Sept. 20, 1949. C. C. CUTLER 2,482,158

DIRECTIVE ANTENNA SYSTEM

Filed July 21, 1945 5 Sheets-Sheet 1

FIG. 1

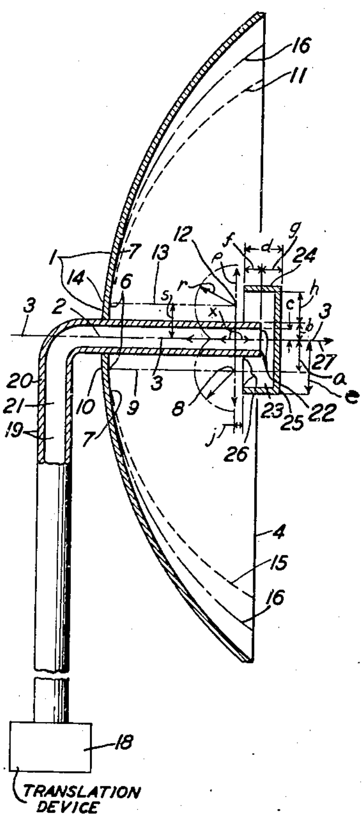


FIG. 2

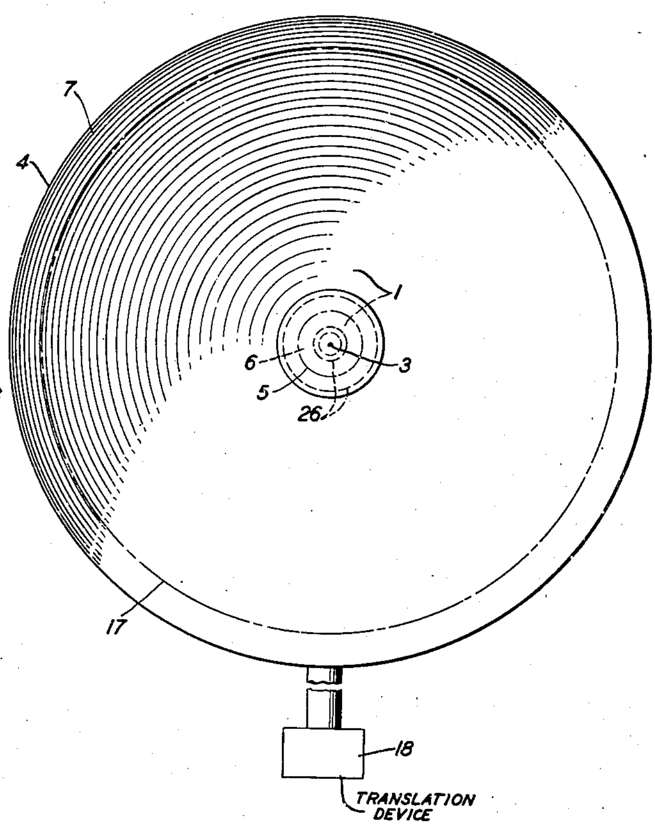
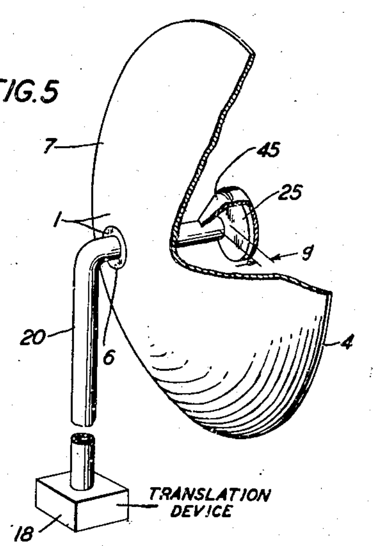


FIG. 5



INVENTOR
C. C. CUTLER
BY A. J. Zerbarini
ATTORNEY

Sept. 20, 1949.

