

April 5, 1955

W. D. LEWIS

2,705,754

DIRECTIVE ANTENNA SYSTEMS

Filed Jan. 24, 1945

3 Sheets-Sheet 1

FIG. 2

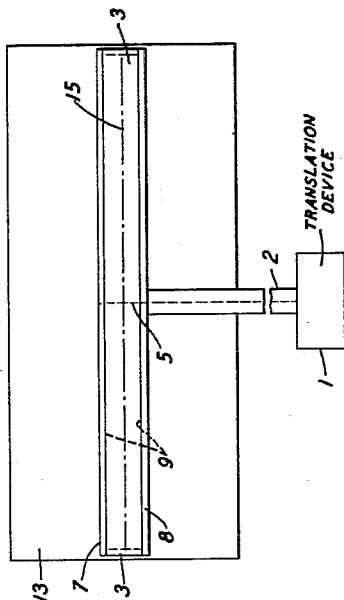


FIG. 1

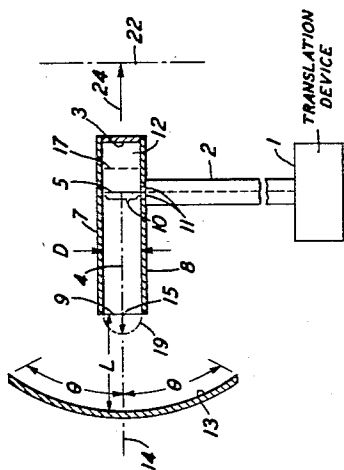


FIG. 4

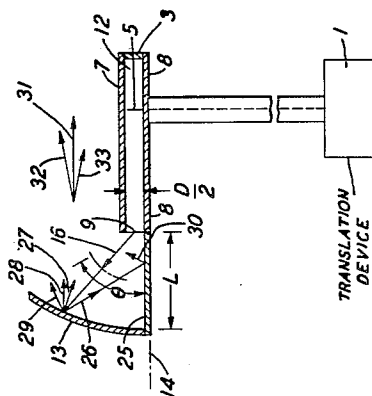
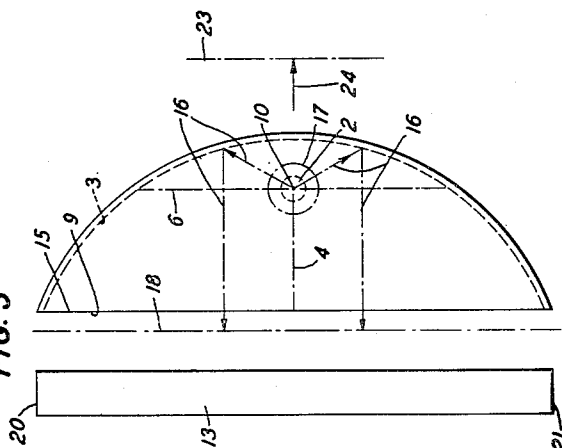


