

Sept. 9, 1947.

A. P. KING

2,427,005

DIRECTIVE MICROWAVE ANTENNA

Filed Nov. 6, 1943

3 Sheets-Sheet 1

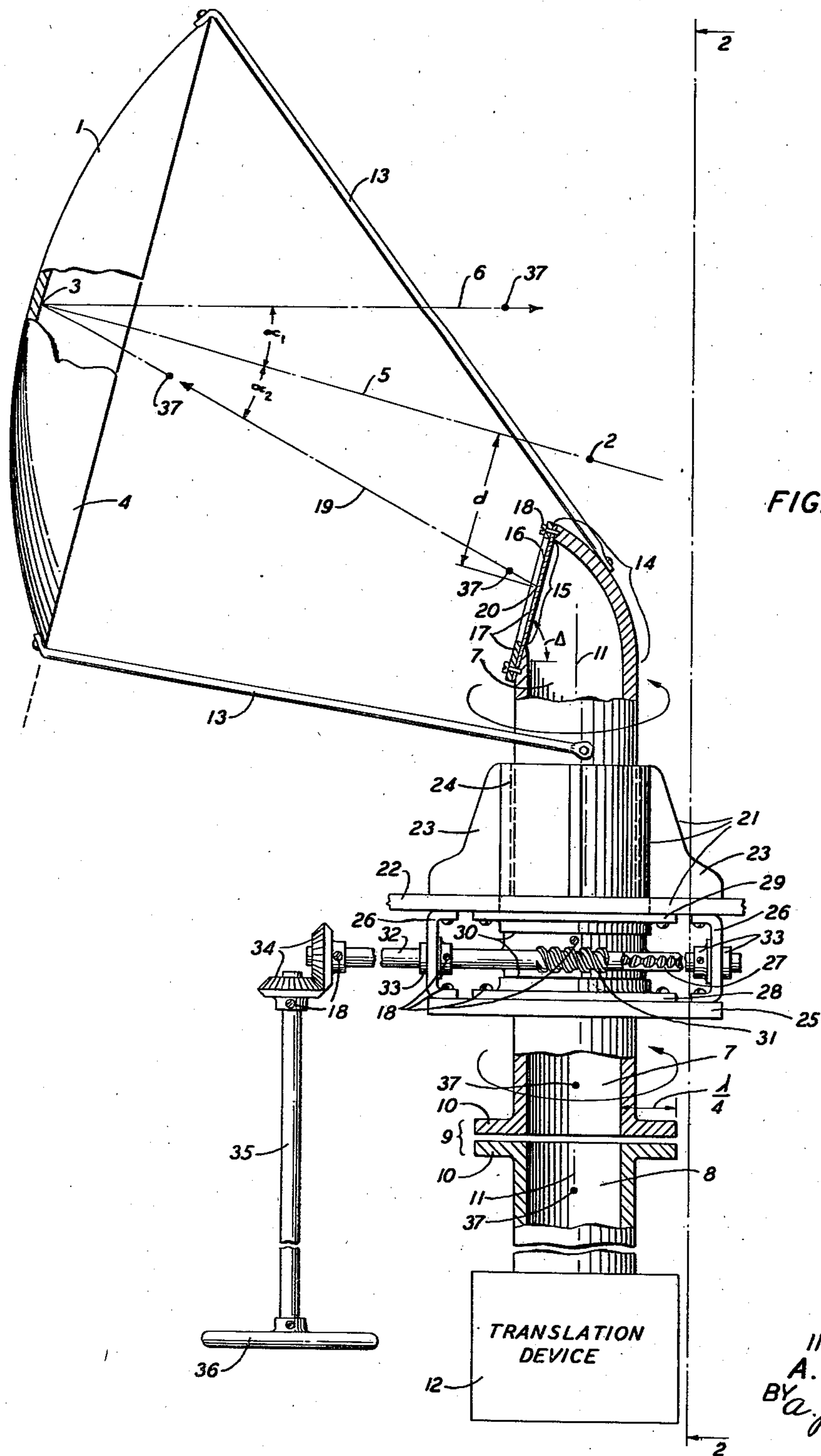


FIG. 1

