

[54] **WIDE-ANGLE PLANAR-BEAM, ANTENNA
ADAPTED FOR CONVENTIONAL OR
DOPPLER SCAN USING CURVED ARRAYS**

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[51] Int. Cl. **H01q 3/26**

[58] Field of Search **343/113 DE, 770,
343/771, 854**

[56] **References Cited**

UNITED STATES PATENTS

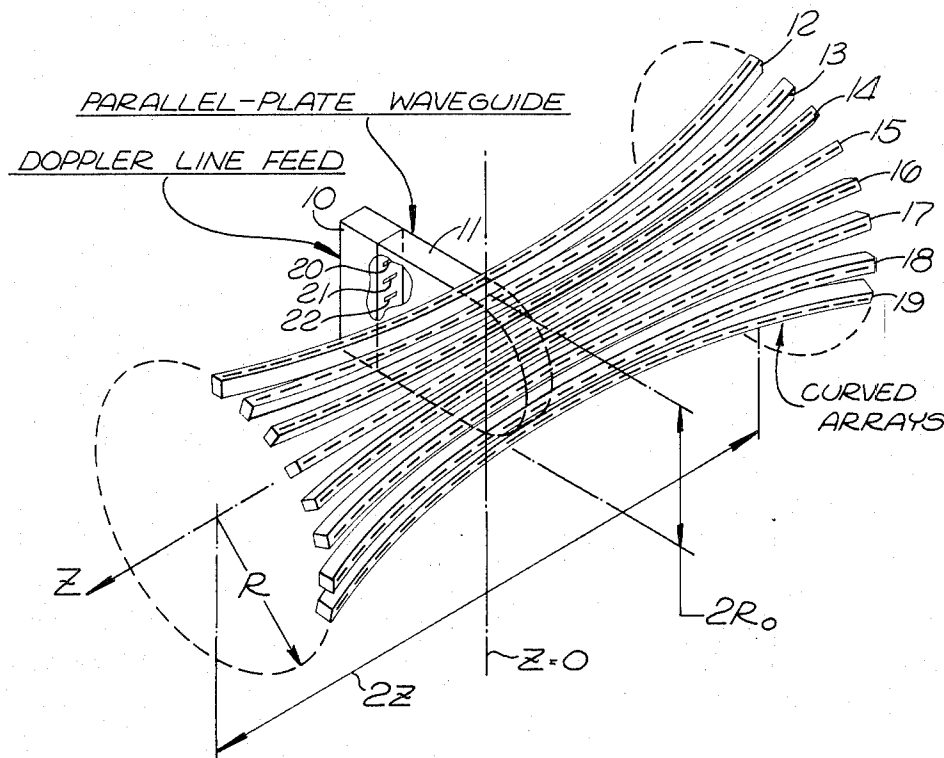
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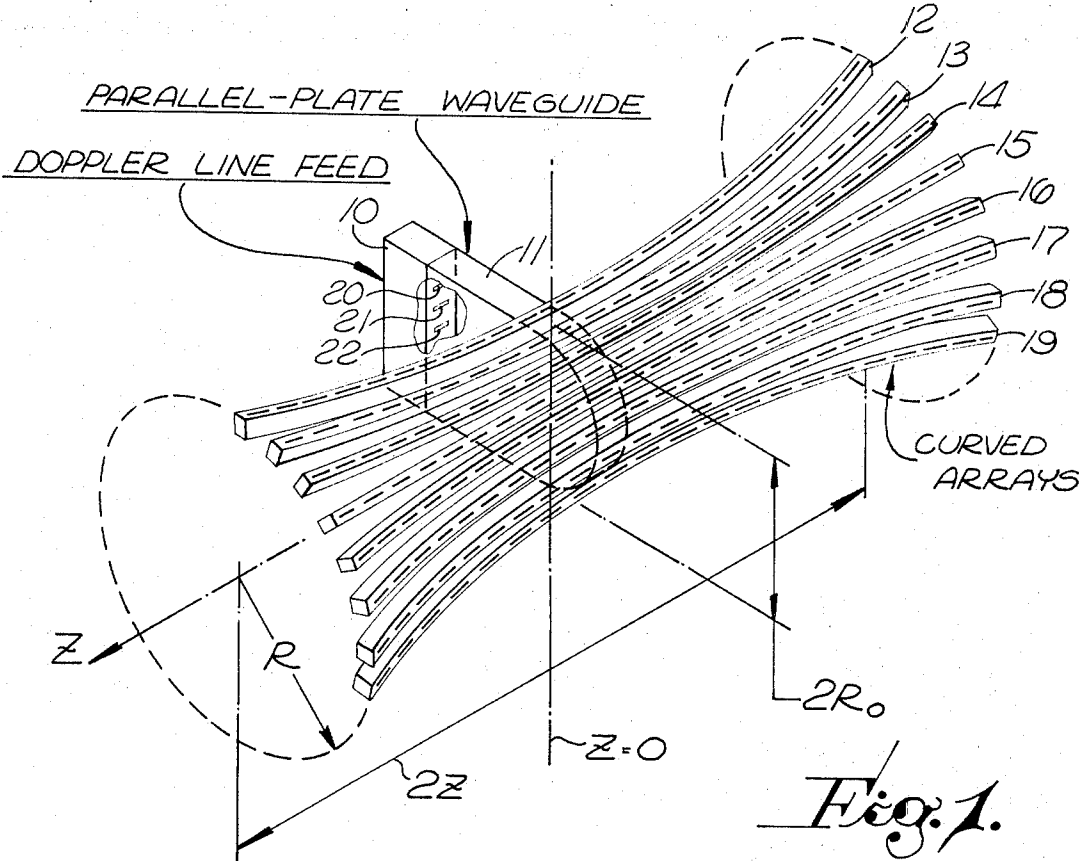
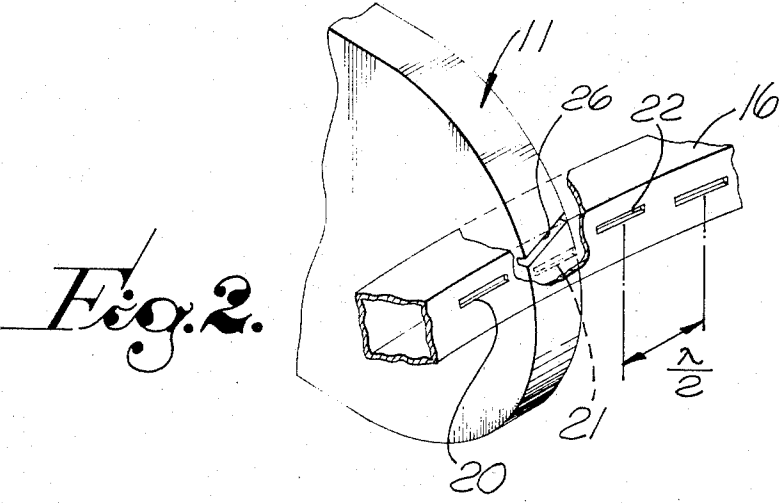
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[57] **ABSTRACT**