FIG. 3



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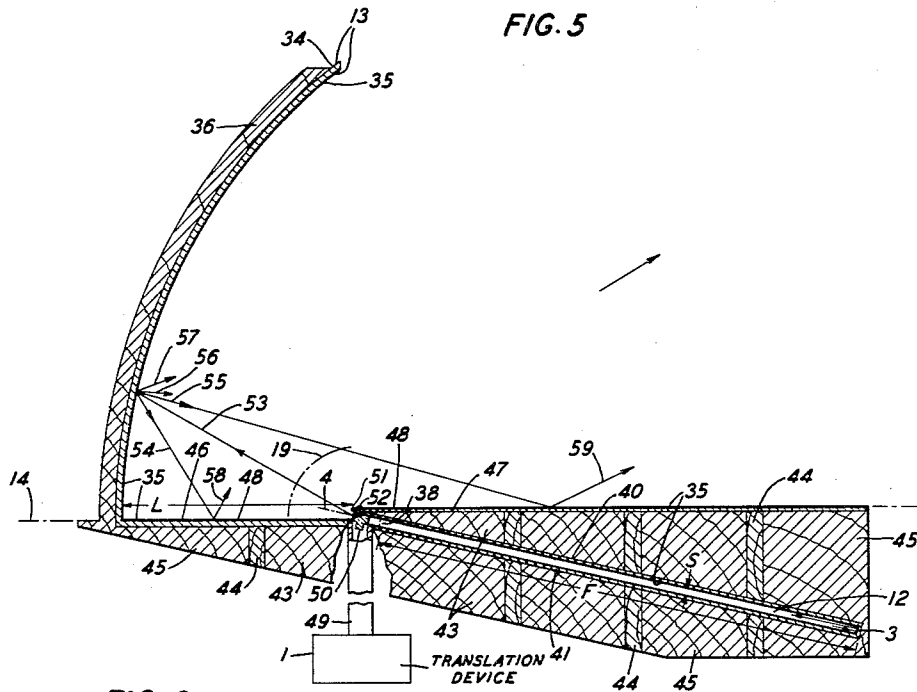
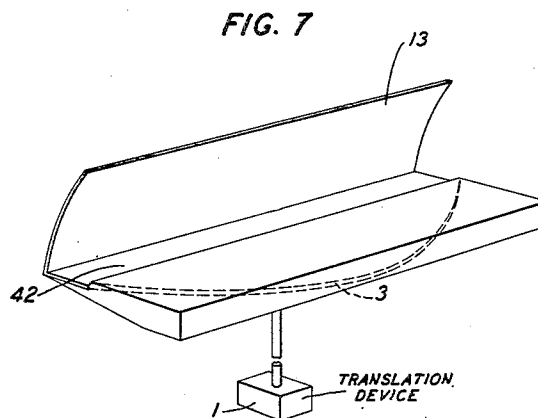
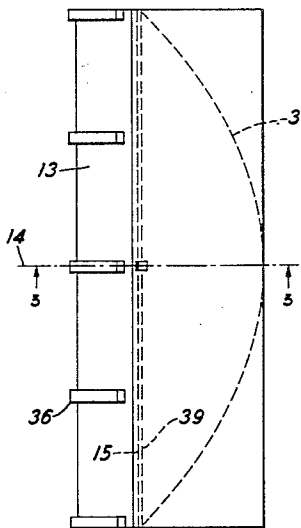


FIG. 6



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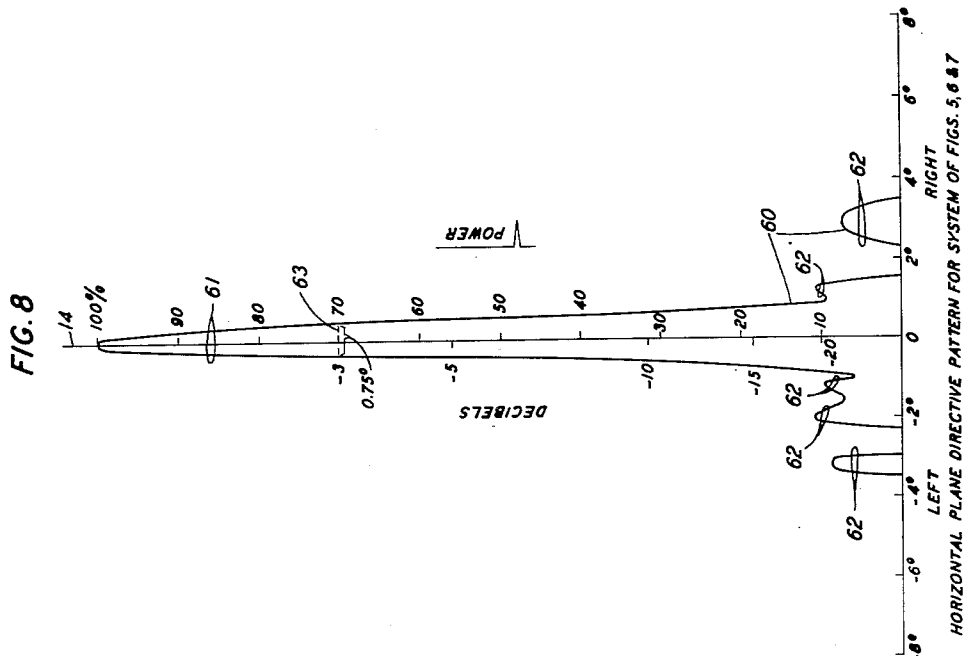
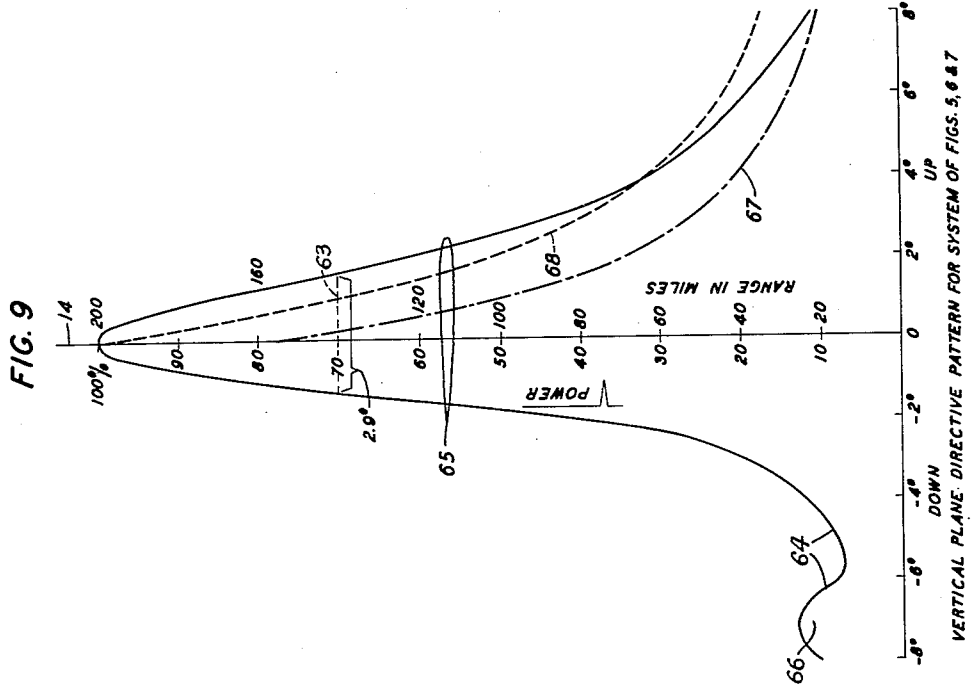
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DIRECTIVE ANTENNA SYSTEMS