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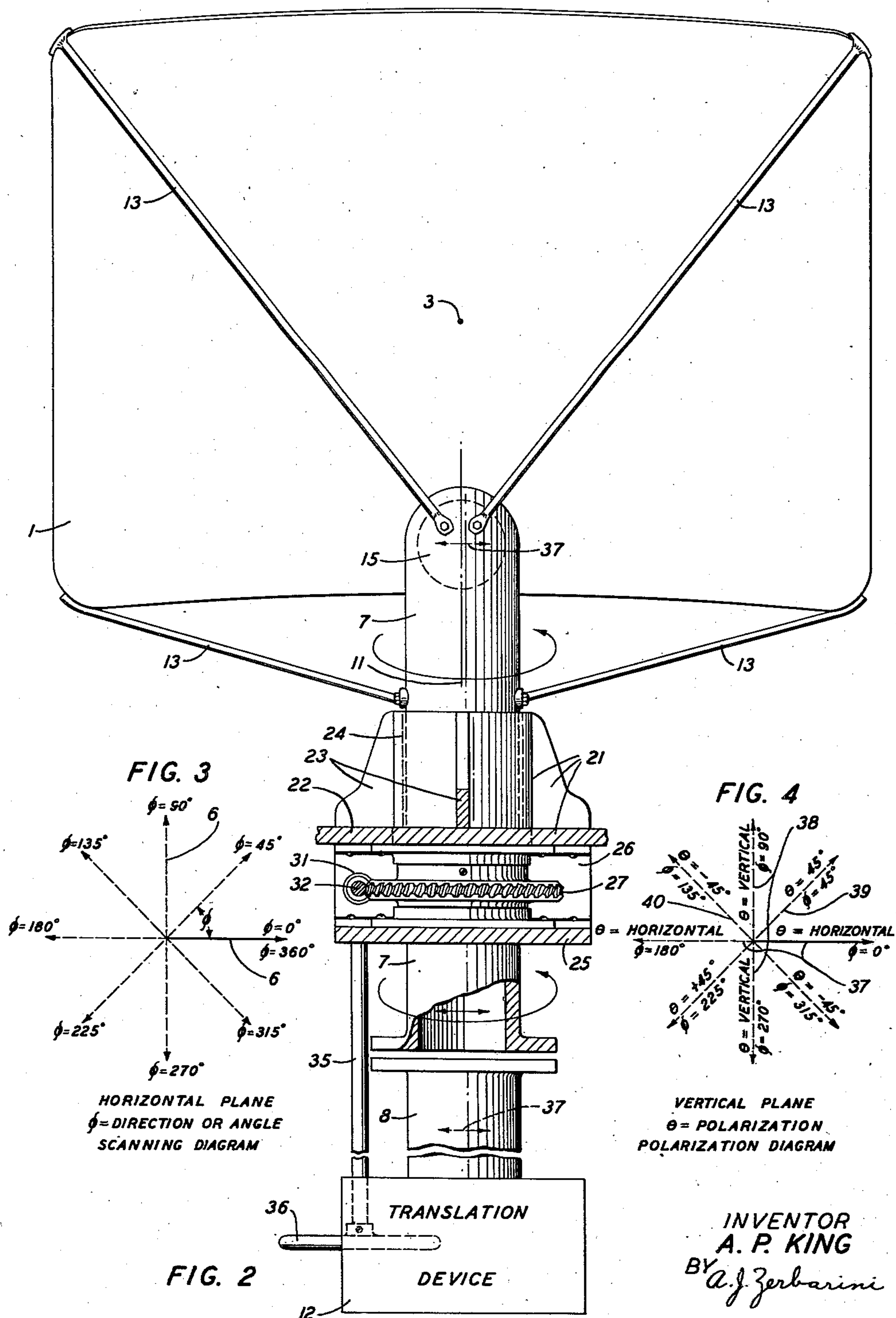
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3 Sheets-Sheet 2



