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[54] OMNIDIRECTIONAL MULTIBEAM ARRAY ANTENNA

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[52] **U.S. Cl.** **343/754,** 343/755, 343/773, 343/854
[51] **Int. Cl.** **H01q 19/06**
[58] **Field of Search** 343/754, 755, 854, 343/773

[56] **References Cited**
UNITED STATES PATENTS

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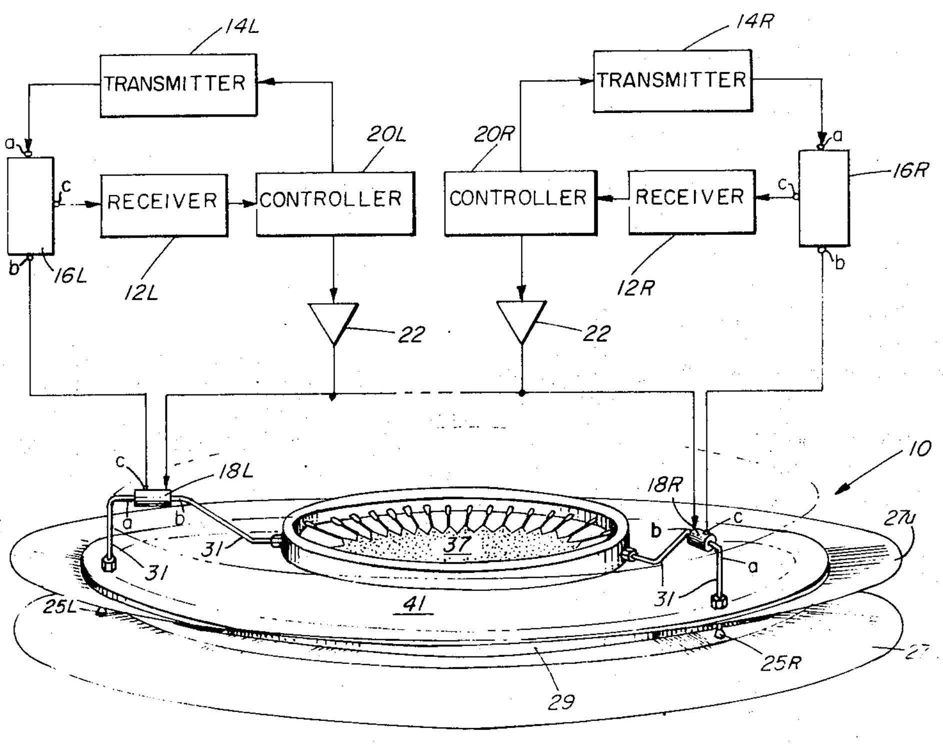
Attorney—Philip J. McFarland et al.

[57] **ABSTRACT**

An omnidirectional multibeam array antenna assembly, for use particularly at radio frequencies, is shown. The preferred embodiment includes a circular dielectrically loaded parallel-plate lens joined by radially disposed transmission lines of equal length to antenna elements disposed on a circle concentric with such lens and radio frequency switching means to permit use of the assembly in either a "transmit" or "receive" mode. The dielectric constant of the material loading the parallel plate lens and the physical diameter of the circular lens are so selected as to produce equal RF path lengths to three (or four) points on a straight line tangent to the arc of elements relative to each one of a plurality of feed ports.