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3 Sheets-Sheet 3



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2,705,754

DIRECTIVE ANTENNA SYSTEMS

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Application January 24, 1945, Serial No. 574,334

11 Claims. (Cl. 250—33.65)

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

As is known, antenna systems comprising cylindrical parabolic reflectors or paraboloidal reflectors and having a high gain, a narrow main beam or major lobe pattern and small minor lobes in the horizontal scanning plane, have been suggested for use in radar systems. Thus, Patent 2,434,253, granted on January 13, 1948, to A. C. Beck and the copending application of C. B. H. Feldman, Serial No. 489,740, filed June 5, 1943, which matured into United States Patent 2,482,162, issued September 20, 1949, each disclose a point-beam antenna comprising a cylindrical parabolic reflector and a wave guide feed or primary antenna. In one embodiment of the system of the Beck patent, the width of the major lobe at the half power point is about 6 degrees, the gain is about 17 decibels and the minor lobes are about 30 per cent of the major lobe. In another system now in use and comprising a paraboloidal reflector and a dual orifice wave guide feed for producing a fan beam, the half power widths in the vertical and horizontal planes are, respectively, 3.4 and 1.8 degrees and the gain is about 32 decibels. While the above systems have been successfully used, it now appears desirable to secure a point-beam system and a fan-beam antenna system which, as compared to prior art paraboloidal or parabolic systems, have a higher gain, a wider operating bandwidth, a sharper major lobe pattern and minor lobes at least as small as those obtained in the prior art systems. At the same time it appears desirable to secure a high gain antenna which is simple in construction as compared to high gain paraboloidal systems heretofore used.

Also, as is now known, several paraboloidal antenna systems have been suggested for securing an unsymmetrical fan-beam, such as a so-called cosecant major lobe pattern. While highly satisfactory results are attainable with the prior art cosecant paraboloidal antennas, these antennas are in general difficult to manufacture and it now appears advantageous to utilize a simple cylindrical parabolic reflector system for securing a cosecant beam.

As used herein, the term "aperture" has its optical meaning and signifies the diameter of the opening, that is, the maximum chord lying in the plane of curvature of a cylindrical parabolic reflector.

It is one object of this invention to secure an antenna system having an exceedingly high gain.

It is another object of this invention to secure an antenna system having a wide band characteristic and a very sharp major lobe.