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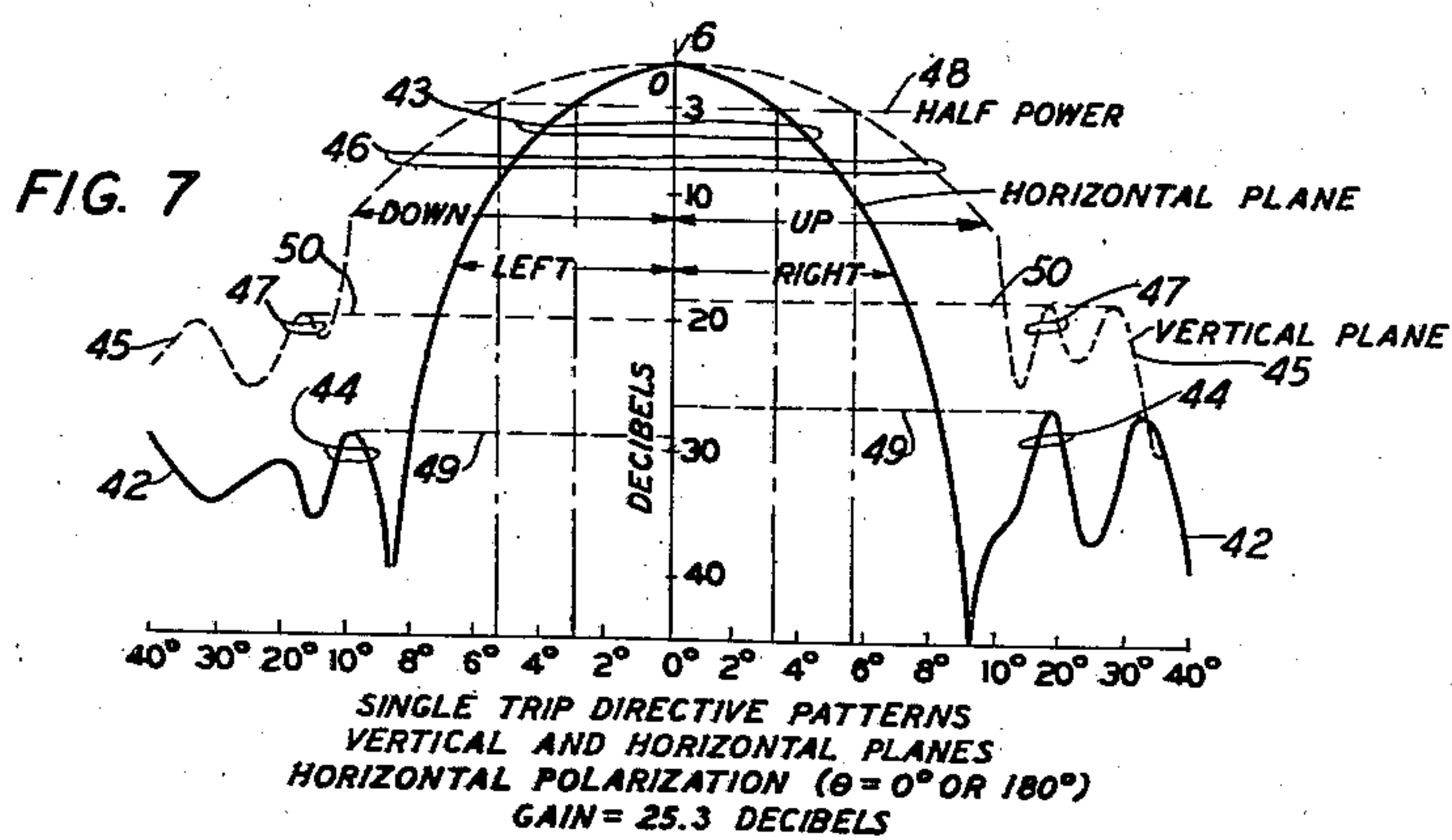
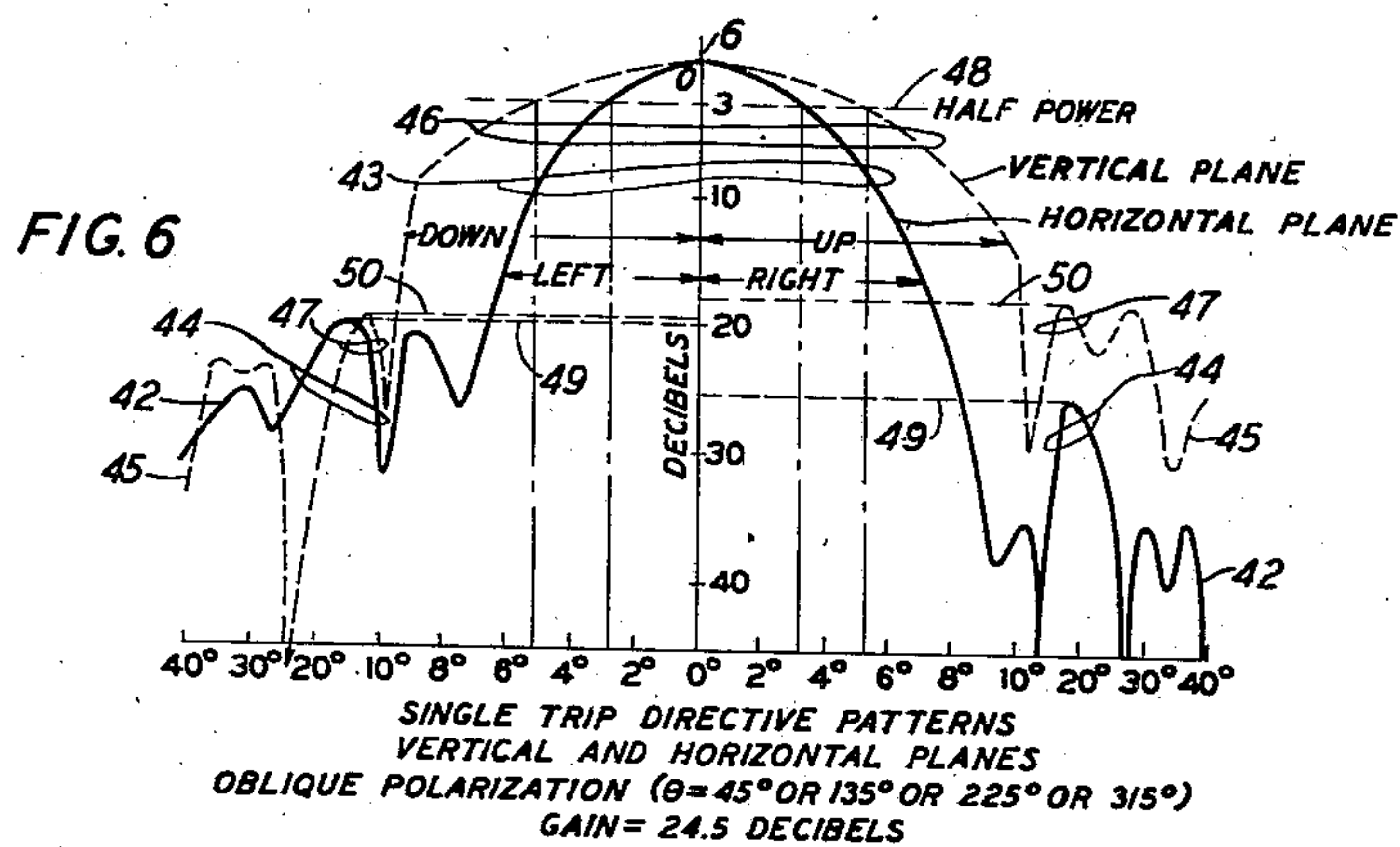