4 Claims, 4 Drawing Figures



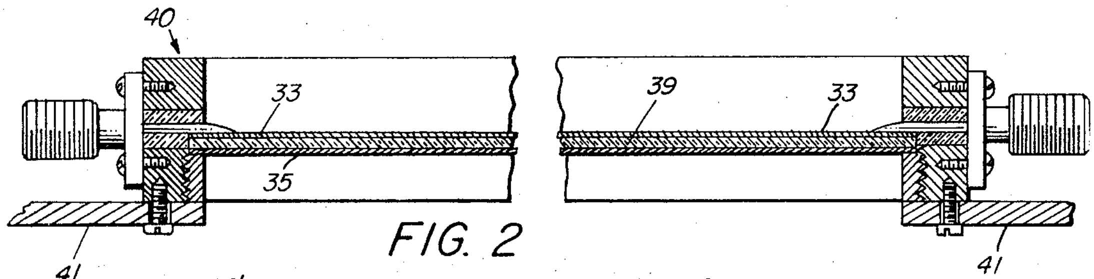


FIG. 2

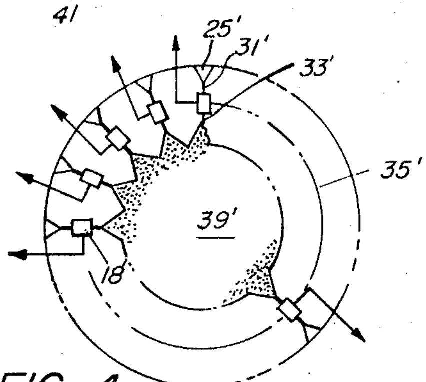


FIG. 4

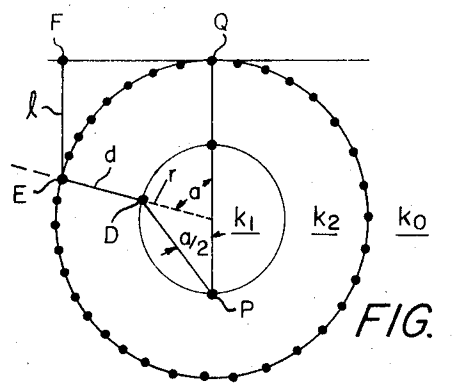


FIG. 3

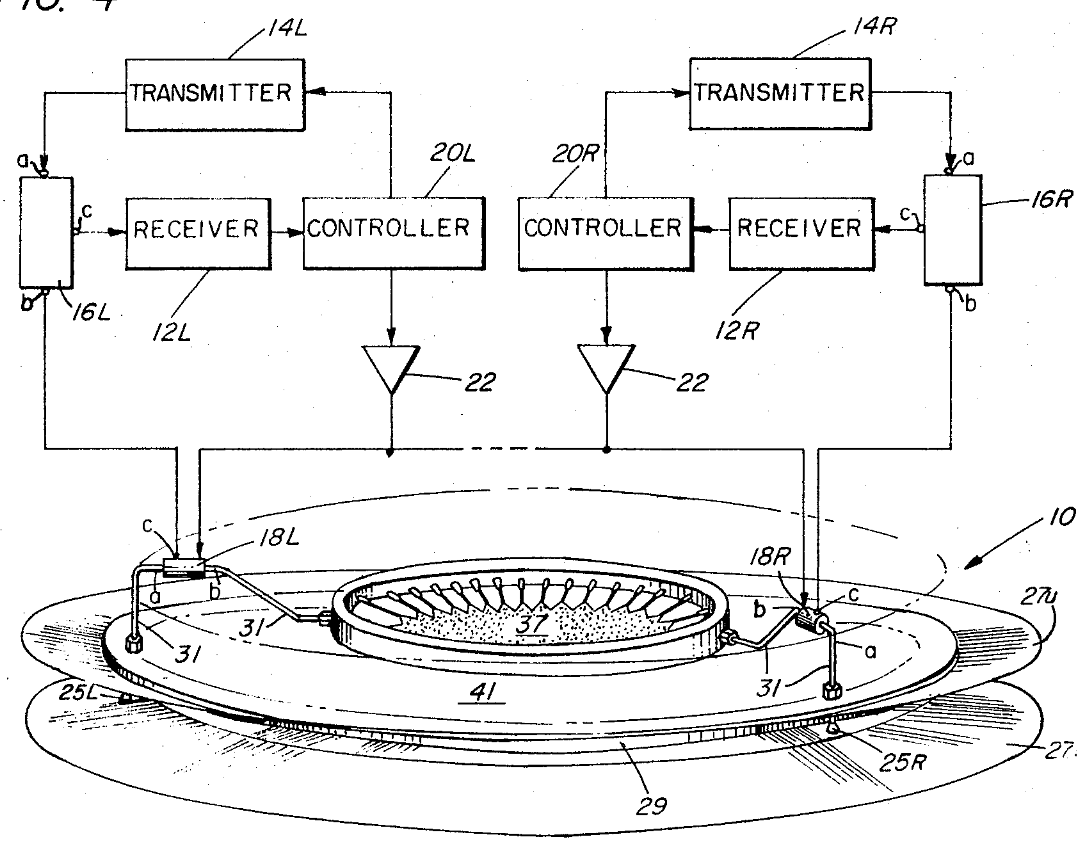


FIG. 1

OMNIDIRECTIONAL MULTIBEAM ARRAY ANTENNA

BACKGROUND OF THE INVENTION

This invention pertains generally to antenna assemblies for radio frequency energy and particularly to antenna assemblies for producing a plurality of simultaneously existing beams of radio frequency energy.

It is known in the art that a plurality of simultaneously existing beams of radio frequency energy may be formed in space in several different ways. One approach, if it is desired that each beam utilize the entire aperture of an antenna array, is to use a so-called "multi-beam" array antenna assembly. In a typical assembly of such a type, each antenna element in an array is connected, through constrained paths of predetermined length, to each one of a number of feed ports. With the electrical length of each one of the constrained paths properly adjusted (through variation of the lengths of the transmission lines and the dimensions of a parallel-plate lens making up the required constrained paths between the antenna elements and the feed ports) it is possible, then, to create any desired number of beams. It is, however, difficult, if not impossible, to arrange the components of any known multibeam array antenna assembly so that the beams produced will cover a field exceeding a semicircle (for a linear array) or a hemisphere (for a planar array).

If it be desired that the field covered by beams from a multibeam array antenna assembly exceed either a semicircle or a hemisphere, it is now felt to be necessary to use a lens antenna, for example an antenna incorporating a so-called "Luneberg" lens to form the required beams. Such a lens, as is well known, is a dielectric lens in which the dielectric constant of the lens material varies with distance from the center of the lens. While, in theory, the dielectric constant of the lens material in a Luneberg lens should vary smoothy, it is difficult to make a lens in such a way. It is, therefore, common practice to approximate an ideal variation by "zoning," i.e., by laminating materials having dielectric constants which differ in a desired way. Obviously, however, even such an expedient is both costly and difficult to implement.

