United States Patent

Maune

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[54] **FLUSH MOUNTED STEERABLE ARRAY ANTENNA**

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[73] Assignee: **Hazeltine Corporation**

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[52] **U.S. Cl.** **343/766,** 343/778, 343/854, 343/911

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

[58] **Field of Search**..................343/771, 763, 766, 853, 761, 343/762, 768, 854, 708, 768, 718, 911

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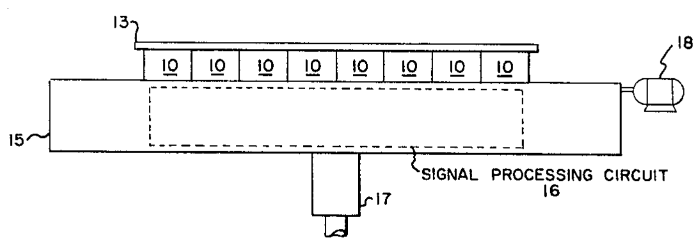
Attorney—Kenneth P. Robinson

[57] **ABSTRACT**

A rotatable directional antenna which remains flush with the surface on which it is mounted including an array of radiating elements which are arranged in parallel columns. Energy of equal phase is coupled to the elements that comprise each column. The array produces a beam of electromagnetic energy which is steerable within a plane which includes the broadside direction of the array by varying the phase of the energy coupled to each of the columns of elements. The array is rotatable about its broadside axis thereby permitting the plane within which the beam can be steered to rotate about the broadside axis. A region in space can thereby by scanned while the array remains flush with the surrounding surface. Alternate arrangements are also covered.