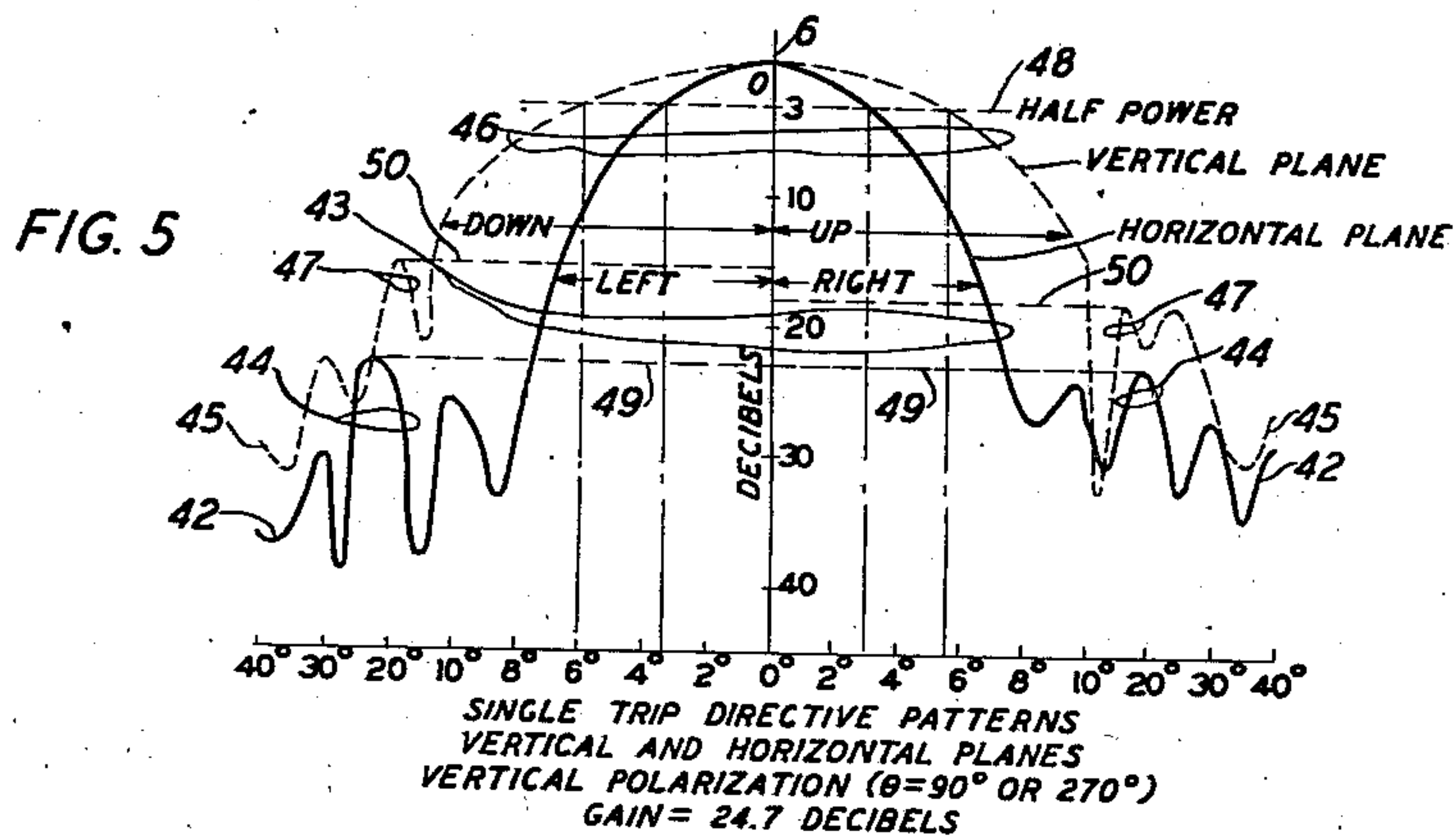
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DIRECTIVE MICROWAVE ANTENNA