C. C. CUTLER

2,482,158

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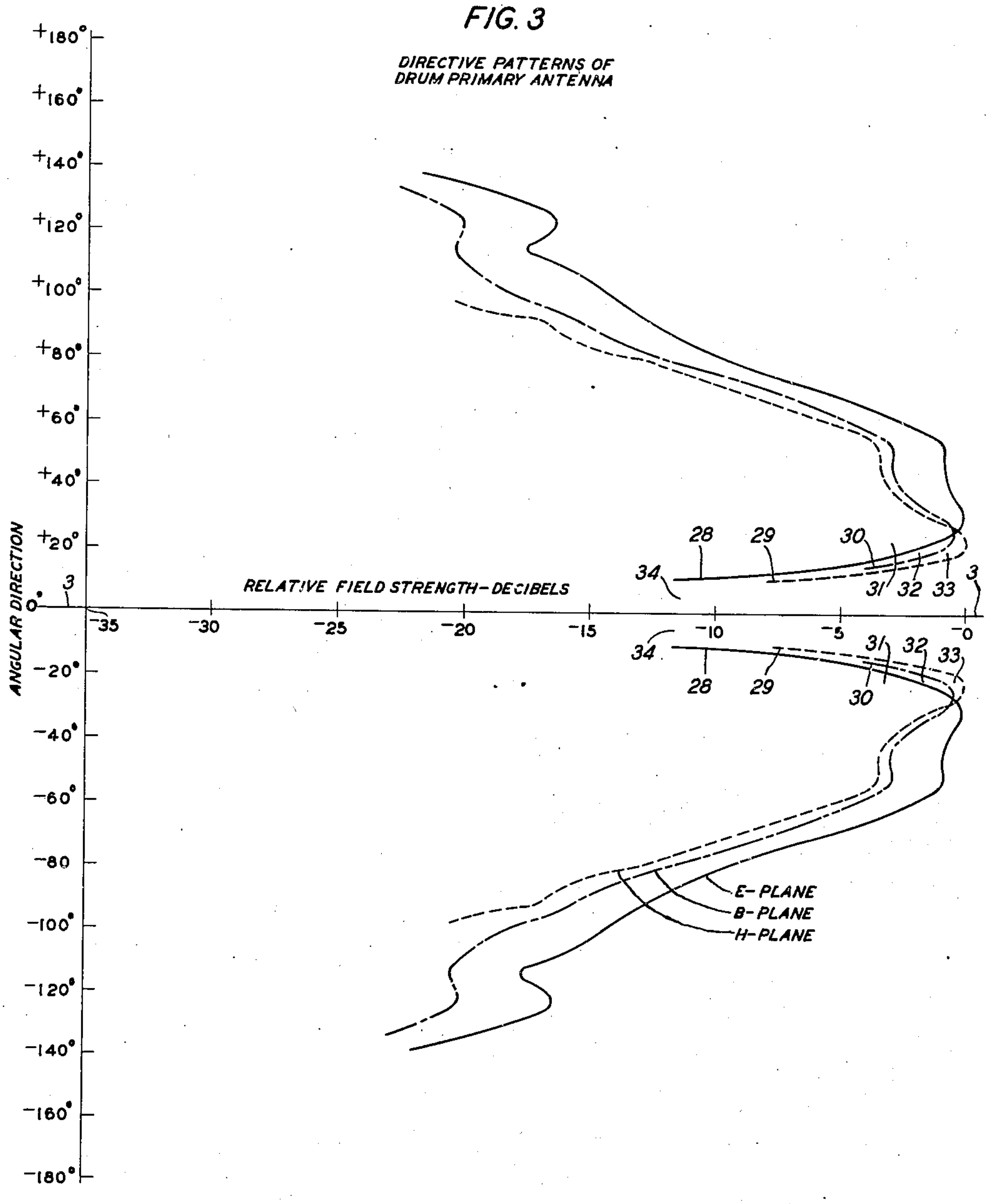
FIG. 3