It is another object of this invention to secure a simple, easily constructed inexpensive antenna system having a high gain, a wide band characteristic and a directional pattern in a given plane comprising a sharp major lobe and negligible minor lobes.

It is another object of this invention to secure an easily constructed fan-beam antenna system having in the horizontal plane a sharp major lobe pattern and in the vertical plane a cosecant major lobe pattern.

One embodiment of the invention comprises a large main cylindrical parabolic reflector having a long horizontal line focus, a small auxiliary cylindrical parabolic reflector facing the large reflector and having a short vertical line focus, a pair of parallel end plates attached to the bottom and top ends of the small parabolic reflector and spaced a half wavelength or less, and a primary antenna aligned with the focal line of the small reflector. The horizontal longitudinal axis of the rec-

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tangular orifice, formed by the two end plates and the short vertical ends of the small reflector, is aligned with the horizontal focal line of the large reflector.

In operation, the primary antenna energizes the short auxiliary reflector and, by reason of the small spacing and the action of the short parabolic reflector, a flat or plane wave front is produced in the rectangular orifice. After leaving the orifice the wave front becomes cylindrical and the main reflector transforms the cylindrical wave front into a flat wave front. Since the orifice of the main reflector is large, and since the wave front produced is flat, a high gain is realized. The short parabolic reflector produces highly directive action in the horizontal plane and the long parabolic reflector produces directive action in the vertical plane, so that an exceedingly sharp point-beam is secured.

In a modification, only the upper half of the main reflector is utilized and a horizontal plane reflector is attached to the bottom longitudinal edge of this half section of the main reflector so as to extend in front of and in the axial plane of the main reflector. In operation, waves reflected downwardly by the main reflector are reflected skywardly whereby a fan-beam, the upper half of which conforms to a cosecant pattern, is obtained.

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, 2 and 3 are respectively side, front and top views of one embodiment of the invention;

Fig. 4 is a side view of a different embodiment of the invention;

Figs. 5, 6 and 7 are respectively sectional side, top and perspective views of still another embodiment of the invention; and

Figs. 8 and 9 are measured directive patterns for the embodiment of Figs. 5, 6 and 7.

Referring to Figs. 1, 2 and 3 reference numeral 1 denotes a translation device such as a radar transceiver and numeral 2 denotes a coaxial line comprising an inner conductor and an outer conductor. Numeral 3 denotes an auxiliary cylindrical parabolic metallic reflector having an axis or axial plane 4, a short focal line 5 having the dimension "D" a half wavelength long or less and a long latus rectum 6. Numerals 7 and 8 denote metallic plates or guide members which are attached to the top and bottom ends of the short parabolic reflector 3 and form therewith a rectangular orifice 9. The longitudinal dimension of the orifice 9 and the aperture of the reflector 3 are coincident and equal in length. The extreme portion 10 of the inner line conductor extends through an insulator 11 in the bottom plate 8 and forms a linear primary antenna member aligned with the vertical focal line 5 of the reflector 3. The linear antenna member 10, the parabolic reflector 3 and the end plates 7, 8 constitute an auxiliary line-type antenna 12, hereinafter termed a parallel-plate or "box" antenna. Reference numeral 13 denotes a main cylindrical parabolic reflector having a focal length "L," an axis or axial plane 14, a long focal line 15, the focal line 15 being aligned with the longitudinal dimension of the rectangular orifice 9.

In operation, waves supplied by the transceiver 1 are conveyed over line 2 to the linear antenna member 10 and are thence radiated. As shown by arrows 16, the waves emitted by member 10 impinge upon reflector 3 and are then directed toward the rectangular orifice 9. In the horizontal plane containing the reflector axis 4, the wave front 17 of the waves emitted by member 10 is circular, as shown by the circular line, Fig. 3, and the parabolic reflector 3 converts this circular front to a linear front which is represented by the line 18, Fig. 3. In the vertical plane containing the focal line 5 of reflector 3 the wave front 17 of the waves emitted by member 10 is almost linear, as illustrated in Fig. 1, by reason of the small spacing between the end plates 7, 8; and it remains linear in the parallel-plate antenna 12. Hence, in the rectangular orifice 9, the wave front is flat. The wave front of the waves emitted by orifice 9 and propagated toward the main reflector 13 remains linear in the horizontal plane containing the focal line 15 as shown

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by line 18, but in the vertical plane containing the axis 14 of reflector 13, the wave front becomes circular after leaving orifice 9, as shown by the dot-dash curve 19, Fig. 1. Consequently, as is desired, the long or main reflector 13 is energized or illuminated by a wave arriving from the focal line 15 and having a cylindrical wave front.