6 Claims, 7 Drawing Figures



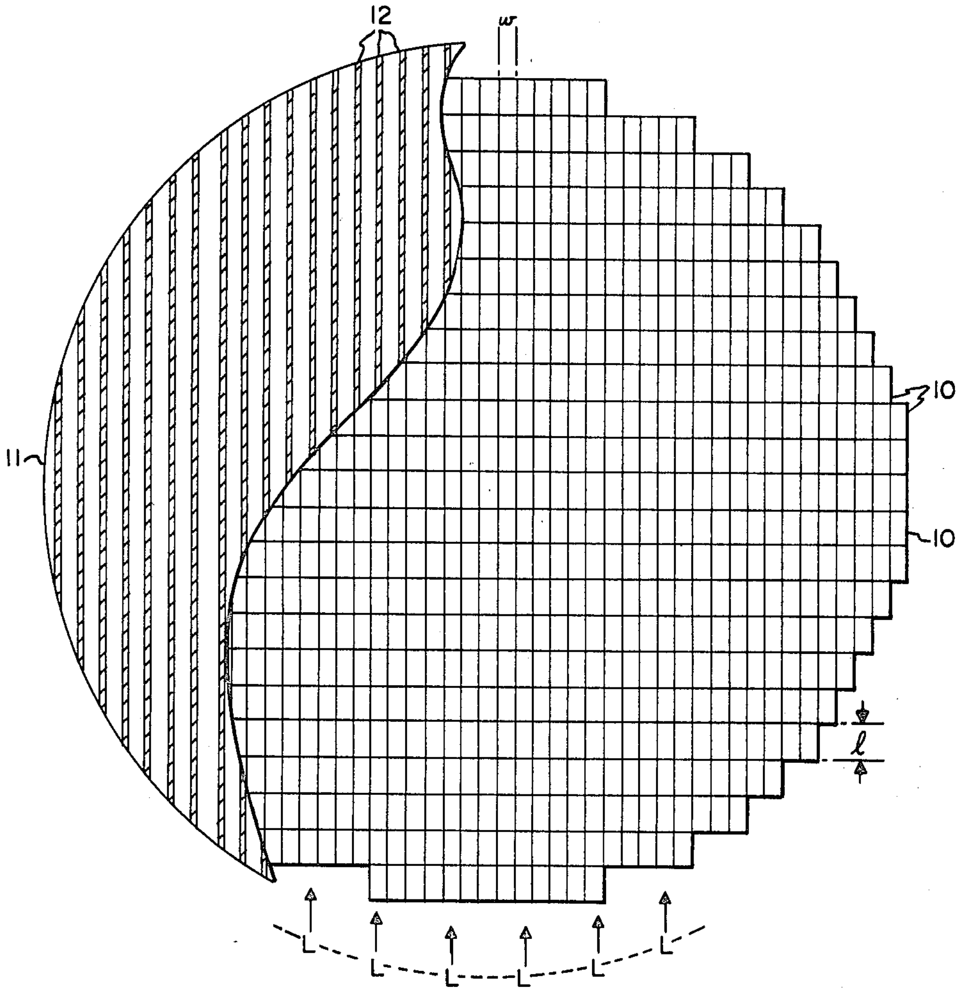


FIG. 1

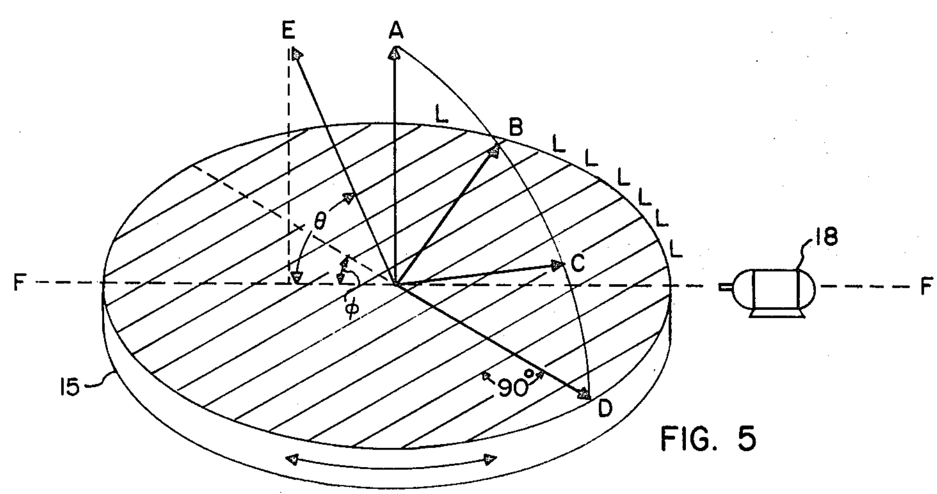


FIG. 5

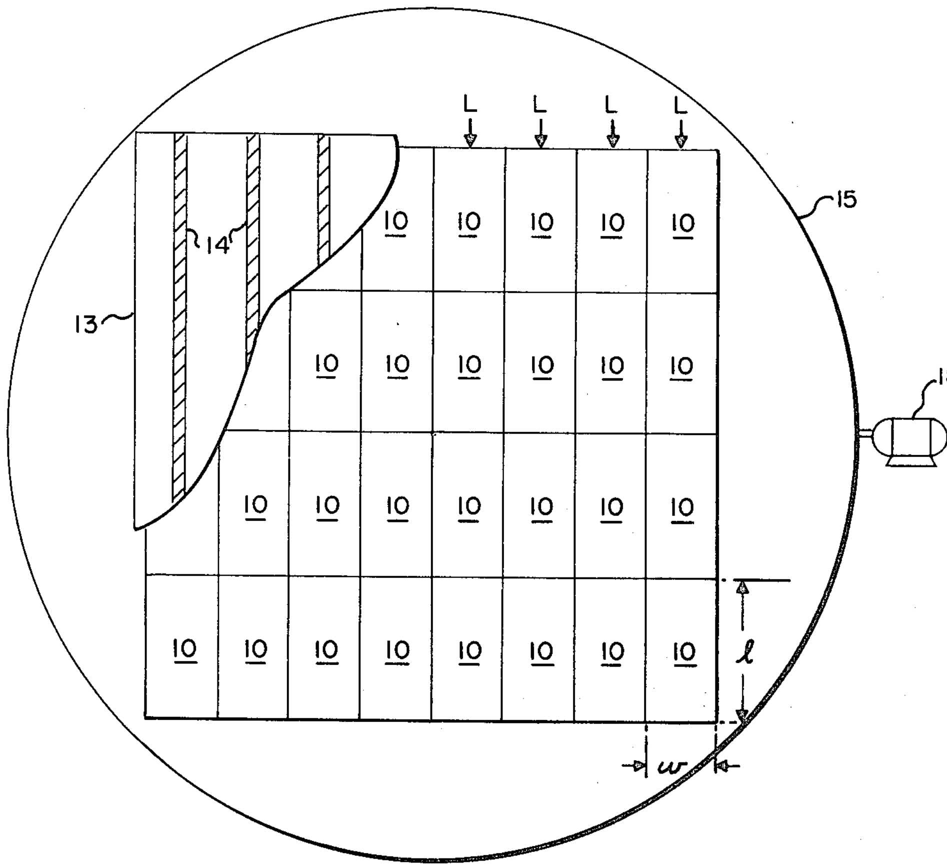

L
L
L
L
15
14
13
18
10
l
w

FIG. 2

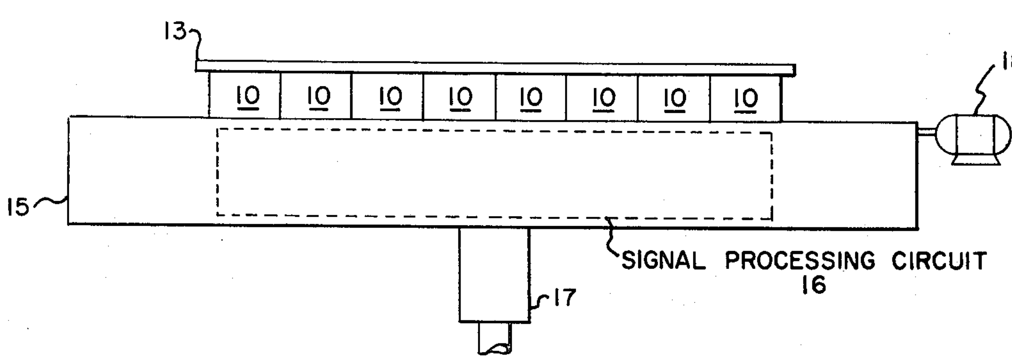

13
18
10
15
SIGNAL PROCESSING CIRCUIT
16
17

FIG. 3

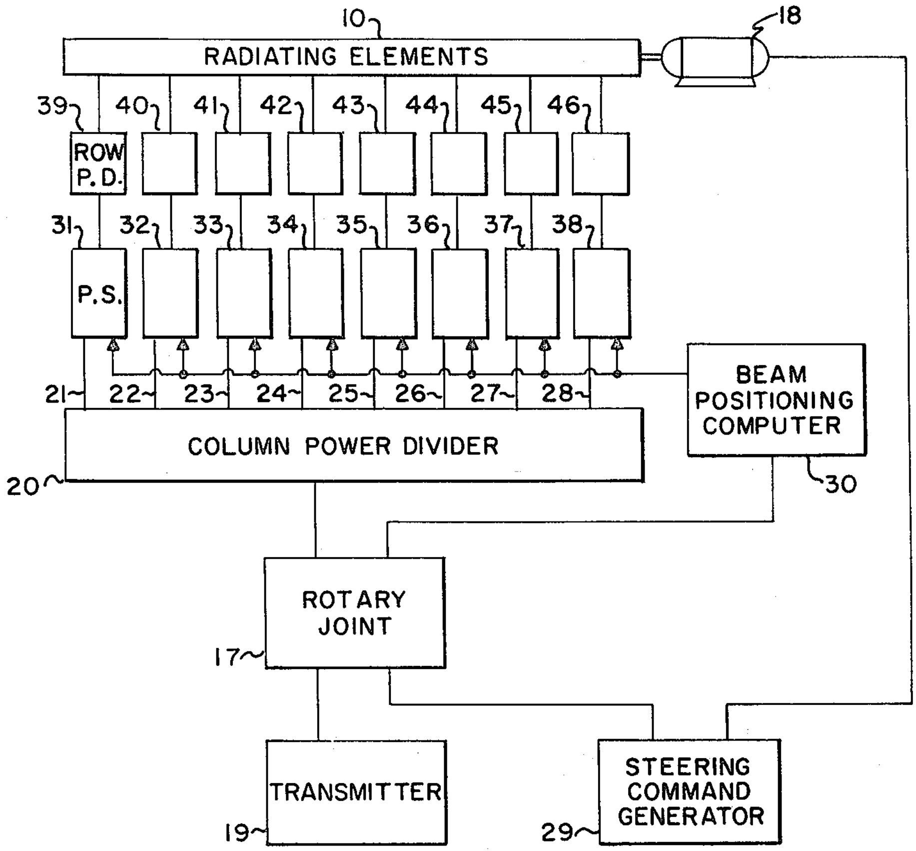


FIG. 4

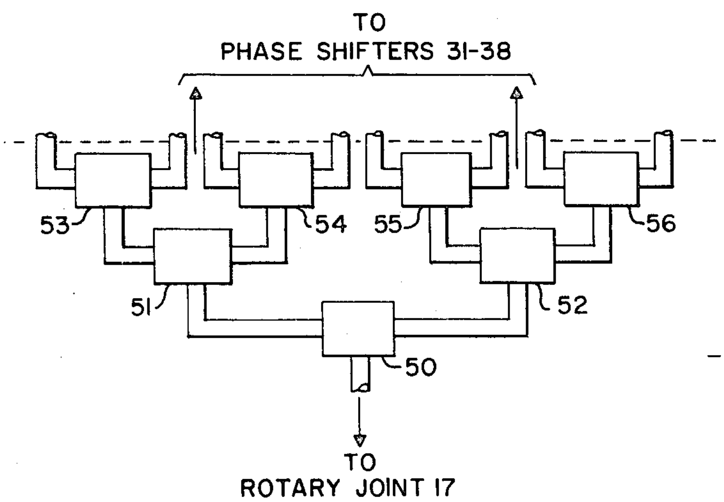


FIG. 6

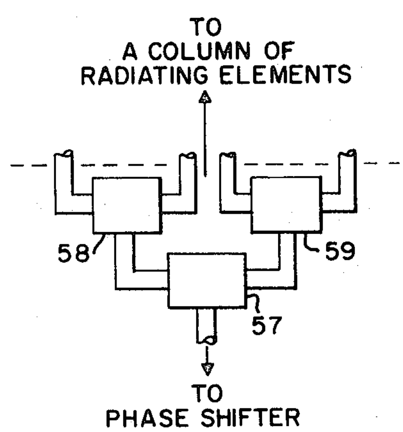


FIG. 7

FLUSH MOUNTED STEERABLE ARRAY ANTENNA

BACKGROUND OF THE INVENTION

Electromagnetic communication systems often require a high effective radiated power. This may be accomplished by utilizing a very high power transmitter with an omnidirectional antenna or a lower power transmitter with a high gain antenna. For reasons of power consumption, particularly in systems mounted in an aircraft, the high power transmitter is usually impractical and a high gain antenna is required.

A high gain antenna, by its definition, has a narrow beam. In order that its gain may be used to advantage, it is necessary that the beam be steerable in space so that the power may be radiated in a desired direction. For use in a high performance aircraft, there is the further requirement that the antenna be flush mounted in order to avoid deterioration of aircraft performance that might result from the disturbance of the aerodynamic characteristics by a protruding antenna.

PRIOR ART