INVENTOR
C.C.CUTLER
BY A. J. Zerbarini
ATTORNEY

DIRECTIVE ANTENNA SYSTEM

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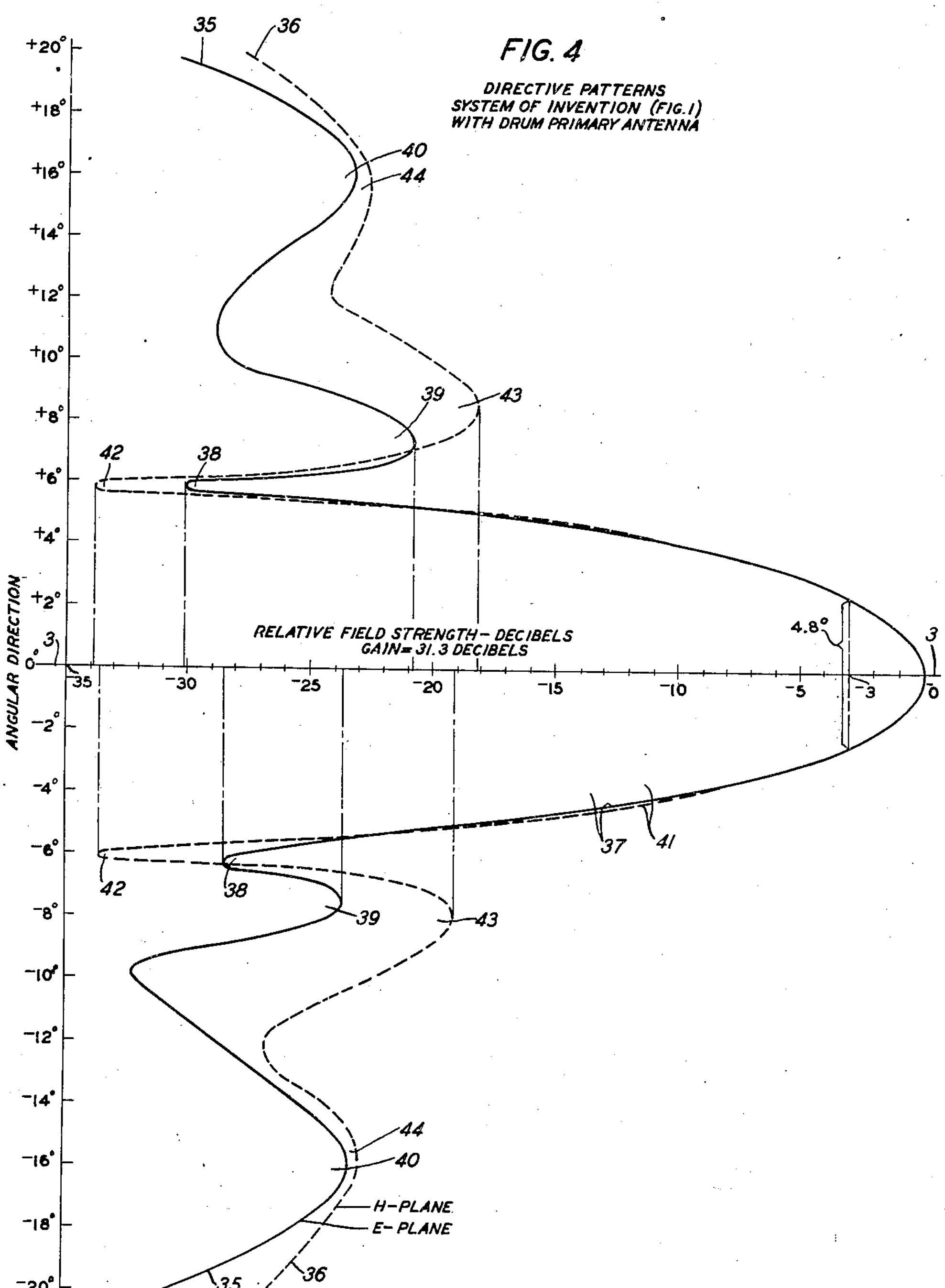
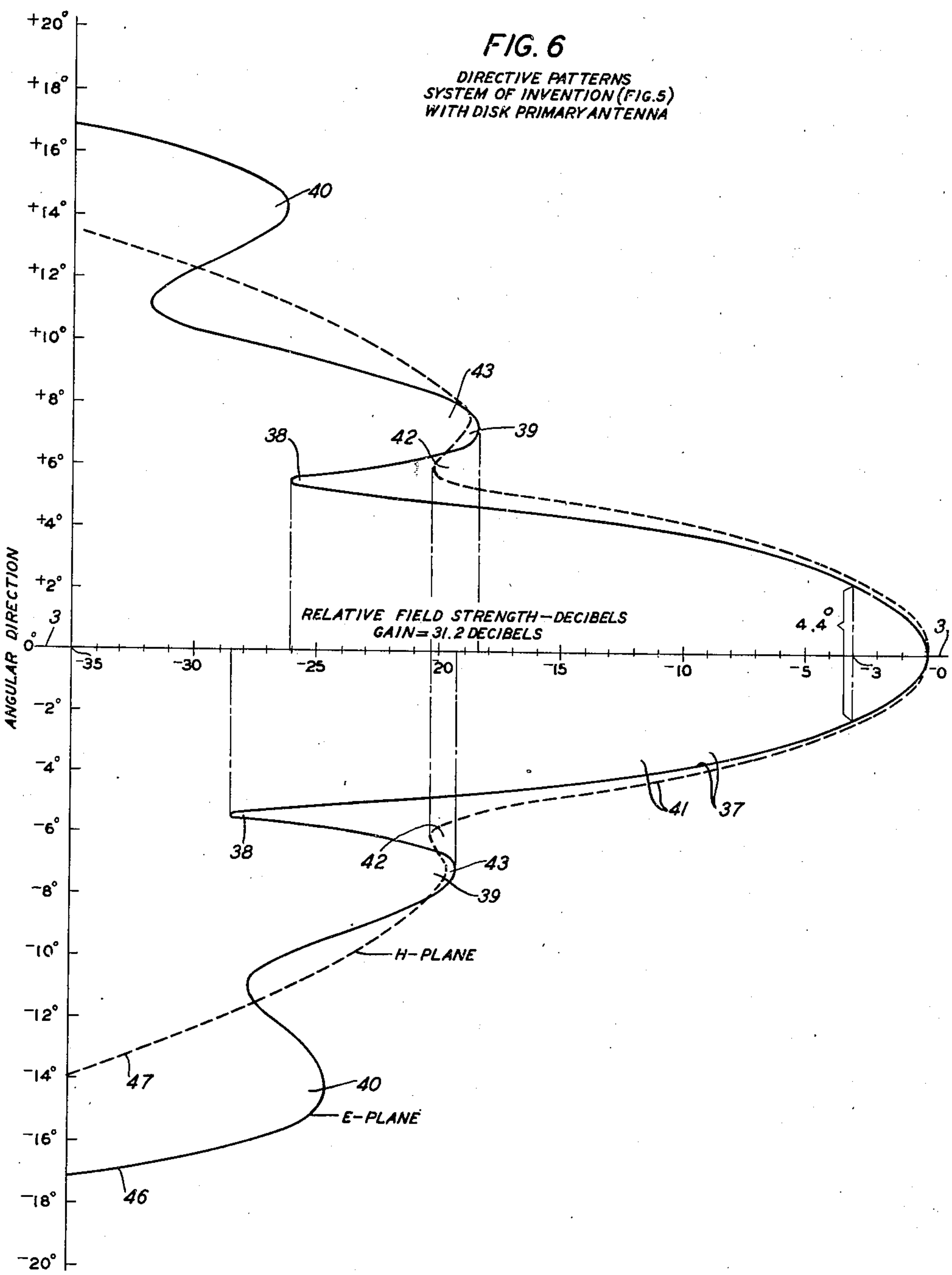
FIG. 4



