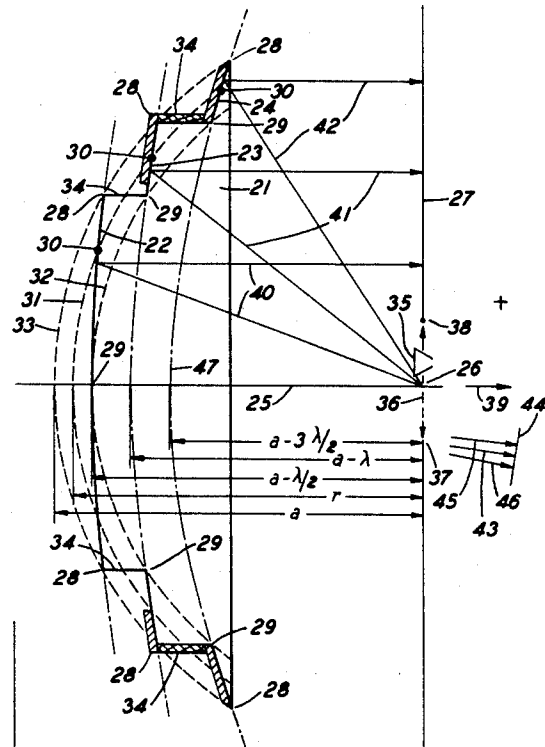
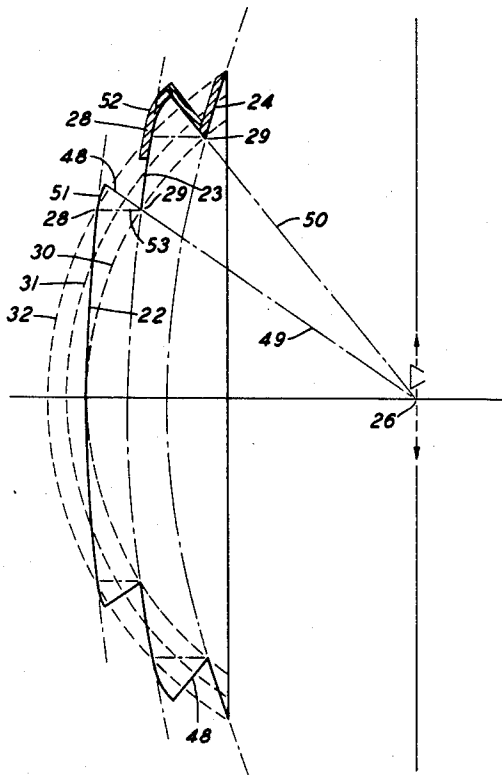


FIG. 4



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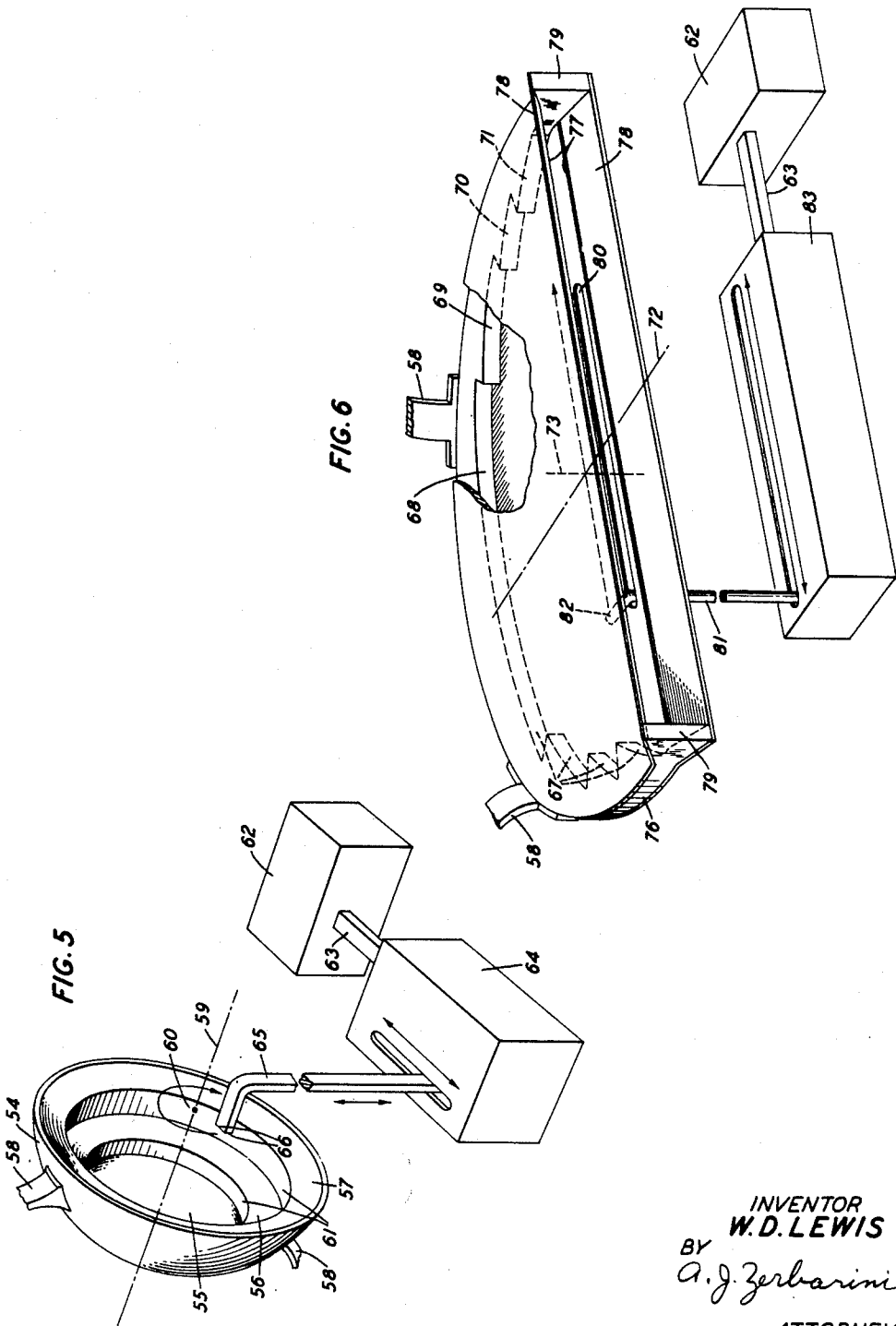
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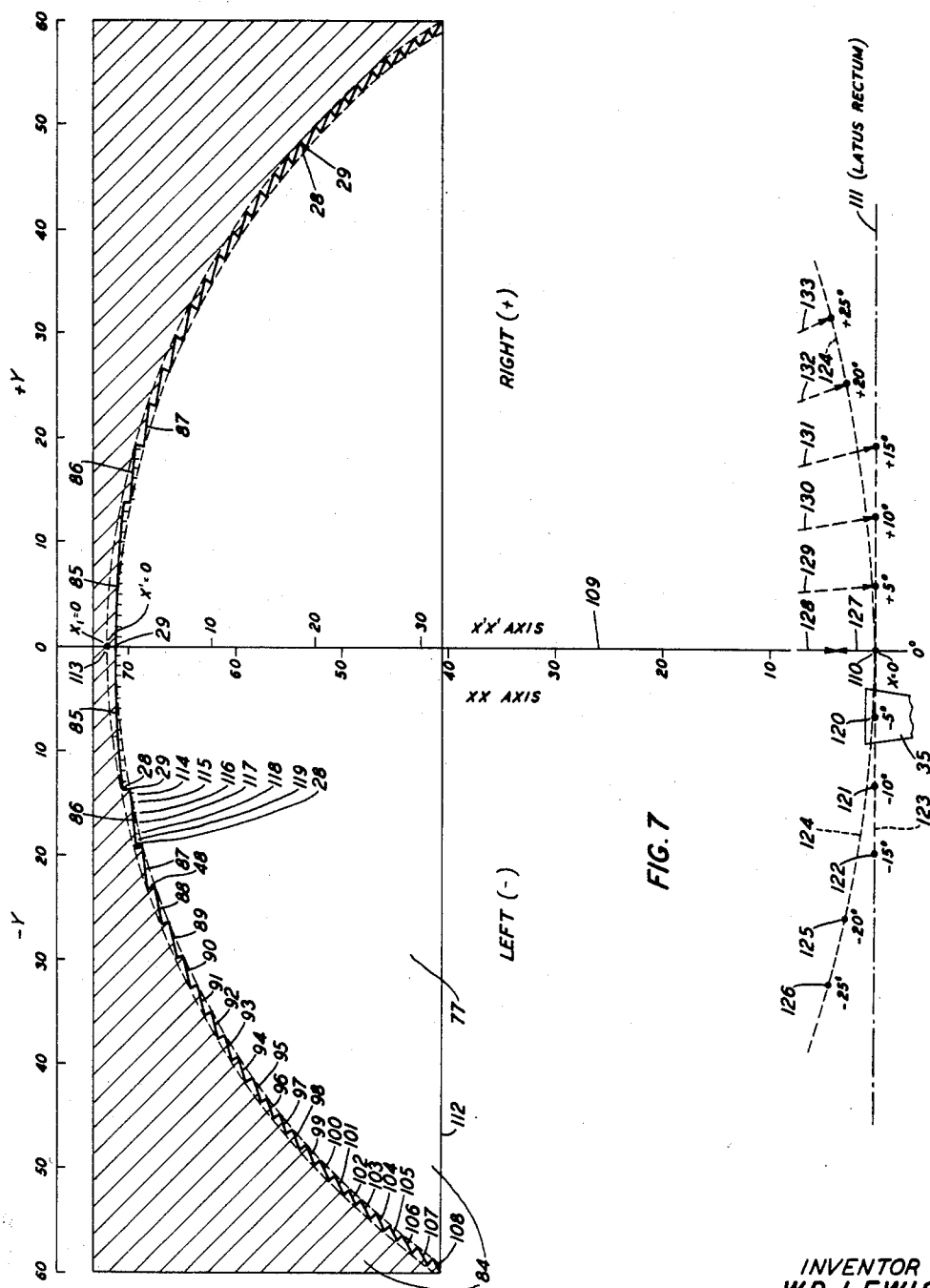
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## DIRECTIVE ANTENNA SYSTEM