SUMMARY OF THE INVENTION

Therefore, it is a primary object of this invention to provide an improved multi-beam array antenna assembly which is adapted to provide a field of coverage exceeding, for a linear array, a semicircle and, for a planar array, a hemisphere.

Another object of this invention is to provide an improved multibeam array antenna assembly which meets the primary object of this invention without requiring the use of a dielectric lens in which the dielectric constant of the lens material is varied.

These and other objects of this invention are attained generally by providing an array configuration which is, in terms of its electrical dimensions, perfectly symmetrical. Thus, in the case of a linear array, individual antenna elements are disposed along the circumference of a circle, each one of such elements being connected, through a radial transmission line and a concentric circular parallel-plate lens, to appropriately disposed feed ports. By properly selecting the radii of the cicles and the dielectric material in the parallel-plate lens, radio frequency energy passing between each one of the feed ports and the antenna elements is delayed so that the field of the directive beams associated with the antenna elements covers 360°. Similarly, if the antenna elements disposed on the surface of a sphere are connected through radial transmission lines and a concentric spherical lens, to appropriately positioned feed ports, the field covered by the beams from such elements may be spherical.

BRIEF DESCRIPTION OF THE DRAWINGS

For a more complete understanding of this invention, reference is now made to the following description of a preferred embodiment of this invention, as illustrated in the accompanying drawings, in which:

FIG. **1** is an isometric view, somewhat simplified, of a multi-beam array antenna assembly according to my invention, such assembly being shown, in combination with a block diagram of other major components, as a part of an omnidirectional transponder system;

FIG. **2** is a cross-sectional view of the multibeam array antenna assembly shown in FIG. **1**;

FIG. **3** is a sketch illustrating the principle of operation of the contemplated multibeam array antenna assembly; and

FIG. **4** is a plan view, somewhat simplified, of a multibeam array antenna according to my invention, such assembly being made by using printed circuit techniques.