INVENTOR
C. C. CUTLER
BY A. J. Zerbarini
ATTORNEY

FIG. 6

DIRECTIVE PATTERNS
SYSTEM OF INVENTION (FIG. 5)
WITH DISK PRIMARY ANTENNA



INVENTOR
C. C. CUTLER
BY
A. J. Zerbarini
ATTORNEY

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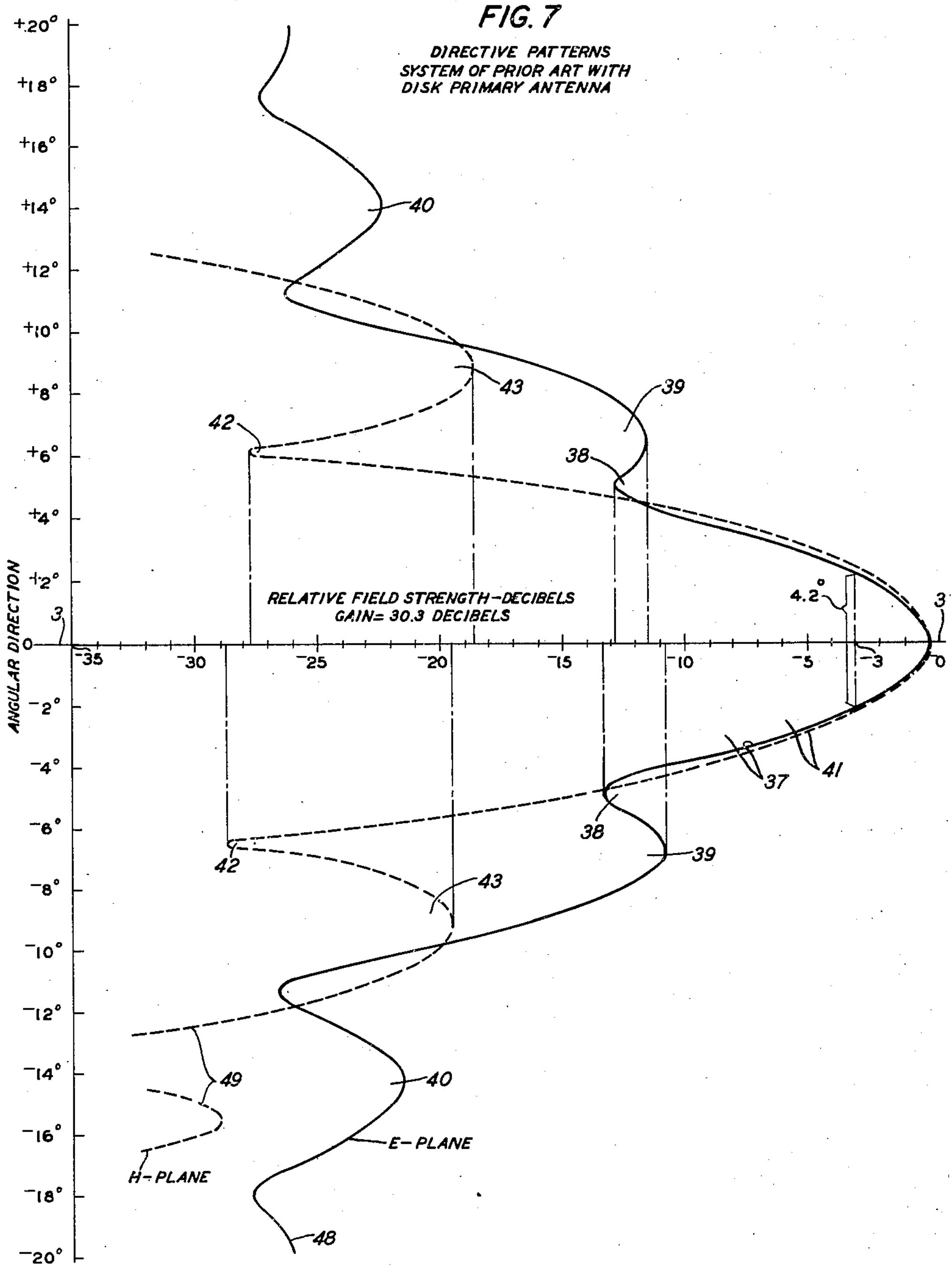
FIG. 7