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DIRECTIVE ANTENNA SYSTEM

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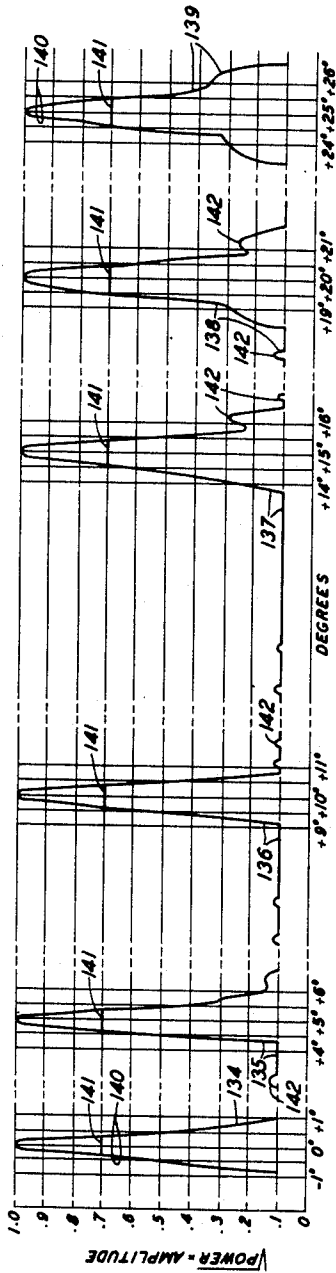


FIG. 8

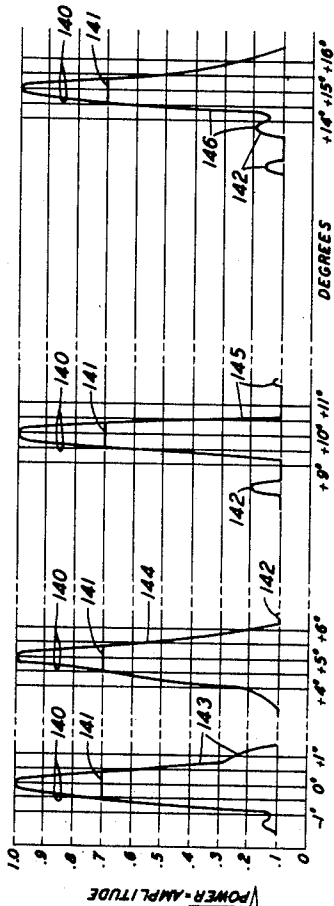


FIG. 9

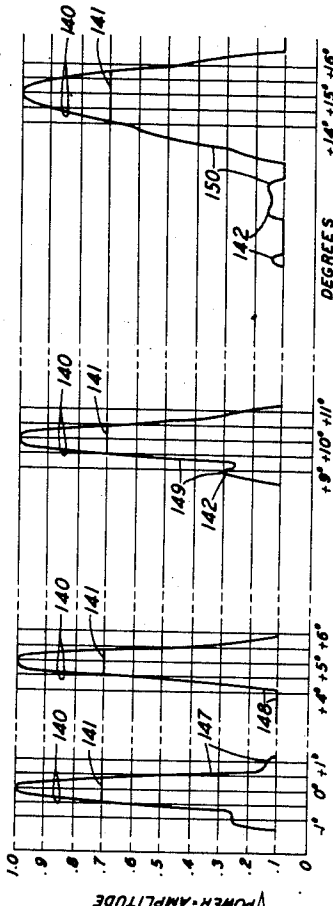


FIG. 10

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2,695,958

## DIRECTIVE ANTENNA SYSTEM

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Application July 31, 1944, Serial No. 547,396

10 Claims. (Cl. 250—33.65)

This invention relates to antenna systems and particularly to directive antenna systems.