The auxiliary or short reflector 3 produces maximum action along the intersection of the axial planes 4, 14 of the two reflectors so that the illumination of the long reflector, Fig. 3, is tapered from a maximum at the center to values less than maximum at the transverse ends 20 and 21. In the vertical plane containing axis 14 of reflector 13, the circular wave front 20 is transformed by the long reflector 13 into a linear wave front, as shown by the straight dot-dash line 22, Fig. 1 and, in the horizontal plane containing the focal line 15, the parabolic reflector 13 functions in a sense as a plane reflector so that the linear wave front is not changed, as shown by the straight line 23, Fig. 3. In other words, the cylindrical wave front derived from the plane wave along the focal line 15 is converted to a plane wave front which is propagated in the axial direction 24. As compared to the wave front produced by prior art systems comprising cylindrical parabolic reflectors, and which produce a so-called fairly flat wave front, applicant's system produces a purely flat, or more nearly perfectly flat, wave front.

Partly by reason of the purely flat wave front secured, an exceedingly high gain for a main reflector having a given aperture, is obtained. The beam produced by the system of Figs. 1, 2 and 3, comprising a "full" main reflector, is essentially a point-beam, the half power widths of the major lobe patterns, taken in the horizontal and vertical planes, being exceedingly small. While the vertical and horizontal plane patterns are interdependent to some extent, generally speaking, the horizontal directivity is produced by the directive action of the short parabolic reflector 3 whereas the vertical plane directivity is produced by the directive action of the long parabolic reflector 13. In reception, the converse operation obtains by virtue of the reciprocity theorem. Obviously, if desired, the reflectors 3 and 13 may be rotated 90 degrees so that the focal lines of the auxiliary reflector 3 and the main reflector 13 are, respectively, horizontal and vertical, instead of as shown in Figs. 1, 2 and 3. The high gain system of Figs. 1, 2 and 3 is much easier to construct or manufacture than a comparable paraboloidal system and much less bulky than a comparable horn system.

In the system of Figs. 1, 2 and 3, when the waves pass through the rectangular orifice 9 separated by distance "D" some reflection occurs. This reflection may be reduced by increasing "D." As "D" is increased, however, the directivity of the orifice 9 increases and the illumination at the edge of the main reflector 13, and therefore the efficiency of the antenna, decrease. If the aperture of the main reflector or, stated differently, if the aperture angle 2θ is fixed, a compromise value of D must be used. If, for a given value of 2θ , the compromise value of D is not entirely satisfactory, the aperture angle 2θ may be decreased and both "L" and the size of the structure may be increased, whereby the efficiency and the gain in the on-axis direction 24 are increased and the gain in the so-called side or off-axis directions is decreased.

Referring to Fig. 4, the antenna system is substantially the same as that illustrated by Figs. 1, 2 and 3 except that the lower half of the main reflector 13 and the lower half of the parallel-plate antenna 12 are omitted and a plane horizontal reflector 25 extends from the bottom longitudinal edge of the half size reflector 13 to the bottom end plate 8 of the auxiliary antenna 12. The spacing between the end plates is $D/2$. As in the system of Figs. 1, 2 and 3, a flat wave front is produced in the rectangular orifice 9 and waves are emitted as, for example, in direction 16 towards the half size long reflector 13. The waves impinging upon the long reflector are reflected or reradiated by the segmental portions of the reflector 13 in various directions as, for example, directions 26, 27, 28 and 29. Since only the upper section of the long reflector is utilized, the beam width in the vertical plane is greater than the beam width in the horizontal plane, and a fan-beam is secured. Also, a portion of the reflected wavelets are reflected by the horizontal reflector 25, as illustrated by arrow 30. As a result, while maxi-

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mum action in the vertical plane occurs primarily along the axial direction 31, the intensities of the wavelets emitted in the upward directions as, for example, direction 32 are considerably greater than the intensities of the waves emitted in the downward directions as, for example, direction 33. In other words, a distorted or unsymmetrical fan-beam is secured. Also, if for a given θ , the compromise value of $D/2$ is not entirely satisfactory, θ may be decreased and L increased, whereby the efficiency and the axial or on-axis gain are increased and the off-axis is decreased somewhat.