An antenna involving a plurality of linear arrays disposed about a surface of revolution formed about a horizontal axis by rotation of a double-ended hyperbolic curve. Each of the arrays follows a line conforming to that surface of revolution but lying entirely in a plane also containing the horizontal axis of the surface of revolution. The antenna elements of each array are excited from a transmission line such as a waveguide which is, in turn, fed from a centrally located parallel-plate waveguide planar beam generating arrangement. A conventional or Doppler-scan array provides the excitation for the so-called parallel-plate waveguide converter. The radiated beam shape tends to hold its focus and therefore has uniform width in elevation over the full azimuth beamwidth at all useful elevation beam positions.

5 Claims, 2 Drawing Figures





WIDE-ANGLE PLANAR-BEAM, ANTENNA ADAPTED FOR CONVENTIONAL OR DOPPLER SCAN USING CURVED ARRAYS

CROSS REFERENCES TO RELATED APPLICATIONS

U.S. Patent application Ser. No. 272,451 filed July 17, 1972, entitled "A Technique For Generating Planar Beams From A Linear Source or Linear Phased Array" (Jeffrey T. Nemit, inventor) contains disclosure pertinent to the description of the present invention. Accordingly, the disclosure of that application is incorporated herein by reference as though fully set forth herein.

BACKGROUND OF THE INVENTION

1. Field of the Invention

The invention relates to scannable antennas and in particular, to antenna systems relating to air navigation and guidance systems requiring vertical angle determination and an accurately maintained uniform beam shape over the beam azimuth width at all useful elevation beam positions.

2. Description of the Prior Art

The above referenced U. S. patent application is itself descriptive of an improvement in antenna systems known and used in connection with the so-called Doppler-scan technique. The related prior art preceding that invention is typically described and referenced in U. S. Pat. Nos. 3,613,096 and 3,670,338. U. S. Pat. application Ser. No. 210,699 filed Dec. 22, 1971, now U.S. Pat. No. 3,728,729 is also a useful reference for background information in describing the state of the prior art. Those references also are useful in understanding the nature of the problems encountered in Doppler-scan systems, for example. The utility of the present invention is particularly great in connection with systems of those types.

U. S. Pat. application Ser. No. 272,451 (above-referenced) describes a device employing a circular aperture, parallel-plate waveguide converter excited by a linear Doppler-scan array or alternatively by an electronic scan phased array or the like. The purpose of that parallel-plate structure, as is fully described in that application Ser. No. 272,451, is the conversion of fundamentally conical-coordinate beams to planar-coordinate beams. That device is employed as an element in the novel combination of the present invention as hereinafter described.

In U. S. Pat. No. 3,653,057, entitled "Simplified Multi-Beam Cylindrical Array Antenna With Focused Azimuth Patterns Over A Wide Range of Elevation Angles", a system for tailoring the beam shape of a scanning antenna for wide-angle performance in the non-scanning coordinate is described. That device uses multiple beams to achieve the desired effect, and while satisfactory in typical L-band systems, is relatively inefficient at C-band and above.

The manner in which the present invention builds on the techniques of the prior art and the extent to which it affects improvements thereover will be evident as this description proceeds.

SUMMARY OF THE INVENTION

The combination of the present invention involves the use of the coordinate converting parallel-plate waveguide arrangement of the aforementioned U. S.

Ser. No. 272,451 patent application, as a feed for a plurality of curved linear arrays emplaced about the theoretical surface of revolution formed by rotation of a double-ended hyperbolic outwardly convex curve at a predetermined radius about a horizontal axis. The array arrangement produced is vertically oriented functionally, i.e., it is intended to produce vertically scannable beams having predetermined azimuth characteristics which remain substantially constant over the useful elevation scanning angles. The reference U. S. Pat. No. 3,653,057, on the other hand, is horizontally oriented by the same criterion.

It may be said to be the general objective of the present invention to produce a basically vertically oriented antenna (although its use as a horizontally oriented device is not entirely precluded) to form horizontal fan beams of substantial azimuth angular width, the said antenna being adapted for scanning in elevation without deterioration of the uniformity of the beams at various elevation beam positions. Use of a simple linear array does not accomplish this objective because its beams have a conical shape when scanned. The circular parallel-plate waveguide described in the aforementioned U. S. Ser. No. 272,451 used by itself, provides the required planar beam for consistency with coordinate systems utilized in the so-called Doppler scan air navigation and guidance systems. However, the use of that circular parallel-plate waveguide arrangement as described in the reference, is limited in wide angle coverage in the non-scanning coordinate, due to defocusing which distorts the elevation beamwidth at wide azimuth angles.

If it is imagined that an observer from a distance looks down the beam toward this antenna and is able to "see" the cross-sectional shape of the total beam, that shape would appear somewhat in the shape of a "dogbone". This is because defocusing at azimuth angular extremes tends to fatten the beam in the elevation coordinate at those azimuth extremes. The present invention, which is particularly adapted to use at radar C-band operation and above, employs an optical technique to provide the required wide-angle beam in an arrangement affording the planar coordinates effected by the aforementioned Ser. No. 272,451 device as a feed, while providing a more idealized focusing to eliminate the so-called dog bone effect.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a pictorial view of an antenna arrangement in accordance with the present invention.