As is known, antenna systems comprising a conventional oscillating or rocking parabolic reflector and a primary antenna member positioned at the focus, and systems comprising a stationary parabolic reflector and a primary antenna movable through or about the focus, have been suggested for use in radar systems of the scanning type. Also parabolic reflectors associated with a pair of alternately energized primary antennas displaced equally from the focus have been used in radar systems of the lobe switching type. In the scanning arrangements utilizing parabolic reflectors the three requirements of rapid scan, wide scanning angle and high gain, in a sense oppose each other. For example, the gain is proportional to the size of the reflector aperture or diameter as measured in wavelengths. More specifically, the rocking reflector system is not always completely satisfactory because, assuming a large reflector aperture is used in order to secure a high gain, the large aperture prohibits rapid movement of the reflector. In the prior art scanning systems utilizing a conventional passive member, such as a parabolic reflector, and a primary antenna moving through the focus, while a fairly narrow beam or major lobe is secured with the primary antenna at the focus, the lobe widens, the gain decreases and the minor lobes become pronounced as the spacing between the focus and the primary antenna increases. In fact, when the primary antenna is displaced an amount sufficient to align the lobe axis with the extreme angular directions in the scanning sector, as in a wide scan system, the lobe often becomes bifurcated whereby ambiguous scanning obtains. As a result, scanning by means of a moving primary antenna has been satisfactorily achieved over only a relatively small angle or sector. Accordingly, it now appears desirable to secure a high gain system which permits rapid wide angle scanning.

It is one object of this invention to obtain, in an antenna system a steerable major lobe pattern the width of which remains substantially constant during movement of the lobe.

It is another object of this invention to secure, in an antenna system comprising a passive member having a focus and a primary antenna member displaced in a given plane from the focus, a directive pattern in said plane which is substantially the same as that obtainable in the aforementioned plane with a primary antenna at the focus.

It is a further object of this invention to secure in a radar antenna system comprising a reflective member having a focal point and a primary antenna moving about the focal point, a major lobe pattern in each plane containing the reflector axis which is substantially the same as that obtainable in said plane with the primary antenna at the focal point.

It is still another object of this invention to obtain, in a radar antenna system comprising a cylindrical parabolic reflector and a primary antenna oscillating along the latus rectum of the reflector, optimum scanning over a wide angular sector in the plane of oscillation of the primary antenna.

As used herein, the term "focus" is generic to "focal point" and "focal line" or "linear focus"; the term "phase" refers to "phase angle" and not to polarity; the term "propagation" is generic to "reception" and "emission"

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or "transmission"; and the term "conic" is generic to "parabola," "ellipse" and "hyperbola."

In accordance with one embodiment of the invention the antenna system comprises a plurality of coaxial, con-focal cylindrical parabolic zone reflectors or annular facets having focal lengths which differ a half-wave-length or a multiple thereof. The corresponding segmental portions, such as the approximate mid-points, of the zones are located on the circumference of an "inter-mediate" circle having its center on the common focal line of the zones. The outer edges of the zones lie on the circumference of an "outer" circle and the inner edges are positioned on the circumference of an "inner" circle, the three circles being concentric and the outer and inner circles having radii which differ preferably, but not necessarily, a half-wavelength. Considering any pair of intermediate adjacent parabolic zones and assuming the reflector comprises a large number of zones, the adjacent zone boundaries are connected together by plane non-reflective members extending parallel to the common axis of the zones. If the reflector comprises only a few zones the non-reflective members preferably extend along radii of the outer circle, the outside edge of each member being connected to the edge of the adjacent inner zone and the inside edge being connected to the edge of the outer zone by an elliptical reflector. One focus of the elliptical reflector is at the common focus of the parabolic zones and the other focus is at the edge of the inner zone.

A primary transceiving antenna member, such as a wave guide aperture, is positioned substantially in the common focal plane of the zones, and a translation device is connected to the primary antenna. Means are provided for oscillating the primary antenna along a substantially linear path aligned in part with the common latus rectum of the zones and having its mid-point superimposed on the common center of the aforementioned circles. The maximum displacement of the primary antenna, corresponding to one-half of the linear path, is relatively small as compared to the radius of the intermediate circle. In a modification, the path of oscillation is circular. Also, if desired, means for switching the primary antenna between two positions displaced from the focus may be used in place of the means for oscillating the primary antenna.

In transmission, wave components emitted by the primary antenna impinge on the zones and each zone taken by itself functions as a conventional parabolic reflector associated with an on-focus primary antenna.

Considering any pair of zones, the components are reflected in the same direction for a given position, on or off the focus, of the primary antenna since the zones are positioned on the circumference of a circle. The angle  $\alpha$  between the common direction of maximum radio action for a given position of the primary antenna and the common zone axis is dependent upon the position or displacement of the primary antenna and, if the displacement is zero, the common direction of action and the common zone axis are coincident. In addition, assuming for the moment that the primary antenna is at the focus, the wavelets propagated via all zones in a direction coincident with the common zone axis, and hereinafter termed the "on-axis" or "axial direction," combine in phase agreement, inasmuch as the focal length of the two zones differ a half-wavelength or any multiple thereof. Stated differently, for the condition just assumed, the wavelets produce a plane wave front parallel to the latus rectum. Also, by reason of the aforementioned differences in the zone focal lengths, the wavelets combine to produce a wave front, which is substantially plane and perpendicular to the off-axis direction when the primary antenna is displaced from the focus and the axis of the major lobe of the system is aligned with an off-axis direction. The elliptical reflector functions to eliminate the small aberration or so-called edge effect produced at the inner edge of each intermediate zone.