Referring now to FIG. **1**, it may be seen that a transponder system according to this invention comprises a multibeam array antenna assembly **10** (to be described hereinafter) **12R**, **12L** and transmitters **14R**, **14L**, one of each of the latter cooperating, through appropriate circulators **16L**, **16R**, **18L**, **18R**, with such assembly (in response to signals from an associated one of a plurality of controllers **20L**, **20R** and buffer amplifiers **22**) to receive and transmit radio frequency energy. The just-mentioned components of the system, except for the multibeam array antenna assembly **10**, are conventional in construction. Thus, the circulators **16L** – **18R** may each be a known three-port "Faraday rotation" circulator wherein radio frequency energy entering one port may be directed to another selected port by controlling the direction of magnetization of the field of an electromagnet (not shown). Assuming a "normal" direction of the magnetic field controlling each one of the circulators **16L** – **18R** to be the direction which permits radio frequency energy to pass only from port *a* to port *b* or from port *b* to port *c* and a "reverse" direction to permit such energy to pass only from port *b* to port *a* or from port c to port *b*, it may be seen that the circulators **16R**, **16L**, **18R**, **18L** may be so actuated as to direct radio frequency energy as follows. Radio frequency energy entering port *a* of circulator **18R** exits therefrom through port *b*, passed to port *c* of circulator **18L** and then, from port *c* to port *b* of circulator **16L**. Upon exiting from port *c* of circulator **16L**, such energy passes to receiver **12L**. None of the radio frequency energy may, however, pass to receiver **12R** because circulator **18R** prevents passage of such energy from port *a* to port *c*. Upon actuation of the controller **20L** and a "reverse" direction signal being applied to the circulators **18L**, **18R**, radio frequency energy from transmitter **14L** is, therefore, caused to pass through circulator **16L**, circulator **18L** (via ports *c* and *b*) and circulator **18R** (via ports *b* and *a*). Similarly, if radio frequency energy is received at port a of circulator 18L (such circulator being in its "normal" condition) such energy is passed through circulator 18L to circulator 18R and circulator 16R to actuate receiver 12R. The signal out of the latter, then, causes controller 20R to produce a "reverse" direction signal (for circulators 18R, 18L) and a trigger signal for transmitter 14R. The radio frequency signal out of the latter is, therefore, conducted, through circulators 16R, 18R and 18L, to port a of the latter. Each one of the controllers 20L, 20R may consist, for example, of appropriate delay and signal forming circuits to produce, in response to a signal out of its corresponding receiver 12L, 12R, a reversing signal for the electromagnets of circulators 18L, 18R and a trigger signal for its associated transmitted 14L, 14R.

In passing, it will be noted that, for clarity in the drawing and simplicity of explanation, only two sets of receivers, transmitters and controllers and circulators have been shown and described. It will be evident to one of skill in the art, however, that a similar set of elements would be provided in a working embodiment of this invention for each antenna element in the multibeam array antenna assembly 10.

Referring now to FIG. 2 along with FIG. 1, it may be seen that the multibeam array antenna assembly 10 here is made up of a plurality of antenna elements, as antenna elements 25L, 25R, equally spaced and positioned in any convenient manner, in an annular horn (not numbered) but formed from conducting flared sections 27*u*, 27*d* and backwall 29. The dimensions and shape of the annular horn are not essential to the invention and may be changed to shape the beams as desired in the plane orthogonal to the circle on which the antenna elements are mounted. Each antenna element is connected through a constrained path, here consisting of lengths of transmission line 31 and connectors (not numbered) circulator 18r or 18L (each of which here is considered to be initially in its "normal" condition), to a different one of printed lines 33 and a ground plane 35 of microstrip circuitry (not numbered) which may be supported centrally of the annular horn. Each one of the printed lines 33, in turn, is terminated (through matching sections, not numbered) in a printed circle 37 which is concentric with the circle on which the antenna elements 25 are mounted. It is here noted that the electrical length of all the radial paths from the center of the printed circle 37 through any printed line 33, transmission line 31 and circulator is the same.