INVENTOR
C.C.CUTLER
BY A.J. Zerbarini
ATTORNEY

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2,482,158

UNITED STATES PATENT OFFICE

2,482,158

DIRECTIVE ANTENNA SYSTEM

Cassius C. Cutler, Oakhurst, N. J., assignor to Bell Telephone Laboratories, Incorporated, New York, N. Y., a corporation of New York

Application July 21, 1945, Serial No. 606,426

3 Claims. (Cl. 250—33.65)

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

As is known, highly directive point-beam antenna systems comprising a conventional paraboloidal reflector and a front or rear feed of the dielectric guide type have been suggested for use in the microwave field and in particular in the microwave radio detecting and ranging or so-called "radar" field. For example, Figs. 1 and 2 of my copending application, Serial No. 518,377, filed January 15, 1944, now Patent No. 2,422,184, issued June 17, 1947, illustrate a prior art point-beam antenna system comprising a main conventional paraboloidal reflector, a dielectric guide extending through the reflector vertex to the reflector focus and having at its end a primary antenna aperture, and a front disk reflector facing the aforementioned aperture and the main reflector. While, in general, the prior art systems, including the one just described, are being used with success, the results secured are by no means entirely satisfactory, principally because the electric or E plane and the magnetic or H plane major lobe patterns are substantially different in shape and, in both planes, pronounced or relatively strong minor lobes are obtained. The difference in the shapes of the two patterns, and the relatively large intensity of the minor lobes, may be ascribed to the fact that the primary antenna aperture does not transceive a perfectly spherical wave front or, stated differently, does not sufficiently approximate or simulate the ideal point source or point receiver for a paraboloidal reflector. As is well understood, especially in the optical art, a paraboloidal reflector converts a spherical wave front originating at its point focus into a plane or flat wave front perpendicular to the reflector axis and, conversely, transforms an incoming plane wave front into a spherical wave front centered on the focus. If the active or primary antenna element at the point focus is not dimensionless, a perfectly flat wave front is not established in the case of transmission and, in reception, the spherical wave front incoming to the primary antenna is not absorbed in an optimum manner, that is, maximum directive action in transmission, and in reception are not obtained. Considered in terms of optics, under the condition assumed above, undesired

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aberration occurs and the system is, strictly speaking, not aplanatic. Accordingly, it appears desirable to obtain a paraboloidal antenna reflector system which substantially avoids the detrimental operational effects inherent in conventional prior art reflector systems and which, in addition, possesses distinct advantages over the reflector systems heretofore suggested.

It is one object of this invention to transmit or receive a maximum amount of radiant energy along a given path or direction.

It is a further object of this invention to obtain, in a point-beam directive antenna system, a directive characteristic which is symmetrical about the axis or direction of maximum action.

It is another object of this invention to secure, in a point-beam directive antenna system, E and H plane major lobe patterns having the same shape.

It is another object of this invention to obtain, in a point-beam directive antenna system, a directive pattern in any plane comprising a symmetrical major lobe having a narrow half power width, deep nulls adjacent thereto, and minor lobes of negligible intensity.

It is another object of this invention to transform a quasi-toroidal wave front into a plane wave front.

It is another object of this invention to produce, in transmission, a flat wave front and, conversely, in reception, to absorb a maximum amount of energy from an incoming flat wave front, utilizing a concave antenna reflector at least a portion of which has a parabolic contour.

It is still another object of this invention to obtain, in an antenna system comprising a concave passive reflector and an active or primary antenna therefor, directive radio action comparable to that theoretically obtainable in a hypothetical system comprising a paraboloidal reflector and a true point or dimensionless primary antenna at the reflector focal point.

As used herein the term "wave guide" generically applies to conductive guides, such as a two-wire or coaxial line, and to dielectric guides such as a bare, solid dielectric rod or a metallic pipe containing a liquid, solid or gaseous dielectric substance. The term "feed" applies broadly to the primary or active antenna, which cooperates with the main reflector or secondary antenna, and to the associated dielectric guide; and this term is applicable to receiving, as well as transmitting, systems. In transmission, the feed supplies or feeds the energy delivered by the transmitter to the main reflector, and in reception it supplies or feeds the energy collected by the main reflector to the receiver or other utilization device. Also, as used herein, the term "directive characteristic" connotes the directive quality, considered in the solid or in three dimensions, of an antenna, whereas the term "directive pattern" signifies the trace or projection on a specified plane, such as the E plane or H plane, of the directive characteristic.