In accordance with another embodiment of the invention, the antenna comprises coaxial paraboloidal zones having a common focal point and means for moving the primary antenna along a linear path containing the focal

point, or means for moving the primary antenna about the focal point and along a curvilinear path such as a circular or elliptical path. In this embodiment the approximate mid-points of the zones are spaced on the surface of a sphere having its center on the common focal point. If the reflector comprises a large number of zones the adjacent zones are preferably connected by means of non-reflective members corresponding to sections of right cylinders having a common axis and different diameters. If the reflector includes a large number of zones the adjacent zones are connected by two contiguous members, one of which is aligned with the radius of the sphere and is shaped like a truncated cone, and the other of which corresponds to a surface of revolution formed by rotating a section of an ellipse about its focus at the center of the sphere.

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

Figs. 1 and 2 are diagrams used for explaining the invention;

Fig. 3 is a diagrammatic sectional view of one embodiment of the invention;

Fig. 4 is a diagrammatic sectional view of another embodiment of the invention;

Fig. 5 is a perspective view of a reflector constructed in accordance with the invention and comprising paraboloidal zones;

Fig. 6 is a perspective view of a reflector constructed in accordance with the invention and comprising cylindrical parabolic zones;

Fig. 7 is a sectional view of a zoned parabolic reflector comprising a large number of zones; and

Figs. 8, 9 and 10 illustrate measured directive curves for the system of Fig. 7.

Referring to the two-dimension diagram of Fig. 1, reference numeral 1 denotes a curve of the equation

$$r=r(\theta)=r(-\theta) \quad (1)$$

where, in polar coordinates  $r$  is the radius vector and  $\theta$  the vectorial angle. Reference numeral 2 denotes the pole or origin having the rectangular coordinates  $o, o$  and numerals 3 and 4 denote, respectively, the XX or polar axis and the YY axis. Numeral 5 designates the position of a primary antenna or a source which moves along the YY axis. The position 5 has the rectangular coordinates  $o, y$ . Now by design

$$y \ll r \quad (2)$$

so that the distance  $d_6$  from the source 5 to point 6 on curve 1 is, as shown in Fig. 1, approximately equal to

$$r-y \sin \theta \quad (3)$$

and the distance  $d_7$  from source 5 to point 7 on curve 1 is approximately equal to

$$r+y \sin \theta \quad (4)$$

Hence,

$$d_7-d_6=2y \sin \theta \quad (5)$$

Consequently, assuming curve 1 represents a reflector, when a spherical wave front starting from point 5 has just reached point 7 it has, by reason of reflection or reradiation, reached points on a circle 8 having its center at point 6 and a radius equal to  $2y \sin \theta$ . Hence the wavelets reflected by the pair of elemental portions 6 and 7 form a plane wave front as shown by line 9 which is drawn from point 7 tangent to circle 8. Stated differently, the wavelets reflected at points 6 and 7 are cophasal for the propagation direction 10 which is perpendicular to the wave front 9 and forms with the XX axis an angle  $\alpha$  whose sine is equal to

$$\frac{2y \sin \theta}{2r \sin \theta} = \frac{y}{r} \quad (6)$$

It may be noted by way of explanation that if the reflector corresponding to curve 1 were a conventional parabolic reflector, and if the source 5 were at the focus or origin 2, the radius vector  $r$  would vary and wavelets reflected by its various elemental reflector portions would be cophasal for the single direction coincident with the XX axis. Hence a narrow major lobe would be secured. With the source displaced from the origin 2, however, certain wavelets reflected by the hypothetical parabolic reflector completely reinforce or agree in phase for several di-

rections and a wide major lobe is obtained. The width of the lobe is related to the displacement of the source and, assuming the source moves along the YY axis, the lobe width varies as the source moves. Also, if the reflector were circular the center of the circle being at 2, that is, if  $r$  is made equal to a constant, the two wavelets reflected by every pair of segments, such as 6 and 7, would be cophasal for direction 10, but the wavelets reflected by the various sets or pairs of segments would not be in phase. In accordance with the invention, the segments or zones of the reflector are, considering the  $x$  and  $y$  planes and disregarding for the moment the  $z$  plane, (1) arranged on the circumference of a circle having a radius vector  $r$  equal to a constant  $k$ , whereby the wavelets reflected by each pair of corresponding zones combine in phase for the single direction 10 when the source is at  $o, y$ . The equation for the circle is

$$x^2+y^2=k^2 \quad (7)$$

As shown below, the segments or zones comprise coaxial confocal parabolic sections whereby, with the source at the focus 2, the wavelets are in exact phase agreement for direction 10. With the source displaced from the focus as, for example at 5, the wavelets are in substantial phase agreement for the principal direction of action, for example, direction 10. Accordingly, in the plane containing the reflector axis and the linear path traversed by the source, the zones should be arranged on the circumference of a circle having its center at the intersection of the reflector axis and the path.

Referring to the three dimension diagram of Fig. 2, it will now be shown that, considered in the solid, the zones should lie on the surface of sphere having its center at the aforementioned intersection or focus. Reference numeral 12 denotes a reflector having its axis aligned with the XX axis, a vertex 13 at point  $v, o, o$ , and a focal plane parallel to the YZ plane. With the primary antenna at the origin 14, the major lobe or beam is, as shown by arrow 15, parallel with the XX axis and the wave front 16 is perpendicular to the XX axis. Numeral 17 denotes an elemental reflector portion having the coordinates  $x, y$  and  $z$  and spaced a distance  $r_1$  from the origin 14. Now if the primary antenna is moved to the point or position 18 having the coordinates  $o, y_2, o$  and spaced a distance  $r_2$  from the segment 17, the axis 19 of the major lobe makes an angle with the XX axis and the wave front 20 forms an angle  $\Phi$  with the wave front 16. The difference  $D$  in distance,  $r_1-r_2$ , represents the change in phase angle of the energy at the reflector, which change produces the beam shift. By design

$$y_2 \ll r_1 \quad (8)$$

The distance  $r_1$  is given by the following equation

$$r_1 = \sqrt{x_1^2 + y_1^2 + z_1^2} \quad (9)$$

and the change or difference  $D$  in distance is

$$D = r_1 - r_2 = \sqrt{x_1^2 + y_1^2 + z_1^2} - \sqrt{x_1^2 + (y_1 - y_2)^2 + z_1^2} \quad (10)$$

$$= r_1 - \sqrt{x_1^2 + y_1^2 - 2y_1y_2 + y_2^2 + z_1^2} \quad (11)$$

$$= r_1 - \sqrt{r_1^2 - 2y_1y_2 + y_2^2} \quad (12)$$

$$= r_1 - r_1 \left[ \frac{1 - 2y_1y_2 + y_2^2}{r_1^2} \right]^{1/2} \quad (13)$$

Expanding the binomial, we get

$$D = r_1 - r_1 \left( \frac{1 - y_1y_2}{r_1^2} + \frac{y_2^2}{2r_1^2} \text{ and other terms with } y_2^2 \right) \quad (14)$$

and higher powers of  $y_2$

$$\frac{y_2}{r_1}$$

is less than 1, so that all terms containing  $y_2^2$ , or higher powers of  $y_2$ , may be neglected.