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3 Sheets-Sheet 3



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DIRECTIVE MICROWAVE ANTENNA

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8 Claims. (Cl. 250—11)

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This invention relates to directive antennas and particularly to microwave antennas suitable for use in radar or radio scanning systems.

As is known, paraboloidal reflectors associated with a "front" feed or a "rear" feed are widely used in microwave radar antenna systems for scanning in a given plane such as the horizontal plane. The feed or primary antenna member usually comprises a wave guide having an aperture facing the reflector or secondary antenna member and positioned in the scanning plane. In general, in rear feed arrangements, the wave guide extends in the scanning plane along the reflector axis and through the reflector vertex, and in the front feed arrangement, it extends perpendicular to the scanning plane and across one-half the reflector opening. The copending application of C. C. Cutler, Serial No. 518,377, filed January 15, 1944, and Patent 2,409,183, granted on October 15, 1946, to A. C. Beck, describe, respectively, a rear feed arrangement and a front feed arrangement. In the prior art systems described above, the wave guide feed often produces, by reason of secondary reflective effects, distortion of the radiated and received fields and undesired, relatively large minor lobes in the directive pattern taken in the scanning plane. Accordingly, it now appears advantageous to eliminate the distortion effect and to secure a cleaner and more satisfactory directive pattern in the scanning plane. In addition, assuming the paraboloidal reflector and associated wave guide feed are rotated for horizontal scanning and the waves transceived by the antenna have a polarization, which rotates in a plane approximately vertical as the paraboloid is rotated in the horizontal plane, it appears desirable to eliminate the above-mentioned distortion effect in a manner such as to minimize splitting of the wave polarization during the scan and particularly when the polarization is oblique as, for example, 45 degrees.

As used herein the term "polarization splitting" refers to the tendency of a linearly polarized wave to resolve into two quadrature components which combine to produce a circularly polarized or an elliptically polarized resultant. Also as used herein, the term "microwaves" includes decimetric, centimetric and millimetric waves.

It is one object of this invention to obtain a highly efficient and highly directive microwave antenna.

It is another object of this invention to eliminate, or at least minimize, polarization splitting

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in an antenna system utilizing rotating polarization.

It is another object of this invention to prevent in an antenna system comprising a primary antenna member and a secondary reflective member facing the primary member, distortion of the emitted and received fields by the primary antenna and associated structure.

It is another object of this invention to obtain a scanning antenna having in the scanning plane a directional pattern or characteristic which includes a narrow undistorted major lobe and minor lobes having an extremely low intensity relative to that of the major lobe.

In accordance with one embodiment of the invention, a highly satisfactory directive characteristic is obtained in the horizontal scanning plane by utilizing as a secondary antenna member a section of a paraboloidal reflector having its principal axis extending downwardly from its vertex, and a vertical circular wave guide feed having at the top an elbow or bend and a slanting transceiving aperture facing the reflector. The elbow is acute, that is, less than 90 degrees and preferably in the order of 70 to 80 degrees. The paraboloidal reflector is rigidly supported by the vertical wave guide and the entire guide is positioned below the horizontal scanning plane and the reflector axis. More specifically, the plane of the tilted aperture and the plane of the opening of the tilted paraboloidal reflector are approximately parallel, and the reflector axis coincides with the bisector of the acute angle in the vertical plane formed by the horizontal plane and an imaginary line connecting the vertex of the reflector and the mid-point of the tilted aperture. The value of the angle just mentioned is related to the size and focal length of the reflector and, in one embodiment actually constructed, the angle was 29 degrees. A radar transceiver is connected through a main guide and a rotating wave guide junction to an end opening at the bottom of the vertical feed guide for successively supplying to and receiving from the vertical guide, transverse waves polarized in a given direction in the horizontal plane. Means are provided for rotating the vertical guide and attached reflector about the longitudinal axis of the vertical guide, whereby scanning in the horizontal plane over a 360-degree angle may be obtained. As the directive pattern, including the major lobe, rotates 360 degrees or less in the horizontal plane, the polarization of the waves emitted or collected after reflection by a target rotates through 360 degrees, or less, in a plane which is approxi-

mately vertical. By reason of the acute angle elbow, splitting of the polarization when the main wave is obliquely polarized is minimized. Also, since the entire feed structure is spaced an appreciable distance from the scanning plane, the minor lobes of the directive pattern in the scanning plane are relatively few in number and their intensities are at least 20 decibels below the major lobe for all polarizations. In the horizontal plane the width at the half power point of the major lobe is relatively small, that is, 5.8 degrees to 6.6 degrees for all polarizations; and in the vertical plane the lobe width at the half power point is somewhat greater, that is, 11.0 degrees to 11.4 degrees for all polarizations. In other words, the antenna system has a "fan" beam. If, instead of the above-mentioned vertical guide, a pair of feed guides having apertures horizontally spaced from the reflector axis are utilized, as in the lobe-switching system disclosed and claimed in the above-mentioned patent of A. C. Beck, the two guides including the apertures are, in accordance with the invention, positioned below the horizontal scanning plane.