In accordance with one embodiment of the invention, an antenna system comprises a paraboliform reflector having a reflecting surface corresponding to that obtained by rotating a parabola, and more particularly its axis, about a line parallel to the parabola axis and herein termed the "reflector axis." The focus of the paraboliform reflector is a circular, or more accurately, a circumferential line; and this focal line or focal circle is included in a plane extending perpendicular to the reflector axis. The primary antenna for the reflector comprises a wave guide having an annular aperture positioned on, that is, coincident with, the circular focal line. In operation, the E and H plane major lobes are substantially the same, and very sharp, and the minor lobes are negligible.

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, respectively, side sectional and front views of one embodiment of the invention;

Fig. 3 illustrates the measured directive patterns for the primary antenna in the embodiment of Figs. 1 and 2;

Fig. 4 illustrates the directive patterns for the complete embodiment of Figs. 1 and 2;

Fig. 5 is a perspective view of another embodiment of the invention;

Fig. 6 illustrates the directive patterns for the embodiment of Fig. 5; and

Fig. 7 illustrates, for comparison purposes, the directive patterns of a comparable prior art antenna comprising a conventional paraboloidal reflector and a front disk reflector.

Referring to Figs. 1 and 2, reference numeral **1** denotes a concave main reflector having a vertex **2**, a reflector axis **3**, a circular opening **4** and a circular or circumferential focal line **5**, that is, a focal circle or ring focus **5**. The reflector **1** has a flat central or inner portion **6** and an outer parabolic surface **7** and hence, in any plane containing axis **3**, its contour or configuration is paraboliform. In general, the surface of reflector **1** corresponds to that obtained by rotating the axis of a parabola, and the parabolic curve portion lying on one side of the parabola axis, about a given line parallel to the parabola axis, and in a manner such that the axis of the parabola rotates about the line and generates a cylinder. Thus, in Fig. 1, reference numerals **8**, **9** and **10** denote, respectively, the focal point, the axis and the vertex of a parabola, the upper portion of which is represented by a dash-dash line **11** and the lower portion of which coincides with the lower portion of reflector **1**. By rotating the parabola about the axis **3** of reflector **1** a paraboliform surface is generated or obtained, the numerals **12**, **13** and **14** denoting, respectively, the focal point, the axis and the vertex of the parabola when it assumes a position **15** opposite from position **11**. The focal points **8** and **12** lie on the ring focus or curvate focal line **5**. As will be explained hereinafter, the distance a between the reflector axis **3** of the main reflector **1** and the parabola axis **9**, or **13**, that is, the radius a of the ring focus **5**, is critically dependent upon the design of the primary antenna. For purpose of comparison, numeral **16**, Fig. 1, and numeral **17**, Fig. 2, denote, respectively, the parabolic contour and circular opening of a true paraboloidal reflector having an axis aligned with the axis **3** of the paraboliform reflector **1**.

Reference numeral **18** denotes a translation device such as a radar transceiver and numeral **19** designates a dielectric circular guide comprising a metallic tube **20** containing a dielectric **21** (air) and having an outside radius b and an inside radius c. The guide **19** extends through the vertex portion **6** of reflector **1** and along the reflector axis **3**. It is connected at its near end to device **18**, and a circular iris or opening **22** of radius c is provided at its far end. Numeral **23** denotes a metallic cup or drum having a depth or axial length d and comprising a cylindrical wall or rim **24** and a circular disk reflector **25** attached thereto and having a radius e. In practice, the wall **24** and disk **25** are preferably formed from one piece of sheet metal. The disk **25** faces both aperture **22** and the main reflector **1**. The guide **19** projects into the drum **23** a distance f and forms with the outer surface of guide **19** an annular antenna aperture **26**. A streamline housing (not shown) of electrically transparent material encloses the drum **23** and antenna aperture **26** and rigidly secures the drum primary antenna to guide **19**.

The axial spacing between the disk **25** and the iris **22**, and the radial spacing between guide **19** and the rim **24** are denoted, respectively, by the reference letters g and h. The circular iris **22**, the circular disk **25**, the annular antenna aperture **26** and the ring focus **5** are coaxially related and centered on the main reflector axis **3**. The radius a of the ring focus **5** is greater than the radius c of iris **22** and smaller than the radius e of disk **25**. More specifically, the ring focus **5** is positioned equally distant from the inner and outer peripheries of aperture **26**, and at a distance j measured along axis **3** from aperture **26**. In one embodiment actually constructed in accordance with Fig. 1 and tested at an operating or design wavelength λ equal to 3 centimeters, as discussed below in connection with Figs. 3 and 4, the dimensions a, b, c, d, e, f, g, h and j were approximately 0.64λ, 0.33λ, 0.30λ, 0.66λ, 1.0λ, 0.29λ, 0.37λ, 0.66λ and 0.165λ, respectively.

In operation, Figs. 1 and 2, assuming device **18** is a radar transceiver, microwaves supplied by the transmitter in device **18** are conveyed over guide **19** and emitted at the iris **22**. The waves impinging upon the disk reflector **25** and reflected thereby pass through the annular antenna aperture **26** and illuminate or energize the entire concave main reflector; and are thence propagated primarily in the direction **27** aligned with the reflector axis **3**. In reception, the converse operation is obtained, and the incoming echo waves impinging upon reflector are directed into the drum **23** and thence conveyed over guide **19** to the receiver and indicator in device **18**.