To complete the description of the microstrip circuitry it may be seen (FIG. 2) that the ground plane 35 is formed by applying, using printed circuit techniques, a conductive coating to one side of a dielectric substrate 39 and applying, again as by using printed circuit techniques, to the opposite surface of such substrate. The microstrip circuitry is then mounted in a clamping ring assembly 40 which is adapted, as shown, to receive connectors (not numbered) for each one of the transmission lines 31. The microstrip circuitry, then, is held in position relative to the antenna elements 25 by an annulus 41 secured in any convenient manner to the clamping ring assembly 40 and the annular horn.

Referring now to FIG. 3, the manner in which the just described multibeam array antenna assembly 10 operates may be seen. A moment's thought before proceeding will make it clear that, because the circulators 18L, 18R, 16L, 16R are simply radio frequency switches and because the length of line between any one of the transmitters 14L, 14R and the junction of the printed lines 33 with the transmission lines 31 is common to radio frequency energy from all antenna elements 25, the point marked P may be deemed to be the origin of such radio frequency energy, i.e., point P is the phase center of a feed port. Thus, the electrical length of the path of radio frequency energy from point "P" to the diametrically opposite antenna element 25, i.e., to the point marked Q may be written as: $PQ_e = 2k_1r + k_2d$ (1)

where r equals the radius of the printed circle 37 measured to the phase center of the matching section or printed "horn" (in wavelengths in free space at a design frequency); d equals the length of any one of the transmission lines 31, all of which are equal, (in wavelengths in free space at a design frequency); and k_1 and k_2 are, respectively, the index of refraction (meaning the square root of the effective dielectric constant) of the dielectric substrate 39 and the dielectric material in the transmission line 31.

Similarly, the electrical length of the path of radio frequency energy from point P to a selected antenna element 25 (other than the one diametrically opposite point P) and thence to a point F on a planar wavefront designated FQ may be written as:

$$PD_e + DE_e + EF_e = 2k_1r \cos a/2 + k_2d + (r+d)k_o\,(1-\cos a) \qquad (2)$$

where a is the angle between the radial lines from the center of the ring of elements to the antenna elements at point Q and E; and, k_o is the square root of the dielectric constant of free space (taken to be 1).

Setting Eq. (1) equal to Eq. (2) and solving for k_1, the following is obtained.

$$k_1 = (r+d)\ (\sin^2 a/2)/(r)\ (1-\cos a/2) \qquad (3)$$

Further, if the angle a is assumed to be 45°, then $k_1 = 1.924\ (r+d)/(r)$ (4)

It will be observed that (r+d) equals the radius of the circle on which the antenna elements 25 are mounted and r equals the radius of the printed circle 37. Thus, it is evident that, so long as the index of refraction of the material chosen for the dielectric substrate 39 exceeds 1.924, the length d is greater than zero and has a definite relationship (depending on the actual value of the selected k_1) to the length r. It follows, then, that by selecting a material with a k_1 somewhat greater than 1.926 (say a k of 4.0) for the dielectric substrate, a multi-beam array antenna assembly may be designed for any desired number of antenna elements with sufficient space being available between the periphery of the printed circle 37 and the antenna elements 25 for the printed lines 33, the transmission lines 31, the circulators 18L, 18R and any required connectors.

Further, by adding an identical length of line to each of the circuit paths between each feed port and its corresponding element, as with semi-rigid cable, the parallel plate lens and associated switches may be positioned in any convenient location with respect to the array elements rather than physically concentric with them.