FIG. 2 is a detail illustrating the nature of the individual linear arrays in more detail and their relationship with the parallel-plate coordinate converting feed.

DESCRIPTION OF THE PREFERRED EMBODIMENT

As hereinabove indicated, the present invention is a novel device relying on, and building from, the principles taught generally in U. S. Pat. No. 3,653,057 and incorporating the device of U. S. application Ser. No. 272,451 entitled "A Technique For Generating Planar Beams From A Linear Doppler Line Source or Linear Phased Array" as an element of the novel combination.

Referring now to FIG. 1, a typical embodiment of the invention is illustrated. It is, functionally speaking, vertically oriented in that it produces a fan-beam in azimuth scannable or positionable in elevation. Such de-

vices have broad utility in connection with elevation determining systems such as the so-called Doppler navigation systems hereinbefore referenced. The line Z is a substantially horizontal axis, or axial line, for reference. A plurality of curved arrays identified by the numbers 12 through 19 on FIG. 1, represents a portion of those which might be disposed circumferentially about the theoretical surface of revolution represented by the double horn-shape. Depending upon the exact application, these arrays might be disposed around a circumferential sector of less than 90° or as much as 180°. In the Doppler type landing aid system, the vertical beam excursion (the elevation angular sector of interest) may be only 20° to 30°. There is no reason however, why the configuration of FIG. 1 could not be made operative from horizon to horizon. On that basis, the arrays would be disposed over an arc of more than 180°, omitting the bottom side of the antenna system where it would face the ground. From the teaching of the aforementioned U. S. Patent application Ser. No. 272,451, the analogy between Doppler-scan antennas and conventional scanning beam antennas becomes apparent. Accordingly, the technique for providing a wide-angle planar-beam with a conventional scanning antenna, will also apply to a Doppler-scan antenna. Actually, it will be realized from that reference, that either conventional or Doppler-scan from the device of that reference operating alone, is possible, however, as described above, there is a defocusing problem so that the elevation width of the fan beam is not constant over the beam width in azimuth.

In the description of the new antenna technique according to the invention as follows, it will be apparent that microwave optical principles have been employed to obtain wide-angle performance. It is convenient for description to refer to the analogous conventional scanning antenna with its plane waves at different angles. The analogy which validates the system of the present invention with either conventional scanning beam excitation or as a Doppler-scan system, having been discussed in U.S. Patent application Ser. No. 272,451, will not be repeated here.

Referring now to FIG. 1, an embodiment which may be called a confined-feed approach, includes a vertical Doppler-scan line feed 10 exciting a circular aperture parallel-plate waveguide arrangement 11, which converts the conical beams of the line feed alone to a series of planar beams. Since the resulting beams, however, would not be capable of performing over wide azimuth angles because of the inherent defocusing in the elevation plane, the parallel-plate waveguide is used only as a feed coupled to a set of curved quasi-horizontal arrays, the aforementioned arrays 12 through 19. Those arrays provide correct phasing for substantially perfect focus in elevation at every azimuth angle. The formulation for the array curve is determined by maintaining radiation normal to the surface and by varying the radius to provide for proper phasing at the corresponding angle or, expressed mathematically:

$$dR/dZ = \tan \theta \quad (1)$$

$$R \cos \theta = R_0 \quad (II)$$

where

R_0 = minimum radius

R = variable radius

Z = horizontal axis measured from the center axially outward and

θ = azimuth angle

It will be seen from the foregoing, that the phase around any circumference for a given value of Z is determined only by the parallel-plate waveguide feed. Equation II determines the focused azimuth angle θ for each R , and Equation I provides a theoretical surface normal to that angle θ at that radius R . Solving these equations results in the required curve shape in accordance with the expression:

$$R/R_0 = \cosh (Z/R_0) \quad (III)$$

It should be emphasized that a comparable analytical approach for the case of radiation at an angle other than normal to the surface is possible.