One type of high gain antenna is a parabolic reflector and feed which is mechanically rotated by a system of gimbals or similar method. The mechanically rotated reflector characteristically occupies a different volume of space for each beam position and accordingly does not remain flush with the surface on which it is mounted for all beam positions. A flush mounted antenna is desirable for many applications and as stated above is virtually essential for high speed, high performance aircraft.

A phased array in which the beam is steered by varying the phase of the energy coupled to each of the radiating elements is a high gain flush mounted antenna. However, a phased array having the desired beam width and steering resolution requires hundreds of individual radiators and associated phase shifters. The phase shifters are a very expensive item, particularly phase shifters that operate in the upper portion of the frequency spectrum. A fully phased array suitable for mounting on an aircraft therefore could be prohibitably expensive.

SUMMARY OF THE INVENTION

Objects of the present invention therefore are to provide new and improved high gain antennas which remain flush with the mounting surface over a range of scan angles and to provide such an antenna which does not require a phase shifter for each radiating element.

In accordance with the present invention there is provided a rotatable directional antenna which remains substantially flush with the adjacent surfaces over the range of beam positions which comprises an array of radiating elements responsive to supplied energy for collectively propagating a narrow beam of electromagnetic energy; first means for varying the phase of the energy supplied to one or more of the radiating means so as to cause the narrow beam of electromagnetic energy to be positioned at different beam angles, all