Figs. 5, 6 and 7 illustrate, except for certain constructional details, a double parabolic system which has been actually constructed and successfully tested, the design wavelength of the system being about 9.8 centimeters. The system comprises the upper half section of a main reflector 13 having a horizontal axis or axial plane 14 and a long horizontal focal line 15, and an auxiliary parabolic antenna 12 tilted downwardly so that its axis 4 makes an acute angle with the horizontal. The main reflector comprises a wooden form 34 covered with copper foil 35 and supported by the wooden members 36. The length and height of the main reflector 13 are approximately 32 and 7 feet, respectively, corresponding to 99.5 and 22.4 wavelengths. The focal length "L" of the main reflector is 42 inches corresponding to about 10.9 wavelengths.

The auxiliary antenna 12 comprises a cylindrical parabolic reflector 3 having a short focal line 38 and a long latus rectum 39. A pair of parallel plate members 40 and 41 are attached to the ends of reflector 3. As shown on the drawing, the parabolic reflector 3 and the parallel plate members are constructed of wood covered with copper foil 35. The feed reflector 3 has a focal length "F" of 94 inches corresponding to approximately 24.3 wavelengths and the spacing S between the metallic surfaces of the plate members 40 and 41 is approximately one and a quarter inches corresponding to 0.324 wavelength. The longitudinal dimension of the rectangular orifice 42 formed by the plate members 40 and 41 and the ends of the auxiliary parabolic reflector 3 is 31 feet and 8 inches corresponding to about 98.4 wavelengths and is aligned substantially with the horizontal focal line 15 of the main reflector 13.

The tilted box antenna 12 is supported in an iron and wood framework or cradle 43 comprising the longitudinal wooden beam members 44 and the transverse wooden members 45. The top of the cradle is equipped with the wooden platforms 46 and 47 which are covered with copper foil 35. The platform 46 extends horizontally from the bottom of the main reflector 13 to the rectangular orifice 42 of the parallel-plate antenna 12 and the platform 47 extends from the rectangular orifice 42 horizontally over the parallel-plate antenna 12. While the copper foil covered platforms are not exactly in the same horizontal plane they constitute, or function as, a single horizontal plane reflector 48. By tilting the auxiliary antenna 12 so that its axis 4 and the horizontal reflector form an acute angle and mounting it in the framework 43, the parallel-plate antenna is accurately positioned in a manner utilizing simple supporting structure and, at the same time, the use of the extended horizontal reflector 48 is permitted.

Reference numeral 49 denotes an air-filled wave guide connected at its lower end to a translation device 1 and equipped at its upper end with a polystyrene plug 50. The plug 50 projects into the parallel-plate antenna 12. The surface of the plug 50 facing the auxiliary parabolic reflector 3 is unshielded and extends parallel, and adjacent, to the focal line 38 of reflector 3; and the surface facing the main reflector 13 is shielded by the brass member 51. The plug 50 and brass member 51 are securely held in position by means of the screw 52. Hence the plug 50 constitutes a unidirectional primary horn antenna aligned, substantially, with the focal line 38 of the small parabolic reflector 3 and oriented so as to illuminate reflector 3, but not reflector 13.

The operation of the system of Figs. 5, 6 and 7 is believed to be obvious in view of the explanation given above in connection with Figs. 1, 2, 3 and 4. Briefly considered, waves are supplied by the translation device or transceiver 1 over guide 49 to the primary horn antenna 50 and thence emitted, as a cylindrical wave, toward the small parabolic reflector 3. This cylindrical wave is transformed, by the parabolic reflector 3 and

by reason of the small spacing between the end plates 40 and 41, into a plane wave at the rectangular orifice 42. After leaving orifice 42, the wave becomes cylindrical, as shown by the circular line 19, and is propagated toward the main reflector 13. The entire main reflector is illuminated and, as in the system of Fig. 4, reradiation or reflection occurs at each segmental portion of the main reflector 13, the waves reflected by the long reflector 13 being vertically polarized, substantially. On the drawing, the arrow 53 illustrates a typical direction of propagation of the waves emanating from the rectangular orifice 42 and the arrows 54, 55, 56 and 57 represent several of the reflected components for this direction. While most of the components are reflected in directions which avoid the horizontal reflector 48, certain of the reflected components are reflected again by the horizontal reflector 48, as shown by the arrows 58 and 59 whereby, as explained in detail in connection with Fig. 9, the energy is propagated primarily in horizontal and upwardly pointing directions. The measured gain of the antenna system of Figs. 5, 6 and 7 is about 41 decibels and the wave front established in the rectangular orifice 39 of the large reflector 13 is within ± 45 degrees of a plane, that is, a zero degree, wave front. In reception, the converse operation obtains.