Hence,

$$D = r_1 - r_1 + \frac{y_1y_2}{r_1} = \frac{y_1y_2}{r_1} \quad (15)$$

But, since all parts of reflector 12 are to contribute cophasal wavelets in direction 17, the change  $D$  should be

$$-y_1 \sin \Phi \quad (16)$$

where  $\Phi$  is the angle between the wave fronts 16 and 20. Consequently, the reflector should have a contour such that

$$r_1 = -\frac{y_2}{\sin \Phi} = a \text{ constant}$$

In other words, the segments or zones of the reflector should lie on a sphere.

Referring to Fig. 3 reference numeral 21 denotes a zoned reflector comprising the three parabolic zones 22, 23 and 24 which have a common axis 25, a common focus 26 and a common latus rectum 27. The zones may be sections of cylindrical parabolic reflectors or paraboloidal reflectors. Reference numerals 28 denote the outer edges of the zones 22, 23 and 24 and numerals 29 designate the inner edges of zones 23 and 24 and the vertex of the inner zone 22. Numerals 30 denote correspondent intermediate points or elemental portions of the zones. The zones are positioned so that the corresponding intermediate points 30 lie on the circumference of an intermediate circle 31. The outer edges or points 28 lie on the circumference of an inner circle 32 and the inner points 29 on the circumference of an outer circle 33, the three circles 31, 32 and 33 being concentric with the common center at the common focus 26. The inner zone 22, the intermediate zone 23 and the outer zone 24 have focal lengths of  $a-\lambda/2$ ,  $a-\lambda$  and

$$a - \frac{\lambda 3}{2}$$

respectively, where  $a$  is the radius of the outer circle 33 and  $\lambda$  is the mean operating or design frequency. Preferably, but not necessarily, the inner and outer circles 32 and 33 have radii differing a half-wavelength, or an odd multiple thereof, whereby the outer edge 28 of zone 23 and the inner edge 29 of zone 24 lie on one line parallel to axis 25 and the inner edge 29 of zone 23 and the outer edge of zone 22 lie on another line parallel to the axis. Expressed mathematically the equation for the outer circle 33 is

$$x^2 + y^2 = a^2 \quad (17)$$

where

$$a = r + \frac{\lambda}{4} \quad (18)$$

and the equation for the inner circle 32 is

$$x^2 + y^2 = \left(a - \frac{n\lambda}{2}\right)^2 \quad (19)$$

where  $n$  is any odd integer. Now the equation, as given on page 78 of the textbook "Analytic Geometry" by W. A. Wilson and J. I. Tracey, for a parabola having its axis aligned with the XX axis 25 and its vertex at the origin is as follows:

$$y^2 = 2px \quad (20)$$

where  $p$  is the distance between the directrix and the latus rectum and is equal to twice the distance between the vertex and the latus rectum. If in Fig. 3 the origin is taken at the vertex of any of the zones, we have

$$p = 2\left(a - n\frac{\lambda}{2}\right) \quad (21)$$

and

$$y^2 = 4\left(a - n\frac{\lambda}{2}\right)x \quad (22)$$

where  $n$  is an odd integer. With the origin transformed to the focus 26 we have

$$y^2 = 4\left(a - \frac{n\lambda}{2}\right)\left(x + a - \frac{n\lambda}{2}\right) \quad (23)$$

Hence the zoned reflector comprises parabolic zones which lie between the circles corresponding to Equations 17 and 19 and each of which is represented by Equation 23. If the zones are numbered 1, 2, 3, etc., beginning with the central zone 22, the coordinates for the point

coincident with the outer edge of the  $m$ th zone, where  $m$  is the zone number, are determined by the equation

$$Y = \sqrt{(2a - m\lambda)n\lambda} \quad (24)$$

and

$$X = -a + n\lambda \quad (25)$$

and the coordinates for the point coincident with the inner edge are determined by the equations

$$Y = \sqrt{(2a - n\lambda)(n-1)\lambda} \quad (26)$$

$$X = -a + \left(n - \frac{1}{2}\right)\lambda \quad (27)$$

The edges 28 and 29 of zone 23 are connected to the adjacent edges of zones 22 and 24 by the non-reflective members 34. If the zones 22, 23 and 24 are parabolic cylinders four separate members 34 are employed, each member being flat and rectangular; and if the zones have paraboloidal surfaces a single member in the form of a tubular right cylinder connects zones 22 and 23 and another hollow cylindrical member coaxial with the first-mentioned tubular member connects zones 23 and 24.

Reference numeral 35 designates a primary antenna member such as a horn or a wave guide aperture which is connected to a transceiver and which is movable along the latus rectum path 36 and between the limiting points 37 and 38. The horn is designed so as to produce a properly tapered illumination of the reflector. The electric polarization of the waves transmitted and received by the primary antenna is linear, the direction of polarization being, for example, vertical.

In operation, assuming for the moment that primary antenna is at the focus 26, waves emitted by the primary antenna 35 and having a spherical wave front are reflected by zones 22, 23 and 24. The reflected wavelets are cophasal in direction 39, since the lengths of the paths 40, 41 and 42 from the focus 26 to the latus rectum plane 27 via zones 22, 23 and 24 differ from each other a wavelength or a multiple thereof. The wavelets impinging upon the electrically transparent connecting members 34 are not reflected. With the primary antenna at position 38 and spaced a distance  $D_{38}$  from the focus 26, the wavelets reflected at the correspondent intermediate segments 30 combine in phase angle agreement for the single direction 43, as indicated by the plane wave front 44. The direction 43 makes with the axis 25 an angle  $-\alpha_{30}$  whose sine is from Equation 6, equal to the ratio of the displacement  $D_{38}$  to the radius  $r$  of circle 31, that is,

$$-\frac{D_{38}}{r} = \frac{D_{38}}{a - \frac{\lambda}{4}} = \frac{4D_{38}}{4a - \lambda} \quad (28)$$

The wavelets reflected by the elemental inner edge portions 29 of the zones combine in phase agreement for a single direction 45 making with the axis 25 a slightly smaller angle  $-\alpha_{28}$  whose sine is

$$-\frac{D_{28}}{r - \frac{\lambda}{4}} = \frac{D_{38}}{a - \frac{\lambda}{2}} = \frac{2D_{38}}{2a - \lambda} \quad (29)$$

and the wavelets reflected by the elemental outer edge portions 28 combine in phase agreement for a single direction 46 making with the axis 25 a slightly larger angle  $-\alpha_{29}$  whose sine is

$$-\frac{D_{38}}{r + \frac{\lambda}{4}} = \frac{D_{38}}{a} \quad (30)$$

The phase angles of the wavelets arriving at the wave front 44 from segments 28, 29 and 30 are slightly different so that the wave front is slightly curved rather than flat. The differences in angles or directions  $-\alpha_{28}$ ,  $-\alpha_{29}$  and  $-\alpha_{30}$  and the phase angle differences for these angular directions are, however, negligible and such that a substantially plane wave front perpendicular to the mean direction 43 is secured.