of the beam positions lying in a plane which includes the broadside axis of the array; and second means for rotating the array of radiating elements about the broadside axis of the array for causing the plane within which the beam position can be varied to rotate about the axis while the antenna remains substantially flush the the adjacent surface; whereby the antenna remains substantially flush with the adjacent surface as the narrow beam of electromagnetic energy scans a region in space.

BRIEF DESCRIPTION OF THE DRAWINGS

For a better understanding of the present invention together with other and further objects thereof, reference is had to the following description taken in conjunction with the accompanying drawings, and its scope will be pointed out in the appended claims.

Referring to the drawings:

FIG. 1 is a top view of a large scale rotatable antenna constructed in accordance with the present invention in which the radiating elements are arranged on a circular mount;

FIG. 2 is a small scale antenna constructed in accordance with the present invention in which the radiating elements are arranged on a square rotatable mount;

FIG. 3 is a side view of the FIG. 2 antenna;

FIG. 4 is a schematic representation of the antenna illustrated in FIGS. 2 and 3;

FIG. 5 is a perspective view of an antenna constructed in accordance with the present invention which illustrates the two types of scanning techniques;

FIG. 6 is an illustration of a column power divider which may be utilized in the FIGS. 2–4 antennas; and

FIG. 7 is an illustration of a row power divider which may be utilized in the FIGS. 2–4 antennas.