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

Figs. 1 and 2 are, respectively, elevational and front views of one embodiment of the invention;

Figs. 3 and 4 are diagrams used in explaining the invention; and

Figs. 5, 6 and 7 are measured directive curves for an antenna system similar to the embodiment illustrated by Figs. 1 and 2 and constructed in accordance with the invention.

Referring to Figs. 1 and 2, reference numeral 1 denotes a tilted rectangular section of a paraboloidal reflector having a focus 2, a vertex 3, an opening 4 and an axis 5 which extends downwardly and forms an acute angle α_1 in the vertical plane with the direction 6 included in the horizontal scanning plane. Numerals 7 and 8 designate, respectively, a rotatable circular guide and a stationary circular guide which are coupled electrically through the rotating junction 9 of a type known in the art and comprising the two parallel quarter-wave open-ended flanges 10. The collinear guides have a common vertical longitudinal axis 11 which is in the vertical plane containing the reflector axis 5. Numeral 12 denotes a translation device, which may be a transmitter, a receiver, or a radar transceiver, the device being connected to an end opening at the bottom of the main fixed guide 8. The paraboloidal reflector is rigidly attached to the rotatable guide 7 by struts 13 and rotates with guide 7, the upper struts being dielectric and the lower struts being metallic or dielectric.

The guide 7 has at the top a bend or elbow 14, the angle Δ of which is acute as, for example, 75.5 degrees, and a tilted circular transmitting-receiving aperture 15 facing the reflector and included in a plane parallel to the plane of the reflector opening 4. Numeral 16 denotes a polystyrene window fitted into aperture 15 and held in place by the flange 17, the flange being secured to guide 7 by bolts 18. As shown on the drawing, the imaginary line 19 extending between the reflector vertex or midpoint 3 and the mid-point 20 of aperture 15 forms an acute angle α_2 in the vertical plane with the axis 5, the angle α_2 being equal to the above-mentioned angle α_1 . Hence the entire feed structure, including guides

7 and 8 and the aperture 15, is positioned below both the horizontal scanning plane and the reflector axis 5, the aperture mid-point 20 being spaced a distance d from the reflector axis 5 in a vertical plane which is, of course, perpendicular to the horizontal scanning plane. This off-focus feed may be termed, for convenience, a "depressed" feed or primary antenna, and should be distinguished from the off-focus "displaced" feed disclosed in the above-mentioned patent of A. C. Beck and in which the spacing between either of the two guide apertures and the reflector axis is included in the horizontal scanning plane.

Considering the mechanical arrangement for supporting and rotating the guide 7 about its longitudinal axis 11, numeral 21 denotes a fixed casting comprising a plate 22, the webs 23 and a sleeve 24. Sleeve 24 is coaxially related to and spaced slightly from the rotatable guide 7, and it functions to some extent as a retaining member for guide 7. Numeral 25 designates a base-plate and numerals 26 denote yokes which extend between plates 22 and 25, the yokes being secured to these plates by bolts 18. Numeral 27 denotes a worm gear which contacts the lower and upper fixed bearing plates 28 and 29 and is fastened by means of the pin or bolt 18 to guide 7. The two bearing surfaces are indicated by the heavy line 30. The bearing plates 28 and 29 are secured, respectively, to plates 25 and 22 by bolts 18. Numeral 31 denotes a worm which is integral with worm shaft 32 and engages worm gear 27. The worm shaft 32 is supported by bearings 33 and is connected through bevel gears 34 to a drive shaft 35 and the handwheel 36. If desired, a motor may be used in place of the handwheel for driving shaft 35 and rotating the entire antenna system.

In operation, assuming device 12 is a radar transceiver, pulsed waves are supplied by device 1 to fixed guide 8, the waves being polarized in the horizontal plane and parallel to the direction or path represented by the dots 37, Fig. 1, and the double-headed arrows 37, Fig. 2. Since the flanges 10 of junction 9 have a radial width of a quarter wavelength and are open ended, they constitute an open-ended quarter-wave line having a zero impedance. Hence, guides 7 and 8 are electrically connected through a zero impedance substantially and the waves in guide 8 pass without substantial loss and without polarization change to guide 7. The waves are emitted through aperture 15 and the associated window 16, impinge upon all parts of reflector 1 and are thence reflected. The reflected wavelets combine to produce maximum action in the horizontal direction 6 which corresponds to the principal axis of the major directive lobe of the system. Considered differently, the aperture emits a wave front which is more or less semi-spherical and, since the aperture and reflector openings are in parallel planes, the spherical wave front is converted into a substantially plane wave front extending perpendicular to direction 6, the resultant angle α_2 of incidence in the vertical plane being equal to the over-all angle of reflection α_1 . In reception, the converse operation obtains by virtue of the so-called reciprocity theorem. More specifically, the echo waves reflected by a distant target are collected by reflector 1 and focused on the aperture 15. The waves are then conveyed by means of guides 7 and 8 to the transceiver 12.