Referring to Fig. 8, reference numeral 60 denotes the measured partial directive pattern, taken in the horizontal plane and at the design frequency of 9.8 centimeters, of the antenna system of Figs. 5, 6 and 7. In determining the pattern, the antenna was connected to a receiver and vertically polarized waves were received from a local test transmitter. As previously indicated, however, the pattern represents the transmitting, as well as the receiving, characteristic. The pattern comprises a major lobe 61 having its axis aligned with the axis 4 of the auxiliary parabolic reflector 3, and the minor lobes 62. It will be noted that the major lobe 61 is symmetrical about its axis and the angular width of the major lobe 61, taken at the half power point 63, corresponding to 0.707 on the power square root scale and -3 decibels on the decibel scale, is exceedingly small, that is, about 0.75 degree. Since the horizontal beam width is very small the azimuthal direction of an incoming wave may be determined with a high degree of accuracy. Accordingly, the double parabolic antenna of Fig. 7, when mounted for horizontal rotation, is particularly suitable for use in an azimuthal scanning radar system. Beyond ± 25 degrees (not shown on Fig. 8) the measured minor lobes are not above -30 decibels. Beyond ± 70 degrees they are not above -40 decibels and beyond ± 80 degrees they are not above -50 decibels.

Referring to Fig. 9, reference numeral 64 denotes the vertical plane directive pattern for the system of Figs. 5, 6 and 7. The pattern includes the major lobe 65 which is aligned with the axis 14 of the main reflector 13 and the small minor lobe 66 on the "down" side of the pattern. The major lobe 65 is about 2.9 degrees wide at the half power point 63 and, since the corresponding width of the major lobe pattern in the horizontal plane is 0.75 degree, the antenna system produces a fan-beam. The "up" half of lobe 65 is, by reason of the action of the horizontal reflector 48, much wider than the "down" half so that the lobe is asymmetrical about its axis.

The curves 67 and 68, Fig. 9, illustrate a pair of ideal vertical patterns for an "early warning" or long range sky-searching radar antenna employed, at a ground or other surface station, for detecting enemy aircraft at all range values up to 200 miles and for observing the approach of the aircraft. Curve 67 was computed on the assumption that the approaching aircraft flies at the constant height of 3 miles, whereas curve 68 is based on the assumption that the aircraft travels at the constant height of 5 miles. Since the ideal curve 67 falls entirely below the antenna pattern, assuming the power output of the radar system to be 500 kilowatts and neglecting ground reflection, the radar system equipped with the antenna system of Fig. 7 is capable of detecting or "illuminating" any target aircraft flying at an altitude of 3 miles and having any range up to 200 miles, and is capable of continuing to detect or observe the aircraft as it approaches the radar station. Also, since the curve 68 is below the pattern 64 for the range values of 60 to 200 miles, enemy aircraft flying at a height of 5 miles and having a range of 60-200 may be detected and thereafter continuously observed.

In addition, the curves 67 and 68 are approximately

cosecant curves and the general slope of the upper half of the antenna pattern 64 is substantially the same as the slope of curve 67 or 68. Stated differently, the pattern 65 of the asymmetrical vertical plane major lobe of the antenna system of Figs. 5, 6 and 7 is essentially a cosecant pattern, whereby uniform illumination of the horizontal target plane, taken at any altitude such as 3 or 5 miles, is secured.

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 since other apparatus may be employed in successfully practicing the invention.

What is claimed is:

1. In combination, a pair of cylindrical parabolic reflectors facing each other, the focal line of one reflector and the latus rectum of the other reflector being parallel and substantially equal in length, a primary antenna element positioned adjacent to the focal line of the other reflector, and a translation device connected to said element.

2. An antenna system for transceiving waves having a given wavelength comprising a first cylindrical parabolic reflector having a short focal line, said short focal line having a length equal to or less than one half of said wavelength, a pair of parallel plates attached to the ends of said first reflector and forming therewith a rectangular orifice having a width equal and parallel to said short focal line, a second cylindrical parabolic reflector having a long focal line equal and parallel to the longitudinal dimension of said orifice, a unidirectional primary antenna positioned adjacent to the focal line of and facing said first reflector, and a transceiver connected to said primary antenna.