DESCRIPTION OF THE INVENTION

FIG. 1 is a top view of a phased array antenna system constructed in accordance with the present invention. The antenna system includes an array of radiating elements **10** arranged in a plurality of parallel columns L of element **10** for propagating a narrow beam of electromagnetic energy. The antenna system also includes an impedance matching structure consisting of a thin sheet of dielectric material **11** parallel to and separated from the array of radiating elements **10** and a plurality of thin flat strips of conductive material **12** mounted on dielectric sheet **11**, said conductive strips collectively having dielectric characteristics over the desired range of wavelengths for providing impedance matching between the array of radiating elements **10** and free space. The dielectric sheet **11** and its associated conductive strips **12** are coextensive with the entire array of elements **10**. However, a portion of the sheet **11** has been removed in FIG. 1 in order to illustrate the arrangement of radiating elements **10**.

FIG. 2 is a top view of a second antenna system constructed in accordance with the present invention. The FIG. 2 system also includes a plurality of radiating elements **10** arranged in a plurality of parallel columns L and a dielectric sheet **13** with associated conductive strips **14**. As in FIG. 1, the dielectric sheet **13** is coextensive with the face of the array of radiating elements **10**. However, even a larger portion of the sheet **13** has been removed in FIG. 2 to more clearly illustrate the arrangement of radiating elements **10**. FIG. 2 also illustrates rotary mount **15** on which the radiating elements **10** are mounted and synchronous motor **18**.

Both the FIGS. 1 and 2 embodiments employ the inventive concept described herein. The principal difference between these embodiments is in the number of radiating elements **10** and associated hardware required to couple energy to each of the radiating elements **10**. The function and operation of each of these systems is substantially the same. The FIG. 1 embodiment, having a considerably larger number of radiating elements **10**, is capable of providing a narrower radiating beam and finer steering resolution. The FIG. 2 embodiment, having fewer radiating elements **10**, is a simpler and less expensive system. In order to facilitate understanding of the present invention, the remainder of this description is directed to the FIG. 2 antenna but it will be apparent that an antenna system can be constructed in accordance with the present invention with fewer radiating elements than in FIG. 2 or with a greater number of radiating elements as is illustrated in FIG. 1.

FIG. 3 is a side view of the FIG. 2 antenna illustrating the radiating elements **10**, dielectric sheet **13**, rotary mount **15**, signal processing circuits **16**, rotary joint **17** and synchronous motor **18**.

FIG. 4 is a block diagram schematical representation of the antenna illustrated in FIGS. 2 and 3 and is described in conjunction with those figures. As illustrated in FIGS. 3 and 4 the antenna system includes transmitter means **19** for supplying RF energy which is to be propagated. Transmitter **19** is of conventional design and includes the oscillators and amplifiers required to supply the radio frequency energy which is to be propagated. The output of transmitter **19** is coupled to signal processing circuit **16** by way of rotary joint **17**. Rotary joint **17** is a conventional coupling device which permits transmission of electromagnetic energy between two waveguide structures while permitting mechanical rotation of one structure. As is illustrated in FIG. **3** and will be more fully explained below, signal processing circuit **16** is mounted on rotary mount **15** and is caused to rotate by synchronous motor **18**.

Signal processing circuit **16** includes column power divider means **20** which divides the RF energy supplied by transmitter **19**, by way of rotary joint **17**, among the columns of radiating elements **10**, so that energy having substantially the same phase is coupled to all the radiating elements **10** that comprise a column of elements L. As illustrated in FIG. **4**, the column power divider **20** divides the RF energy supplied by transmitter **19** into eight parts which are individually coupled from column power divider **20** by leads **21** through **28**.

The antenna system also includes steering command generator means **29** for providing azimuth and elevation information signals which in combination define the desired beam position. Apparatus for providing steering commands are conventional in the art providing either discrete steering commands or error correction signals. For example, if the present antenna system were to be utilized to continuously direct a beam of electromagnetic energy at a communications satellite, the steering command generator **29** would be continuously provided with position correction signals in order to continuously generate the correct azimuth and elevation signals.

The antenna system also includes beam positioning computer means **30** for deriving from the elevation information signal, which is coupled thereto via rotary joint **17**, a plurality of phase information signals suitable for controlling the position of the radiated beam within an azimuth plane which includes the broadside of the axis of the array. The beam positioning computer **30** produces an output corresponding to each of the outputs **21** through **28** of the column power divider **20**.

The antenna system also includes a plurality of phase shifters **31–38** each responsive to one of the outputs of column power divider **20** and one of the phase information signals generated by beam positioning computer **30** for individually controlling the phase of the energy coupled to the radiating elements **10** that comprise a column of elements L with respect to the phase of the energy coupled to other of said radiating elements **10** so as to cause the narrow beam of electromagnetic energy to be positioned within said azimuth plane in accordance with said elevation information.