Considered in more detail, applicant has found by actual measurement that the wave front established by the primary antenna 26 in any plane containing the reflector axis 3 may be expressed in cylindrical coordinates by the equation

$$x^2+(\rho-a)^2=r^2 \quad (1)$$

where a and r are constants and x and ρ are cylindrical coordinates. See "Elements of Analytic Geometry," by P. E. Smith and A. S. Gale, page 394.

The above equation represents a surface similar to a torus which, as is known, is the surface generated by revolving a conic section about a line included in the plane of the section. With r constant the section is a circle and the surface corresponds to a circular torus. Incidentally, when the line mentioned above does not pass through the section, that is, when a is larger than r, the surface generated is the same as that of the well-known toroidal or doughnut-shaped coil. Hence the wave front, considered in the solid or in the three dimensions, produced by the annular antenna aperture 26 is quasi-toroidal with an apparent origin coincident with the circular focus 5. For a drum primary antenna, such as the drum 23 which produces, as explained above, a quasi-toroidal wave front, the proper concave reflecting surface, for optimum gain and an optimum point-beam, is given by the equation

$$(\rho-a)^2=-4Fx \quad (2)$$

where F is the focal length of the reflector, and a is a constant and, as stated above, is the radius of the ring focus 5. See page 179 of the textbook mentioned above.

Equation 2 represents the surface generated by a parabola rotated about a line parallel to its axis at a distance a from the axis. Hence, in accordance with the invention, a paraboliform reflector 1 having a ring focus is utilized with a primary antenna which produces or receives a quasi-toroidal wave front, the ring focus and the apparent origin of the quasi-toroidal front being coincident. The radius a of the ring focus, and therefore the relative areas of the vertex portion and outer portion of reflector 1, are determined by the design or size of the primary antenna 26 and, in particular, by the radius of the circular origin of the quasi-toroidal wave front. In the embodiment of Fig. 1, the radius of the circular origin corresponds to the mean radius of the annular antenna aperture 26.

Referring to Fig. 3, reference numerals 28 and 29 denote, respectively, the measured directive zero or E plane pattern and the measured 90-degree of H plane pattern, of a primary antenna 26 of the drum type, as shown in Fig. 1, the drum dimensions being as given above. While the E plane may have any position, during the test it was horizontal. Reference numeral 30 denotes the directive pattern taken in the 45-degree plane bisecting the dihedral angle formed by the E and H planes and hereinafter termed "B" plane. Reference numerals 31, 32 and 33 denote, respectively, the major lobes of patterns 28, 29 and 30. As shown in Fig. 3, the three patterns are substantially the same so that the major lobes or beam, considered in the solid, is symmetrical about the axis 3 of reflector 1. Because of the unavoidable presence of the guide 19, each major lobe is bifarious or bicephalous and includes a cone-shaped core or axial region 34 of null action. Since the guide 19 extends between the primary antenna 26 and the secondary antenna 1, and is aligned with the beam core, the cone of null action is not significant and the entire reflector 1 is adequately illuminated. The lobe, it will be noted, tapers from a maximum intensity value in the axial region to a value about 10 decibels below maximum at ±80 degrees whereby optimum illumination is obtained as explained in my Patent 2,422,184 mentioned above.

In Fig. 4, reference numerals 35 and 36 designate, respectively, the E plane and H plane measured patterns of a complete system, such as illustrated by Fig. 1, and comprising a main paraboliform reflector having a ring focus and a primary antenna of the drum type. The E plane pattern 35 includes a major lobe 37, the first nulls 38, the first minor lobes 39 and the secondary minor lobes 40; and the H plane pattern includes a major lobe 41, the first nulls 42, the first minor lobes 43 and the secondary lobes 44. As shown, the portions of major lobes 37 and 41 above −10 decibels are exactly superimposed, and the portions below −10 decibels are almost exactly superimposed, so that a point-beam having, as is desired, equal E plane and H plane widths is secured. The half power width of the major lobes 37, 41, taken at the −3 decibel point, is about 4.8 degrees and the axial gain is 31.3 decibels. Also, as is desired, the E plane and H plane first nulls 38, 42 are down at least 30 and 30.5 decibels, respectively; and the E plane and H plane first minor lobes 39, 43 are down at least 21 and 18.5 decibels, respectively.