For target searching in the horizontal plane,

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the guide 7, and therefore aperture 15 and paraboloidal reflector 1, are rotated about the vertical axis 11 of guide 7 by handwheel 36 whereby, as shown in Fig. 3, the direction 6 of maximum action is steered or rotated through a horizontal sector or angle φ having any value from zero to 360 degrees. Ordinarily the opposing directions, φ equal to zero and φ equal to 180 degrees, coincide with the lubber line of the vessel on which the antenna is installed, the directions φ equal to zero and φ equal to 180 degrees being, respectively, the front and rear directions. As aperture 15 rotates through angle φ , the linear polarization 37 of the wave in the aperture rotates, as shown in Fig. 4, through an angle θ in the plane of the aperture, the angle θ being directly related to the angle φ . This follows from the fact that the polarization 37 in guide 7 is fixed and the plane of the aperture 15 rotates about a line perpendicular to the polarization 37 and hence moves in a manner such that the horizontal diameter of the aperture is successively perpendicular and parallel to the fixed polarization 37. If, for example, φ changes 10 degrees, θ changes 10 degrees; and if φ changes 360 degrees, θ in effect, changes 360 degrees. More specifically, referring to Fig. 4, with the direction φ equal to zero or 180 degrees, the polarization angle θ is zero (or 180 degrees) and the polarization is therefore horizontal, as shown by the double-headed arrow 37. With φ equal to 90 degrees (or 270 degrees) the angle θ is 90 degrees (or 270 degrees) and the polarization is therefore vertical, as shown by the double-headed arrow 38. For all other values of φ the polarization is slanting or oblique. With φ equal to 45 degrees or 225 degrees, θ has a plus 45-degree orientation and the polarization is as shown by double-headed arrow 39; and with φ equal to 135 degrees or 315 degrees, θ has a minus 45-degree orientation and the polarization is as shown by double-headed arrow 40, the plus and minus 45-degree orientations or polarizations 39 and 40 being perpendicularly related.

While the plane of polarization rotation of the wave established in aperture 15 is tilted at an angle Δ , Fig. 1, equal to about 75.5 degrees, the action of the paraboloidal reflector is such that the polarization of the waves emitted or collected by the entire antenna system rotates in a substantially vertical plane perpendicular to the direction 6, Fig. 1. With the waves in aperture 15 vertically or horizontally polarized there is only a slight tendency for the waves to split or divide into quadrature components, and so produce a circularly or elliptically polarized wave; and the tendency for the waves to split would be small if the angle Δ of elbow 14 (Fig. 1) were 90 degrees instead of acute. With the waves obliquely polarized, and particularly with θ equal to plus or minus 45 degrees, a right angle elbow would cause excessive wave splitting. In accordance with the invention, the angle Δ of elbow 14 is less than 90 degrees, whereby wave splitting at the oblique polarizations, and particularly with θ equal to plus or minus 45 degrees, is rendered negligible, and the wave splitting with the polarization vertical or horizontal is also negligible. In one system actually tested and comprising a paraboloidal reflector and a depressed feed with an acute angle elbow, the round-trip losses caused by wave splitting were, respectively, 0.1 decibel, 0.3 decibel and substantially zero for the horizontal, 45-degree and vertical polarizations.

Figs. 5, 6 and 7 each illustrate measured, single-trip directive patterns, taken in the vertical