The antenna system also includes synchronous motor means **18** responsive to the azimuth information generated by signal command generator **29** for mechanically rotating the rotary mount **15** about the broadside axis of the array so that the plane in which the beam is steered by varying the phase of the energy coupled to the radiating elements **10** is located at the desired azimuth. The flush mounted antennas thereby remain substantially flush with the adjacent surface as the narrow beam of electromagnetic energy scans a region in space.

For ease of rotation the square array of elements **10** is mounted on a circular rotary mount **15**. Any suitable rotary mount may be employed.

OPERATION

Understanding of the operation of the antenna illustrated in FIGS. **2–4** will be facilitated by an understanding of the basic concepts of the present invention which are illustrated by the FIG. **5** antenna.

FIG. **5** is a perspective view of an antenna system constructed in accordance with the present invention which illustrates the manner in which the two different scanning techniques, rotational and phase shifting, cooperate to provide a flush mounted antenna which can scan a hemisphere. FIG. **5** only depicts the columns L of radiating elements, rotary mount **15** and motor **18** because the purpose of FIG. **5** is to illustrate the two types of scanning techniques.

Since the energy coupled to each of the radiating elements **10** in each column of elements L in FIGS. **1** and **2** has the same phase, a column of elements L can be illustrated as a single radiating element as in FIG. **5**. Each of these elements L, if individually excited, would produce a fan shaped beam lying in the plane defined by arrows A,B,C, D, plane A B C D being perpendicular to the long axis of each of the elements L and including the broadside axis of the array A. Excitation of all the elements L produces a narrow beam of electromagnetic energy which lies in plane A B C D. By varying the phase of the energy coupled to each of the elements L, the position of the radiated beam within plane A B C D can be controlled, and the radiated beam made to assume any position within plane A B C D above the face of the array.

Rotation of rotary mount **15** by the activation of motor **18** causes scan plane A B C D to be rotated about the broadside axis A by a corresponding amount. Since the radiated beam can be positioned anywhere in scan plane A B C D, and scan plane A B C D can be rotated to any azimuth position, the radiated beam can be positioned at any location in the hemisphere which lies above the face of the array. For example, assume it is desired to radiate in the direction of arrow E which lies in the plane which includes the broadside axis A and axis FF. The azimuth signal coupled to motor **18** causes the rotary mount and consequently scan plane A B C D to be rotated about the broadside axis by the angle φ so that scan plane A B C D includes arrow E. Within scan plane A B C D the beam is caused to radiate in the direction of arrow E by adjusting the phase of the energy coupled to each of the elements L as described above in accordance with the elevation signal to achieve the elevation angle θ.

Limiting the scanning due to phase shifting to a single plane drastically reduces the number of phase shifters required, as compared to a fully phased array, which drastically reduces the cost of the array. It also permits scanning in the end-fire direction in all planes of scan as will be more fully described below. Limiting the scanning by mechanical rotation to rotation about the broadside axis permits the antenna to have a low profile. The antenna occupies the same volume in space for all beam positions and therefore can remain flush with the surrounding surfaces over the desired range of beam positions. For example, the antennas of FIGS. **1** and **2**, while propagating out of the plane of the paper remain flush with the plane of the paper for all beam positions.

With reference to the operation of the antenna illustrated in FIGS. **2–4**, the energy to be propagated is coupled to rotary joint **17** from transmitter **19**. Rotary joint **17** permits coupling of the energy to rotary mount **15** and signal processing circuit **16** which is attached to rotary mount **15**. The RF energy to be radiated is coupled from rotary joint **17** to column power divider **20**, which divides the RF energy into eight separate components corresponding to the number of columns of elements L.

The column power divider may consist of a matrix of T junctions **51–56** as illustrated in FIG. **6**. Each T junction divides the energy coupled to it into two equal parts. The energy coupled from rotary joint **17** is thereby divided into eight equal component parts which are individually coupled to one of the phase shifters **31–38**. Other forms of power dividers may also be utilized. For example, for a particular application it may be desirable to have different or varying amounts of energy on each of the outputs **21–28** of the column power divider or to be able to vary the amount of energy at each output. The particular requirement will dictate the configuration.

Each of the outputs **21–28** of column power divider **20** is coupled to one of the phase shifters **31–38**. Phase shifters **31–38** provide control of the phase of the energy of each column L of elements **10** with respect to the others of said columns of elements. The phase shifters may be ferrite phase shifters such as described in "Recent Advances in Digital

Latching Ferrite Devices," L.R. Whicker, 1966 IEEE Convention Record Part 5, Page 49, or other suitable device. Briefly described the ferrite phase shifter consists of a hollow cylinder of ferrite material positioned in a waveguide through which the energy to be delayed is propagated. The ferrite material produces a wave slowing effect which is the equivalent of a phase shift. One or more wires is passed through the hole in the ferrite material. The amount of current passing through the wires determines the amount of phase shift provided by the ferrite material. Therefore, by varying the control current through each phase shifter, the phase of each of the outputs **21–28** can be varied with respect to each of the other of said outputs.