Considered more broadly, with the primary antenna at position 38, each parabolic zone considered by itself functions as a conventional parabolic reflector of the prior art. If zones 22, 23, 24 were modified and included in the same parabolic surface, that is, if a con-



ventional parabolic reflector such as represented by the curve 47 were employed, the difference or angle between the directions traversed by the wavelets reflected from the outer edge 28 and the inner edge or vertex portion 29, and the corresponding phase angle difference, would be relatively large whereby a low gain, a broad major lobe and pronounced minor lobes would be secured. By utilizing for each zone a small parabolic section, the angle between the directions traversed by the wavelets reflected from the inner and outer edges of each zone, and the corresponding phase angle difference, are rendered small. By off-setting the zones so that corresponding segments lie on the circumference of the same circle the wavelets reflected from the corresponding segments, equally distant from the axis X, X', of Fig. 1, agree in phase and direction, or stated differently, the radiations from the several zones are superimposed and reinforced to achieve a maximum effect in substantially a single direction. Moreover, by reason of the zoning, the primary antenna may be displaced from the focus a greater distance without materially widening the lobe than is permissible in prior art systems using a conventional parabolic reflector. Accordingly, by virtue of the zoning, a scanning sector of greater angular width is obtained as compared to the sectors in prior art systems.

As the primary antenna 35 moves from the positive position 38 towards the focus 26 the angles  $-\alpha_{20}$ ,  $-\alpha_{25}$  and  $-\alpha_{30}$  become smaller, and with the primary antenna on the negative side of the axis 25 the angles become positive, the position of the major lobe axis being a function of the sign and amount of the displacement of the primary antenna. As the primary antenna moves from the positive extreme position 38 through the focus 26 to the negative extreme position 37 the width of the major lobe changes only slightly since the difference in the angles or directions  $\alpha_{20}$  and  $\alpha_{30}$  is zero for the focal position 26 and relatively small for each of the extreme positions 38 and 37.

In reception the converse operation obtains by reason of the reciprocity theorem. Briefly considered, the wavelets incoming from a distant station or reflective target along a negative path 43, the zero path 39 or a positive path, and impinging on the zones 22, 23 and 24 are re-directed or focused on the primary antenna 35.

In the system of Fig. 3 some distortion occurs at the inner edges 29 of the zones and at the connecting members 34 when the reflector comprises a relatively few number of zones. As will now be explained, this so-called edge effect may be partially compensated by interposing an elliptical metallic member between each pair of adjacent zones. In Fig. 4 reference numeral 48 denotes non-metallic members which extend from the inner edge 29 of zones 23 and 24 outwardly along the radii 49 and 50 of circle 32. Numerals 51 and 52 denote elliptical metallic members connecting the outer edges 28 of zones 22 and 23 to the outer edges of the plane members 48. The elliptical members 51 and 52 each have an axis aligned with, and a pair of foci on, the radii 49 and 50 respectively, one of the foci being at the common parabolic focus 26 and the other at the zone edge 29 on its axis. Since the spacings between the adjacent points 28 and 29 differ, the members 51 and 52 have different elliptical curvature. In the case of each elliptical member the ellipse may be readily determined since the two foci and the point 28 on the ellipse are known.

The system of Fig. 4 operates in the same manner as the system of Fig. 3 except that the wavelets emitted at the focus 26 and arriving at the lines 53, which represent the connecting members 34 used in the system of Fig. 3, are focused on the other ellipse focus 29 whereby compensation for the distortion mentioned above is effected.

Referring to Fig. 5, reference numeral 54 denotes a zoned paraboloidal reflector comprising the three zones 55, 56 and 57 and attached to the supporting member 58. The zones have a common axis 59 and a common point focus 60 and the adjacent zones are connected together through the coaxial cylindrical members 61 which are similar in design to members 34, Fig. 3. Reference numeral 62 denotes a radar transceiver which is connected by the horizontal wave guide 63 through a coupling or gear box 64 to the vertical guide 65 having an aperture or primary antenna 65 facing reflector 54 and displaced from the focus 60. The coupler 64 includes means for rotating the primary antenna about the focus 60. The

coupler may be of a conventional type or of the trammel type disclosed and claimed in the copending application of H. A. Baxter and W. D. Lewis, Serial No. 589,336, filed April 20, 1945. This application matured into United States Patent No. 2,541,324, granted February 13, 1951.

In operation the waves are supplied from the transceiver 62 through guide 63, coupler 64 and guide 65 to the rotating aperture 66. The emitted waves are reflected by the zones 55, 56 and 57 and maximum action occurs at an angle to axis 59. As the aperture 66 rotates about the focus 60 the major lobe describes in space a cone having its axis aligned with the reflector axis 59; and conical scanning obtains. As the lobe rotates, its angular width at the half-power point remains constant. Its half-power width is relatively small and, in contrast to prior art wide angle conical scanning antennas, is not materially different from the half-power major lobe width obtained with the aperture 66 at the focus.

Referring to Fig. 6, reference numeral 67 denotes a zoned cylindrical parabolic reflector comprising the conical focal zones 68, 69, 70 and 71, and attached to the supporting members 58. The zones have a common axis 72 and a common focal line 73. Numerals 74 and 75 denote, respectively, a top conductive plate and a bottom conductive plate which are parallel and spaced in accordance with wave guide practice, a half or less of the design or mean operating wavelength. The plates 74, 75 are connected by the semicylindrical or conductive side member 76 which forms with the plates a rectangular opening 77. Numerals 78 designate conductive flares or horn sides attached to the longitudinal edges, and numerals 79 designate end members attached to the short or transverse edges, of the opening 77. The bottom plate 75 contains a longitudinal slot 80 having its axis included in the common latus rectum plane of the zones.

Reference numeral 81 denotes a right angle wave guide having an end aperture or primary antenna 82 facing reflector 67 and slidably mounted in slot 80. The wave guide 81 is connected through the coupler 83 and wave guide 63 to the translation device 62. The coupler 83 includes means for moving guide 81 back and forth along slot 80 and it may be of a conventional type or of the trammel type disclosed and claimed in the aforementioned copending application.