The system of Fig. 5 is the same, from a structural standpoint, as the system of Figs. 1 and 2 except that a disk reflector 25 is utilized in place of the drum 23, that is, the wall 24 is omitted in the system of Fig. 5. The disk reflector 25 is attached to the guide 19 by means of the electrically transparent housing 45. In Fig. 5, the ring focus is between the disk reflector 25 and the end iris 22 in guide 19, whereas in Figs. 1 and 2, it is between the main reflector 1 and the end iris 22. In one tested embodiment of Fig. 5, the spacing g between the disk 25 and the end iris 22 of guide 19 was 0.33λ, as compared to g=0.37λ for the tested embodiment of Figs. 1 and 2; and the radius a of the ring focus was 0.57λ as compared to 0.63λ for the tested system using a drum 23. Also, in the tested embodiment of Fig. 5, the spacing between the disk 25 and the ring focus was 0.13λ and the radius e of the disk 25 was 1.0λ, as in the tested embodiment of Figs. 1 and 2.

The transceiving operation of the embodiment of Fig. 5 is substantially the same as that of the system of Figs. 1 and 2. The disk primary antenna 22, 25 of Fig. 5 produces a quasi-toroidal wave front which differs to some extent from the quasi-toroidal wave front established by the drum primary antenna 22, 25, 26 of Figs. 1 and 2. Also while the directive patterns (not shown) of the disk primary antenna are of the point-beam type, they are not in general as satisfactory as the point-beam patterns shown in Fig. 4 and obtained for the drum primary antenna of Figs. 1 and 2; and accordingly the drum primary antenna of Fig. 1 is preferred over the disk primary antenna of Fig. 5.

Referring to Fig. 6, reference numerals 46 and 47, denote, respectively, the measured E and H plane directive patterns for a system similar to that illustrated by Fig. 5 and comprising a paraboliform secondary antenna 1 and a disk primary antenna therefor. Fig. 7 illustrates, for purpose of explanation and comparison, the measured E plane pattern 48 and the measured H plane pattern 49 for a prior art system comprising a true paraboloidal reflector 16, 17 (Figs. 1 and 2) and a disk primary antenna such as included in the system of Fig. 5. As in Fig. 4, the E plane patterns 46 (Figs. 6) and 48 (Fig. 7) each include a major lobe 37, the first nulls 38 and the first minor lobes 39; and the H plane patterns 47 (Fig. 6) and 49 (Fig. 7) each include a major lobe 41, the first nulls 42 and the first minor lobes 43.

Comparing the E plane patterns 46 (Fig. 6) and 48 (Fig. 8) for the system of the invention, Fig. 5, and the comparable prior art system, it will be seen that the first minor lobes 39, Fig. 6, for the system of the invention are at least −18 decibels down and therefore relatively low, as desired, whereas the first minor lobes 39, Fig. 7 for the prior art system, are only about −12 decibels down. In the H plane, the first minor lobes 43, Figs. 6 and 7, of the two systems have about the same intensity, −19 decibels. The first E plane minor lobes 39, Fig. 7, are very close to the major lobe 37 and in effect form with the major lobe 37 a very wide main lobe at the −12 decibel point, whereby the upper portions of the E and H plane main lobes, Fig. 7, for the prior art system are substantially different and a true point-beam, considered in the solid, is not obtained. On the other hand, the E and H plane major lobes 37, 41, Fig. 6, for the system of the invention are substantially the same down to the −18 decibel point, and a highly satisfactory point-beam is secured. As indicated in the Figs. 6 and 7, the gain of the system of the invention is about 1 decibel greater than the gain of the prior art system.

As is apparent from a comparison of Figs. 4 and 7, the patterns 35 and 36 for the system of Fig. 1, comprising a drum type primary antenna, are greatly superior to those of the prior art system. Thus, in Fig. 4 the major lobes 37 and 41 have equal half power widths and are exactly superimposed, so that an excellent point-beam is obtained, whereas in Fig. 7 the H plane major lobe 37 is wider than the E plane major lobe 41. The first nulls 38, 42 in Fig. 4 are much deeper than those in Fig. 7 and the E plane minor lobes 39, Fig. 4, are much lower than the corresponding minor lobes in Fig. 7. The gain 31.3 decibels for the system of Fig. 1 is 31.3 decibels whereas the gain for the prior art system is about 30.3 decibels. Hence, as compared to the prior art system, the antenna systems of the invention have a higher gain, lower minor lobes, and more desirable point-beams.

Although the invention has been explained in connection with certain embodiments it is to 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.

What is claimed is:

1. In combination, a concave main reflector having an axis and a focal circle, said focal circle being included in a plane perpendicular to and centered on said axis, a dielectric guide extending through the vertex of said reflector and along said axis, said guide having an end circular aperture, and a flat circular reflector facing said aperture and said main reflector, the diameter of said focal circle being greater than that of said circular aperture and smaller than that of said circular reflector.

2. In combination, a paraboliform main reflector having a focal circle, a circular dielectric guide extending through the vertex of said reflector and having an end circular aperture, a drum reflector comprising a cylindrical wall and a circular disk reflector attached to said wall and facing said aperture, the diameter of said focal circle being intermediate to the diameters of said drum reflector and said aperture.

3. A combination in accordance with claim 2, said guide extending into said drum reflector and forming therewith an annular antenna aperture aligned or coincident with said focal circle.

CASSIUS C. CUTLER.

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