In FIG. **4** the signal to be delayed is coupled to the waveguide contained in the phase shifter by one of the leads **21–28**. The signal that controls the amount of phase shift is coupled to the phase shifters **31–38** from the beam positioning computer **30**. The beam positioning computer **30** derives the required phase shifter control signals from the elevation signal coupled thereto from the signal control generator **29** by way of rotary joint **17**. The manner in which the necessary phase shifter signals are derived from the elevation control signal is well known in the art.

The outputs of phase shifters **31–38** are individually coupled to their corresponding row power dividers **39–46**. Each of the row power dividers distributes the energy coupled to it among the radiating elements that comprise one of said columns of radiating elements L. FIG. **7** illustrates a typical row power divider which consists of T junctions **57–59**. Energy coupled to T junction **57** from one of the phase shifters **31–38** is divided into four equal parts which are individually coupled to the elements that comprise radiating elements **10** that comprise one of said column of elements L. As with the column power divider, for a particular application it may be desirable to have a different amount of energy coupled to the elements that comprise one of said columns of elements or a variable amount of energy coupled to said elements. The row power divider may be readily constructed to meet either of these requirements.

While the beam is positioned within the elevation plane by adjusting the phase of the energy coupled to the elements that comprise each of said rows as described above, the azimuth plane is positioned at the desired location by coupling the azimuth signal from signal control generator **29** to synchronous motor **18**. A gearing system causes the rotary mount **15** to rotate when synchronous motor **18** is activated by the elevation control signal. As described in conjunction with the description of FIG. **5**, the beam can therefore be caused to propagate in any direction desired.

An array antenna in accordance with the present invention can be constructed so that the radiating elements **10** propagate either circular or linear polarization and the elements may be arranged so that the scan plane due to phase shifting lies in the electric field plane, the magnetic field plane or any inter-cardinal plane. However, there is particular advantage to arranging the array as illustrated in FIGS. **1** and **2** so that the waveguides propagate only the dominant mode, the TE10 mode, and the waveguides within each column L are stacked in the direction of the magnetic field vector.

As is illustrated in FIG. **1** and more clearly shown in FIG. **2**, each waveguide has an aspect ratio of approximately 2:1, i.e., the length is approximately twice the width. Having this aspect ratio insures that only the TE10 mode propagates, therefore there is no cross polarization and the electric field vector is always perpendicular to the length **1**.

Since all the waveguides in each column of waveguides have energy of the same phase coupled to them, stacking the waveguides within each column so that the magnetic field vectors in each waveguide lie along the same axis makes each column of waveguides function as a single waveguide having a large aperture perpendicular to the electric field vector. Each column of waveguides will therefore produce a fan shaped beam which lies in the plane of the electric field vector. The combined effect of all the columns of radiating elements is to produce a narrow beam of electromagnetic energy which can be positioned anywhere within the plane of the electric field vector by varying the phase of the energy coupled to the elements comprising different columns of radiating elements.

Propagation in the plane of the electric field vector is possible over the entire plane including the end-fire direction. However, propagation in the magnetic field plane is limited to something less than 90 degrees, it being totally impossible to propagate in the end-fire direction in the magnetic field plane. Since in the present invention the beam is always propagated in the plane of the electric field vector, it is possible to scan a hemisphere, whereas in a fully phased array, where steering is accomplished in all directions by phase shifting, it is impossible to scan a hemisphere since steering is limited in the direction of the magnetic field vector.

As previously stated, the FIG. **2** antenna structure includes a thin sheet of dielectric material **13** parallel to and separated from the face of the array of radiating elements **10**. The dielectric sheet **13** is attached to the array around the periphery by suitable fastners. Thin flat strips of conductive material **14** are attached to dielectric sheet **13**, each strip **14** running the length of the dielectric sheet perpendicular to the electric field vector of the array. There is one conductive strip corresponding to each column of radiating elements. The conductive strip **14** collectively have dielectric characteristics over the range of operating frequencies and thereby provide impedance matching between the array of radiating elements **10** and free space. This impedance matching structure also provides environmental protection for the openings in the radiating elements **10**.