The operation of the system of Fig. 6 is believed to be apparent in view of the explanation given above in connection with Fig. 5. Assuming the focal line 73 is vertical, as the reciprocating primary antenna 82 moves horizontally, the major lobe oscillates in the horizontal plane over an angular sector related to the length of the slot 80. As discussed previously, the angular width of the sector may be relatively great. The horizontal plane pattern of the major lobe is relatively narrow at the half-power point and its width remains constant during the scan. The vertical plane pattern of the major lobe is wider at the half-power point than the half-power width of the horizontal plane pattern. Without the flares 78 the half-power width in the electric or vertical plane is relatively wide, and the flares function to decrease the vertical plane width to a desired amount of say 5 degrees. Hence, the system of Fig. 6 has a sharp horizontal plane major lobe pattern and a wide vertical plane major lobe pattern; and a so-called fan beam is secured.

Referring to Fig. 7, reference numeral 84 denotes a multiple zone reflector which was actually constituted and successfully tested. The reflector comprises the twenty-four parabolic cylinders or zones denoted 85 to 108, inclusive, and having a common axis 109, a common focal line 110 and a common latus rectum 111. Numeral 112 designates the aperture of the reflector 84, the aperture diameter being ten feet. The radius  $a$  of the outer circle 33 is six feet. A non-reflective member 48 and an elliptical reflective member (not illustrated) are included between each pair of adjacent zones.

The different parabolic curves or contours of zones 85 to 108, inclusive, were ascertained by determining, in the case of each zone, the rectangular coordinates, as measured in inches, of several points lying on the zone. More specifically, for convenience in measuring, the origin of the axes was in effect transformed from the focus 110 to the intersection 113 of the XX axis and the circumference of the outer circle 33, and measurements were made from the new origin 113 along the XX' axis and the YY axis. The relation between the X and X'

abscissas for a point  $p$  on any zone is given by the following equation:

$$X_1 = a - t = x + \frac{n\lambda}{2} \quad (31)$$

where  $t$  is the distance from the focus 110 to the point  $p$ . Using Equations 24, 25, 26, 27 and 31 the coordinates for the edges or extreme points and the intermediate points for each zone were determined. Thus, for the first or central zone 85 the coordinates for the inner edge point 29, the outer edge point 28 and thirteen intermediate points were ascertained. By way of illustration, the coordinates for the edges of the first zone 85, second zone 86, and the last zone 108, and for several intermediate points spaced an inch apart on the second zone 86, are given in the following table:

|                              | $X_1$ | $Y$   |
|------------------------------|-------|-------|
| Zone 85:                     |       |       |
| Inner edge or vertex 29..... | .67   | 0     |
| Outer edge 28.....           | 1.33  | 13.77 |
| Zone 86:                     |       |       |
| Inner edge 29.....           | 2.00  | 13.71 |
| Intermediate point 114.....  | 2.02  | 14.0  |
| Intermediate point 115.....  | 2.13  | 15.0  |
| Intermediate point 116.....  | 2.24  | 16.0  |
| Intermediate point 117.....  | 2.35  | 17.0  |
| Intermediate point 118.....  | 2.48  | 18.0  |
| Intermediate point 119.....  | 2.61  | 19.0  |
| Outer edge 28.....           | 2.66  | 19.39 |
| Zone 108:                    |       |       |
| Inner edge 29.....           | 31.27 | 58.56 |
| Outer edge 28.....           | 31.94 | 59.82 |

For a 50-degree scan, the primary antenna 35 was moved along the curved path 124 and positioned at the  $-20^\circ$  and  $-25^\circ$  positions 125 and 126. The path 124 is the arc of a circle having a radius of about ten feet and a center four feet behind the vertex 29 which is approximately six feet from the focus 110.

The large multiple zone reflector 84, Fig. 7, was tested at the design frequency corresponding to a wavelength of 3.415 centimeters and at two other frequencies, one lower and one higher than the design frequency and corresponding, respectively, to wave lengths of 3.440 and 3.362 centimeters. In each test, a transmitter was connected to the directive primary antenna or horn 35 and the wave polarization was parallel to the focal line 110. Also, in each test, for a 30-degree scan, the primary antenna 35 was successively positioned at points 110, 120, 121 and 122, spaced 5 degrees along the left or negative half of a linear path 123 and corresponding to the 0,  $-5^\circ$ ,  $-10^\circ$  and  $-15^\circ$ , directions. The mid-point of paths 123 and 124 coincide with the focus 110 and the total length of path 124 subtends 50 degrees as measured from the vertex 29. With the horn or feed 35 at the focal position 110, that is, on the 0 direction the emitted waves are propagated in direction 127 along the axis 109 and the reflected waves are propagated in the opposite direction 128. For the  $-5^\circ$ ,  $-10^\circ$ ,  $-15^\circ$ ,  $-20^\circ$  and  $-25^\circ$  positions of the horn 35, maximum action for the reflected waves occurs in the  $+5^\circ$ ,  $+10^\circ$ ,  $+15^\circ$ ,  $+20^\circ$  and  $+25^\circ$  directions respectively, as shown by arrows 129, 130, 131, 132 and 133. Since the aperture of reflector 84 is relatively large, namely ten feet, the gain is very high.

Figs. 8, 9 and 10 illustrate the measured directive patterns taken in the magnetic plane containing axis 109 and the path 123, 124 for horn 35 and obtained during tests in which frequencies corresponding to the wavelengths 3.415, 3.440 and 3.362 centimeters respectively, were employed. In Fig. 8 reference numerals 134, 135, 136, 137, 138 and 139 illustrate the separate and distinct patterns for the 0,  $+5^\circ$ ,  $+10^\circ$ ,  $+15^\circ$ ,  $+20^\circ$  and  $+25^\circ$  antenna positions. In each pattern reference numeral 140 denotes the major lobe, the line designated 141 represents the angular width of the lobe, as measured at the half-power point and, except in patterns 134 and 139, numeral 142 denotes the minor lobes. For patterns 134 and 139 the minor lobe intensity was 20 decibels below the major lobe intensity. It may be pointed out that, since the reflector 84 is symmetrical about axis 109, the directive patterns for the  $-5^\circ$ ,  $-10^\circ$ ,  $-15^\circ$ ,  $-20^\circ$  and  $-25^\circ$  degree positions are substantially the same as the directive characteristics 135, 136, 137, 138 and 139 for the  $+5^\circ$ ,  $+10^\circ$ ,  $+15^\circ$ ,  $+20^\circ$  and  $+25^\circ$  degree positions, respectively.