3. A combination in accordance with claim 2, a plane reflector extending between said parabolic reflectors.

4. In combination, a main cylindrical parabolic reflector section having a horizontal axial plane and a longitudinal edge included in said plane, a horizontal reflector attached to said edge, said horizontal reflector extending in front of said main reflector section, an auxiliary parabolic reflector facing said main reflector section, said auxiliary reflector having a latus rectum, a focal line and an axial plane extending perpendicular to said focal line, said latus rectum extending parallel to the focal line of said main reflector section, said auxiliary reflector being positioned below said horizontal reflector, said axial plane forming an acute angle with said horizontal reflector, a transceiver, and a primary antenna aligned with the focal line of said auxiliary reflector and connected to said transceiver.

5. In a radio system for transmitting and receiving waves having a given wavelength, a transceiver, a main cylindrical parabolic reflector having a focal line a plurality of said wavelengths long, a line-type antenna comprising a primary antenna element connected to said transceiver and extending less than one half of said wavelength for emitting or receiving a substantially cylindrical wave front, an auxiliary cylindrical parabolic reflector having a focal line less than one half of said wavelength long and aligned with said element, said auxiliary reflector having a latus rectum substantially equal in length to and parallel with the focal line of the main reflector, and a pair of parallel metallic flat members attached to said auxiliary reflector and forming therewith a rectangular orifice, said orifice and the focal line of the main reflector being included in the same plane.

6. An antenna system for transceiving waves having a given wavelength comprising a first cylindrical parabolic reflector having a short focal line, a pair of parallel plates attached to the ends of said first reflector and forming therewith a rectangular orifice having a width equal and parallel to said short focal line, a second cylindrical parabolic reflector facing said reflector and having a long focal line parallel to the longitudinal dimension of said orifice, and a unidirectional primary antenna positioned adjacent to the focal line of and facing said first reflector.

7. An antenna system for transceiving electro-magnetic waves comprising a main cylindrical parabolic reflector section having a first axial plane and a longitudinal edge included in said plane, said main reflector section having a long focal line substantially lying in said first plane, an auxiliary parabolic reflector facing said main reflector section, said auxiliary reflector having a short focal line and an axial plane perpendicular to said short focal line,

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the major portion of said auxiliary reflector being positioned on a side of said first plane opposite said first reflector section, said perpendicular plane of said auxiliary reflector intersecting said first plane along substantially said long focal line, said perpendicular plane forming an acute angle with said first plane, and a unidirectional primary antenna positioned adjacent to the focal line of and facing said auxiliary reflector.

8. An antenna system for transceiving electro-magnetic waves comprising a first cylindrical parabolic reflector having a short focal line and a latus rectum, a pair of parallel plates attached to the ends of said first reflector and forming therewith a rectangular orifice having a width substantially equal and parallel to said short focal line and a length substantially equal and parallel to said latus rectum, a second cylindrical parabolic reflector facing said first reflector having a long focal line substantially equal and parallel to said latus rectum, and a unidirectional primary antenna positioned adjacent to the focal line of and facing said first reflector.

9. An antenna comprising a pillbox type radiating element adapted to radiate energy in a pencil type radiation pattern, means for feeding electromagnetic energy to said pillbox, said pillbox comprising a parabolic cylindrical reflecting surface of small axial dimension and a pair of parallel plane plate members enclosing the ends of said surface, and means for eliminating substantially half of said radiation pattern, said last mentioned means comprising a single plane member extending forwardly of said pillbox in the same plane as one only of said plates.

10. An antenna as claimed in claim 1 wherein said plane member is an extension of one of said plates and has a substantially rectangular shape.

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11. A directive antenna comprising a first parabolic cylindrical reflecting surface having a first focal line, a second parabolic cylindrical reflecting surface having a second focal line and mounted facing said first reflecting surface with said second focal line being skew relative to said first focal line and perpendicular to a line parallel to said first focal line, a conductive end plate mounted perpendicular to said first focal line and extending between said first and second reflecting surfaces with said second focal line adjacent said end plate and on the same side of said end plate as said reflecting surfaces, and radiating means positioned to illuminate said first reflecting surface.

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