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and the horizontal planes, of the system of Figs. 1 and 2. The patterns of Figs. 5, 6 and 7 were obtained with the wave polarization vertical, 45 degrees and horizontal, respectively, the operating wavelength being 9.8 centimeters. In Figs. 5, 6 and 7 numeral 42 denotes the horizontal plane pattern having a major lobe 43 and the minor lobes 44, and numeral 45 designates the vertical plane pattern having the major lobe 46 and the minor lobes 47. The axis of major lobes 43 and 45 coincides with the horizontal direction 6 of maximum action, Fig. 1. It will be observed that, for each of the polarizations, the width at the half power point denoted by line 48 of the major lobe in the horizontal scanning plane is less than the width of the vertical plane lobe so that the beam is fan shaped. As shown in Figs. 5, 6 and 7 the width in the horizontal plane is in the order of 5.8 to 6.6 degrees and the width in the vertical plane is in the order of 11.0 to 11.4 degrees. With the feed depressed, in accordance with the invention, a highly symmetrical major lobe, particularly in the scanning plane, is secured in the case of each polarization and the distortion of the major lobe at the nose, that is, along direction 6, is avoided. The absolute gain of the antenna is, for all three polarizations, 24.5 decibels or greater and is therefore relatively large. In addition, with the guide 7 and aperture 15 depressed and removed from the horizontal scanning plane, the horizontal and vertical plane patterns 42 and 45, for all three polarizations, contain only a small number of minor lobes 44 or 47 in the ± 40 -degree central sector. In the scanning plane, all minor lobes are at least 20 decibels below the major lobe peak intensity, as shown by lines 49, Figs. 5, 6 and 7. More specifically, the intensities of the horizontal plane minor lobes 44 are down 23, 20 and 27 decibels for the vertical, 45-degree oblique and horizontal polarizations, respectively. Hence the antenna of the invention possesses distinct advantages over the prior art antennas comprising paraboloidal reflectors. In the vertical plane, the intensities of the minor lobes 47 are 15.5, 18.0 and 18.0 decibels below the major lobe for the vertical, 45-degree and horizontal polarizations.

In the embodiment of Figs. 1 and 2, a single wave guide feed is employed, and scanning in the horizontal plane is obtained. The invention, however, is not limited to systems having a single feed guide or to a system for scanning in a horizontal plane. Thus, as previously indicated, the invention may be used in connection with dual wave guide feeds, such as the dual feed used in the lobe switching system disclosed in the above-mentioned patent of A. C. Beck; and the entire antenna system may be oriented for scanning in a plane other than the horizontal plane.

Although the invention has been described in connection with a specific embodiment, it should be understood that it is not to be limited to the embodiment described inasmuch as other apparatus may be employed in successfully practicing the invention.

What is claimed is:

1. A directive antenna system for scanning in a given plane comprising a concave reflector having a focus and a primary antenna member therefor, said focus being spaced from and positioned between said plane and said member.

2. A directive antenna system for determining the direction in a given plane of an incoming wave comprising a paraboloidal reflector having an axis angularly related to said plane, a wave

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guide having an aperture facing the reflector, said guide including the aperture being spaced from said plane and said axis.

3. A scanning directive antenna system for determining the direction of an incoming wave in a given plane comprising a wave guide having an aperture near one end, a paraboloidal reflector attached to said guide and facing said aperture, said aperture being spaced from said plane in a direction normal to said plane and said guide extending away from said plane, and means for rotating said guide and attached reflector.

4. In combination, a vertical wave guide having at the top an acute angle elbow or bend and a transceiving antenna aperture, the plane of said aperture being at an acute angle to the longitudinal axis of the guide, means for supplying to said guide waves polarized in a plane perpendicular to said axis, and means for rotating said guide about said axis, whereby the polarization rotates 360 degrees in the plane of said aperture and the polarization splitting is negligible.

5. A directive antenna system comprising a combination in accordance with claim 4, a paraboloidal reflector attached to said guide and facing said aperture, the bisector of the angle between the horizontal plane and a line connecting the mid-points of said reflector and aperture being coincident with the axis of the reflector, whereby maximum action for the entire system occurs in the horizontal plane.

6. In an antenna system, a paraboloidal reflector having its axis extending downwardly at an acute angle to the horizontal plane, a vertical wave guide having at the top an elbow or bend and an aperture facing said reflector, said aperture being in a plane parallel to the opening of the reflector, the angle between the horizontal plane and the line connecting the mid-point of said aperture and the vertex of said reflector being equal to twice the first-mentioned angle, whereby maximum antenna action occurs in the horizontal plane containing said vertex and the horizontal plane directive pattern is not distorted by the wave guide.

7. A directive microwave antenna system having in a given plane of radio action a directive

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pattern including a major lobe and a set of minor lobes, said system comprising a paraboloidal reflector having its vertex in said plane, a wave guide having an aperture facing said reflector and extending away from said plane, the bisector of the angle included between said plane and a line passing through said vertex and the mid-point of said aperture being coincident with the axis of said reflector whereby said pattern is not distorted and the minor lobe intensity is at least 20 decibels below that of the major lobe.

8. An antenna system comprising a paraboloidal reflector having its axis extending downwardly from its vertex at an acute angle to the horizontal plane, a vertical wave guide supporting said reflector and having at the top an aperture facing the reflector, the plane of said aperture being at an acute angle to the longitudinal axis of the guide and parallel to the plane of the reflector opening, said guide being positioned entirely below the horizontal plane, means connected to said guide for supplying thereto or receiving therefrom waves polarized perpendicular to said longitudinal axis, and means for rotating said guide and reflector about said longitudinal axis, whereby the intensities of the minor lobes of the horizontal plane directive pattern are relatively small, the polarization of the emitted or collected wave rotates in a vertical plane as the pattern rotates in the horizontal plane, and the ellipticity or polarization splitting is negligible when the polarization of the emitted or collected wave is oblique.

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