With the foregoing in mind, it may be seen that different constrained paths for radio frequency energy exist between each feed port and the antenna elements. That is, radio frequency energy from any given feed port passes, via paths of different electrical length, to the antenna elements. Obviously, however, only the antenna elements in the semicircle opposite to any feed port co-act to form a beam. Therefore, in the "transmit" mode, radio frequency energy radiated from the antenna elements in the semicircle opposite to a particular feed port is propagated along a planar wavefront in a beam whose axis is an extension of the diameter containing the feed port. The width of the beam is, of course, dependent upon the number of antenna elements in the semicircle and of illumination taper. Conversely, in the "recive" mode, radio frequency energy in a planar wave is intercepted by each antenna element in a semicircle and directed to the diametrically opposite feed port, arriving there substantially "in phase

Referring now to FIG. **4** it may be seen that a multibeam array antenna assembly according to this invention may be made using only printed circuit techniques. Thus, in FIG. **4** one side of a circular dielectric substrate **39'** is partially covered with a ground plane **35'** (the outside of such plane being indicated by dotted lines) and the remainder of the microstrip circuitry is printed on the other side of such substrate. That is, a printed circle **39'** is located centrally of the dielectric substrate **39'** and printed lines **31'**, **33'** are disposed, through unnumbered matching sections, radially of such circle. A circulator **18'** is formed in each one of such lines and the outer end of each is terminated in a monopole antenna element **25'**. The radius of the printed circle **25,** the overall length of each printed line **31'** and the index of refraction of the dielectric substrate **39'** are related one to another as described hereinbefore.

It will evident to one of skill in the art that changes from the illustrated embodiments of my invention may be made without departing from my inventive concepts. Thus, in lieu of a disc-shaped dielectric substrate, a spherical substrate could be used to form a plurality of pencil beams covering a spherical field. Or, alternatively, multiplicity of disc-shaped substrates could be used to feed rings of elements on a cylindrical surface. Further, it is obvious that the disclosed antenna assembly may be used as the radiating and/or receiving element in apparatus other than transponders or direction finders. It is felt, therefore, that this invention should not be restricted to its disclosed embodiments but rather should be limited only by the spirit and scope of the appended claims.

What is claimed is:

1. An omnidirectional antenna assembly for radio frequency energy, such assembly comprising:

a. a plurality of antenna elements disposed at equal intervals along the circumference of a circle;

b. a circular parallel-plate lens concentric with the circle and having a radius less than the radius of the circle, such lens including a dielectric material, the index of refraction, k, of the dielectric material, the radius $(r+d)$ of the circle on which the antenna elements are disposed and the radius, r, of the circular parallel-plate lens are related in accordance with the formula:

$k=(r+d)(\sin^2 a/2)/(r)(1-\cos a/2)$ where a is an angle less than 90°;

c. radio frequency energy conducting means for connecting each one of the plurality of antenna elements to a different point on the periphery of the circular parallel-plate lens, the electrical length of each such conducting means being the same; and,

d. circulator means, in circuit with each one of the radio frequency conducting means, for directing radio frequency energy to and from each one of the antenna elements through the parallel-plate lens.

2. An omnidirectional antenna as in claim **1** wherein the radio frequency conducting means are radio frequency transmission lines.

3. An omnidirectional antenna assembly as in claim **1** wherein the circular parallel-plate lens, the radio frequency conducting means and the circulator means are printed circuits on a first surface of a dielectric substrate.

4. An omnidirectional antenna assembly as in claim **3** having, additionally, an electrically conductive ground plane overlying a second surface of the dielectric substrate.

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UNITED STATES PATENT OFFICE

CERTIFICATE OF CORRECTION

Patent No. 3,754,270 Dated August 21, 1973

Inventor(s) Wilbur H. Thies, Jr.

It is certified that error appears in the above-identified patent and that said Letters Patent are hereby corrected as shown below:

In the Specification

Column 2, line 32, after "hereinafter" insert --and a plurality of receivers and transmitters, as receivers--.

Column 5, line 12, "recive" should be --receive--.

Signed and Sealed this

ninth **Day of** *September 1975*

[SEAL]

Attest:

RUTH C. MASON
Attesting Officer

C. MARSHALL DANN
Commissioner of Patents and Trademarks