Considering the patterns 134 to 139 inclusive, Fig. 8,

the half-power width 141 of the major lobe 140 in each pattern is about  $0.7^\circ$ . Hence scanning of a 50-degree sector ( $\pm 25^\circ$ ) is obtainable, without substantial change in the beam width, by moving the primary antenna 35 along the path 124. The angular width of the sector is in the order of seventy times the half-power width of the beam. By way of contrast, in prior art systems using a conventional parabolic reflector, the maximum sector width obtainable without materially increasing the lobe width, is ordinarily only two or three times the lobe width. Also, in patterns 135 to 138 inclusive, the minor lobes 142 are of relatively low power as compared to the minor lobes usually produced by parabolic reflectors of the prior art and are, therefore, negligible.

Referring to Figs. 9 and 10, reference numerals 143, 144, 145 and 146, Fig. 9, denote the magnetic plane patterns obtained at the 0,  $+5^\circ$ ,  $+10^\circ$  and  $+15^\circ$  horn positions, respectively, for the wavelength of 3.440 centimeters; and numerals 147, 148, 149 and 150 denote the patterns obtained for these horn positions for the wavelength of 3.362 centimeters. The half-power widths 141 of the major lobes 140 of patterns 143, 144, 145 and 147, Fig. 9, and the half-power widths 141 of the major lobes 140 of patterns 147, 148 and 149, Fig. 10, are substantially the same as the half-power widths 141 of the major lobes 140 of patterns 134, 135, 136, 137 and 138, Fig. 8. The half-power width 141 in the 3.362 centimeter pattern 150, Fig. 10, for the  $+15^\circ$  position is slightly greater than the widths in the other patterns of Fig. 10. It is thus apparent from the patterns of Figs. 8, 9 and 10 that the zoned reflector of the invention performs satisfactorily over a band of wavelengths extending from 3.362 to 3.440 centimeters. The band is a 2 per cent band and its mean wavelength is about 0.6 per cent longer than the design wavelengths of 3.415 centimeters.

In general, for a zoned parabolic cylindrical reflector, such as the reflector of Fig. 6 or Fig. 7, the half-power lobe or beam width, the angular width of the scanning sector or scannable field and the band width may be determined approximately from the following equations:

$$\text{Beam width} = \frac{65\lambda}{A} \text{ degrees} \quad (32)$$

$$\text{Sector width} = \frac{12r\lambda}{A\Delta} \quad (33)$$

$$\text{Band width} = 50 - \frac{\lambda}{r - \sqrt{r^2 - \left(\frac{A}{2}\right)^2}} \quad (34)$$

where

$\lambda$  = wavelength

$A$  = diameter of reflector opening (aperture)

$r$  = radius of intermediate or mean circle

$\Delta$  = maximum departure of zone portions from mean circle

$$= \frac{\lambda}{4}$$

It may be pointed out that heretofore, in order to secure a narrow lobe, high directivity and efficient scanning, in general, it has been necessary to utilize parabolic reflectors or passive members disposed along a parabolic curve or surface and, considered from a mechanical or a size standpoint, the use of a parabolic system may not be advantageous. In accordance with the present invention, these desirable results may be secured by employing the principle of zoning and arranging the passive members along a curve or surface which is not parabolic. In short, the principle of zoning eliminates the prior art limitation or necessity of using a parabolic structure and permits a greater freedom in designing the system.

Although the invention has been explained in connection with certain embodiments it should be understood that it is not to be limited to the embodiments described inasmuch as other apparatus may be employed in successfully practicing the invention. In particular, zones having surfaces or contours other than parabolic may be used, provided the corresponding portions of the zone are disposed on the circumference of a circle or a sphere. Also, other types of passive antenna members, such as lens or wave guide apertures, may be employed as zone elements instead of the reflective elements described above; and the principle of zoning is, in accordance with the invention,

equally applicable to so-called transmission gratings and reflective systems. In addition, the invention may be satisfactorily employed with waves or radiant energy other than electromagnetic waves, as, for example, light waves.

What is claimed is:

1. An antenna system comprising a plurality of passive or secondary antenna members spaced unevenly along an arc of a circle, an active or primary antenna member positioned on a diameter of said circle, said active antenna being displaced from the center of said circle, and means for moving said active antenna.

2. An antenna reflector comprising a plurality of elliptical sections having corresponding segmental portions located at spaced points on the circumference of a circle and having a common focus coincident with the center of said circle.

3. An antenna reflector comprising a plurality of parabolic sections having different focal lengths and a plurality of elliptical sections, one of said elliptical sections being included between each pair of adjacent parabolic sections.

4. In combination, a zoned reflector comprising concave passive sections having a common focus, one set of corresponding points of said sections being spaced on the circumference of a circle having its center at said focus, a transceiver, a primary antenna element connected to said transceiver and spaced from said focus.

5. In combination, a reflector comprising a plurality of coaxial confocal parabolic sections having different focal lengths, the mid-points of said sections being unevenly spaced on the circumference of a circle having its center at said focus a primary antenna element connected to a translation device and spaced from the axis of said sections.

6. In combination, an antenna reflector comprising a plurality of coaxial confocal cylindrical parabolic sections having different focal lengths and positioned on the circumference of a circle, a primary antenna element connected to a translation device, and means connected to said element for moving the element along the common latus rectum of said sections.

7. In combination, an antenna reflector comprising a plurality of cylindrical parabolic sections having a common focus and different focal lengths, one set of corresponding segmental portions of said sections being spaced on one circumference and another set of corresponding segmental portions being spaced on the other circumference of two concentric circles, a primary antenna ele-

ment connected to a translation device, and means for oscillating said element along the common latus rectum of said sections and through said common focus.

8. In combination, a concave antenna reflector comprising a plurality of paraboloidal sections having a common focal point and different focal lengths, said sections being spaced on the surface of a sphere, a primary antenna element connected to a translation device, and means connected to said element for moving said element about said point.

9. An antenna reflector comprising a plurality of confocal parabolic zones having inner edges positioned on one circumference and outer edges positioned on the other circumference of two concentric circles, the center of said circles being coincident with the common focus of said zones, the difference between the radii of said circles being a half wavelength or an odd multiple, including the integer one, of a half wavelength and the difference between the focal lengths of said zones being a multiple, including the integer one, of a half wavelength.

10. In combination, a reflector comprising a plurality of coaxial confocal parabolic sections having different focal lengths and spaced unevenly on the circumference of a circle, a primary antenna element connected to a translation device and included in the common focal plane of said sections, means connected to said element for moving said element in said plane relative to the common focus of said sections, the adjacent sections having focal lengths differing a multiple, including the integer one, of a half wavelength.

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