Referring now to FIG. 2, a single one of the arrays 16 is depicted. It will be noted that the radiators of this array are slots (typically 20, 21 and 22) in a waveguide transmission line, the latter being coupled to the aperture of the parallel-plate waveguide 11 through a slot 26 communicating the waveguide 16 and the interior space between the parallel plates of 11. The parallel-plate section 11 is otherwise closed between adjacent ones of those linear arrays. Half-wave (typical) slot spacing is specified for the formation of the beam shape in azimuth. Circumferential spacing of the arrays 12 through 19 would be controlled by vertical beam width considerations, and would normally be on the order of a full wavelength.

Each of the curved arrays 12 through 19 is simply curved, that is, a plane passing through a given one of the arrays and containing the axis Z would also contain all of the array slots. Stated otherwise, it could be said that an observer would see each of the arrays as a straight line viewed broadside, such that it appeared to fall over the axis line Z.

In order to obtain 60° of elevation coverage (for example) Equation III shows that a two-to-one change in radius from R_0 to either extreme end of the so-called surface of revolution, is required. This, in turn, requires a width in the direction of the axis Z which is 2.6 times the minimum radius (a half-width of 1.3 times the minimum radius R_0).

It will be noted that FIG. 2 also shows the details of the array used to excite the parallel-plate region 11. Antenna elements which may be dipoles or slots, are represented typically at 23, 24 and 25, the latter following the general considerations set forth in the aforementioned U.S. Patent application Ser. No. 272,451.

It will be realized that other forms of transmission line, other than the illustrated waveguide transmission line at 16 (also applicable to the other arrays 12 through 15 and 17 through 19) could be employed. A coaxial line, for example, with individual dipoles corresponding to the antenna elements 20, 21 and 22 could be used. Moreover, either cross-sectional dimension of the waveguide 16 could be slotted and used as the radiating face, however, the use of the narrow waveguide dimension as depicted in FIGS. 1 and 2, permits the physical arrangement of a plurality of guides in the configuration with greater ease.

Other variations and equivalents will suggest themselves to those skilled in this art. This arrangement, although generalized as to frequency, is more practical at higher frequencies, for example, C-band and above.

What is claimed is:

1. An antenna system for radiating planar beams scannable in a first angular coordinate and of substan-

tially constant beam width in a second orthogonal angular coordinate, comprising:

a plurality of first linear arrays each including a plurality of first antenna elements disposed along a surface of revolution about an axis Z , said surface of revolution having a variable radius R beginning at R_0 and extending axially in both Z directions substantially in a curve defined by the equation $R/R_0 = \cosh Z/R_0$, said arrays being circumferentially spaced over a portion of said surface of revolution not exceeding 180° of the circumference thereof, each of said arrays following a curved line defined by the intersection of a plane also containing said axis, with said surface of revolution;

feed means comprising a parallel plate waveguide having a semi-circular aperture substantially of radius R_0 , the parallel plates of said waveguide being oriented substantially normal to and within the inside of said surface of revolution;

transition means comprising an energy coupling between each of said linear arrays and said feed means at the corresponding point of contact with said semi-circular parallel plate waveguide aperture;

and means comprising a second linear array having

a plurality of antenna elements located within said parallel plates, said second array extending substantially parallel to a diameter line of said semi-circle, to provide means capable of being scanned.

2. Apparatus according to claim 1 in which each of said first linear arrays includes a transmission line extending along the axial length of said surface of revolution and a plurality of antenna elements coupled thereto and disposed along said transmission line length.

3. Apparatus according to claim 2 in which said transmission lines associated with said first linear arrays are waveguide transmission lines and said first antenna elements are formed by slots in the walls of said waveguide transmission lines.

4. Apparatus according to claim 1 in which said slots in the walls of said waveguide transmission lines are spaced one-half wavelength.

5. Apparatus according to claim 3 in which said axis Z is substantially horizontal and said parallel-plates of said parallel-plate waveguide feed means are substantially vertical, said first angular coordinate thereby being elevation angle and said second orthogonal angular coordinate thereby being the azimuth plane.

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