There are design criteria applicable to any phased array which apply to the present invention and which will be apparent to those skilled in the art. For example, in choosing the cross sectional size of radiating elements **10**, there are the conflicting requirements that a larger aperture produces better focusing while too large a spacing between centers of the elements may result in the propagation of grading lobes; i.e., energy propagated in other than the main beam. For the rectangular grid of elements illustrated in both FIGS. **1** and **2**, grading lobes will be avoided if the center-to-center spacing between the elements in the direction of the electrical field vector is less than one half the free space wavelength at the highest frequency of the operating band. Typically, the center-to-center spacing may be in the order of 0.4 times the free space wavelength.

While there have been described what are at present considered to be the preferred embodiments of this invention, it will be obvious to those skilled in the art that various changes and modifications may be made therein without departing from the invention and it is, therefore, aimed to cover all such changes and modifications as fall within the true spirit and scope of the invention.

What is claimed is:

1. A rotatable directional antenna which remains substantially flush with the adjacent surfaces over the range of beam positions, comprising:

means for supplying RF energy which is to be propagated;

a planar array of radiating elements consisting of a plurality of closely spaced parallel columns of radiating elements for collectively propagating a narrow beam of electromagnetic energy;

a rotary mount for supporting the radiating element;

means for dividing the supplied RF energy among the columns of radiating elements so that energy having substantially the same phase is coupled to all of the radiating elements that comprise a column of elements;

means for providing azimuth and elevation information signals which in combination define the desired beam position;

means for deriving from the elevation information signal a plurality of phase information signals suitable for controlling the position of the radiated beam within an azimuth plane which includes the broadside axis of the array;

a plurality of phase shifters each responsive to one of the outputs of said dividing means and to one of said phase information signals for individually controlling the phase of the energy coupled to the radiating elements that comprise a column of elements with respect to the phase of the energy coupled to others of said elements so as to cause the narrow beam of electromagnetic energy to be positioned within said azimuth plane in accordance with said elevation information;

means responsive to the azimuth information signal for mechanically rotating the rotary mount about the broadside axis of the array for positioning said azimuth plane at the desired azimuth position;

whereby the antenna remains substantially flush with the adjacent surface as the narrow beam of electromagnetic energy scans a region in space.

2. A rotatable directional antenna which remains substantially flush with the adjacent surfaces over the range of beam positions, comprising:

means for supplying RF energy which is to be propagated;

a planar array of linearly polarized radiating elements, responsive to said supplied RF energy, arranged in a plurality of closely spaced parallel columns of radiating elements, each of said elements being arranged to propagate only the dominant mode, with the elements within each column being stacked in the direction of the magnetic field vector for collectively propagating a narrow beam of electromagnetic energy in the plane of the electric field vector;

a rotary mount for supporting the radiating elements;

means for dividing the supplied RF energy among the columns of radiating elements so that energy having substantially the same phase is coupled to all of the radiating elements that comprise a column of elements;

means for providing azimuth and elevation information signals which in combination defines the desired beam position;

means for deriving from the elevation information signal a plurality of phase information signals suitable for controlling the position of the radiated beam within the plane of the electric field vector;

a plurality of phase shifters each responsive to one of the outputs of said dividing means and to one of said phase information signals for individually controlling the phase of the energy coupled to the radiating elements that comprise a column of elements with respect to the phase of the energy coupled to others of said elements so as to cause the narrow beam of electromagnetic energy to be positioned within the plane of the electric field vector in accordance with said elevation information;

means responsive to the azimuth information signal for mechanically rotating the rotary mount about the broadside axis of the array for positioning the plane of the electric field vector in accordance with said azimuth information;

whereby the antenna remains substantially flush with the adjacent surface as the narrow beam of electromagnetic energy scans a region in space.

3. A phased array antenna as specified in claim **2** which additionally includes a thin sheet of dielectric material parallel to and separated from the array of radiating elements and a plurality of thin flat strips of conductive material mounted on said dielectric sheet, said conductive strips collectively having dielectric characteristics over the desired range of wavelengths for providing impedance matching between the array of radiating elements and free space.

4. A phased array antenna as specified in claim **1** in which the array of radiating elements consists of slots or holes in a conductive ground plane arranged on a substantially flat circular rotatable member.

5. A phased array antenna as specified in claim **1** which additionally includes a thin sheet of dielectric material parallel to and separated from the array of radiating elements and a plurality of thin flat strips of conductive material mounted on said dielectric sheet, said conductive strips collectively having dielectric characteristics over the desired range of wavelengths for providing impedance matching between the array of radiating elements and free space.

6. An antenna as specified in claim **2** in which the center-to-center spacing between the elements in the direction of the electric field vector is less than 0.5 times the free space wavelength at the high end of the operating bandwidth.

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