

[54] CYLINDRICAL ARRAY ANTENNA

[75] Inventor: Richard J. Giannini, Setauket, N.Y.

[73] Assignee: Hazeltine Corporation, Greenlawn, N.Y.

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[58] Field of Search 343/100 SA, 100 ST

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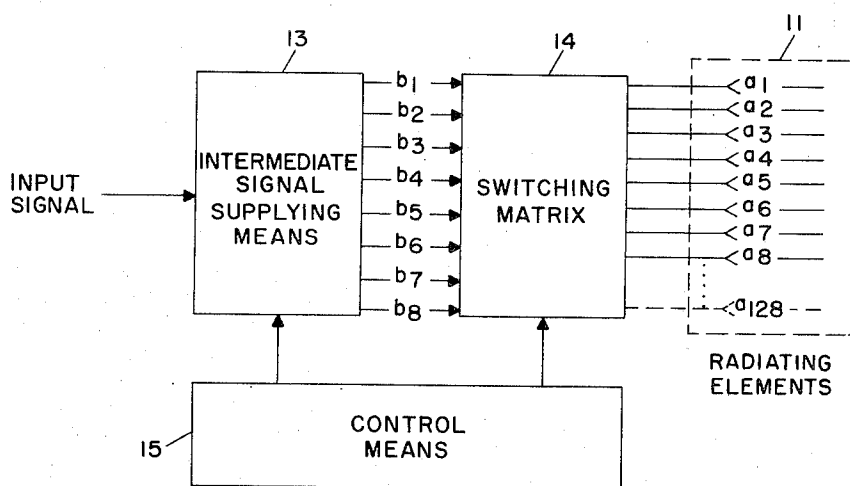
Assistant Examiner—T. M. Blum

[57]

ABSTRACT

Disclosed is a cylindrical array antenna capable of radiating a beam which may be steered in coarse and fine increments to selectable beam positions. In a specific embodiment such an array comprises a plurality of radiating elements arranged in a circular configuration, a plurality of phase shifters which develops a group of intermediate signals having a selected phase distribution and suitable for radiation from the array and a switching matrix which accepts the group of intermediate signals and supplies them to a selected group of the radiating elements. The switching matrix and the phase shifters are electronically controlled so as to cause the beam to be steered to different positions, steering in coarse increments being accomplished by selecting different groups of elements and steering in fine increments being accomplished by selecting different phase distributions for the intermediate signals.

14 Claims, 5 Drawing Figures



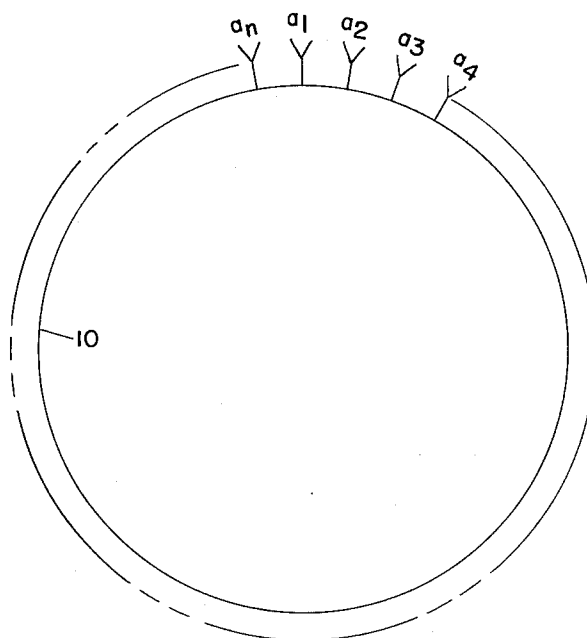


FIG. 1

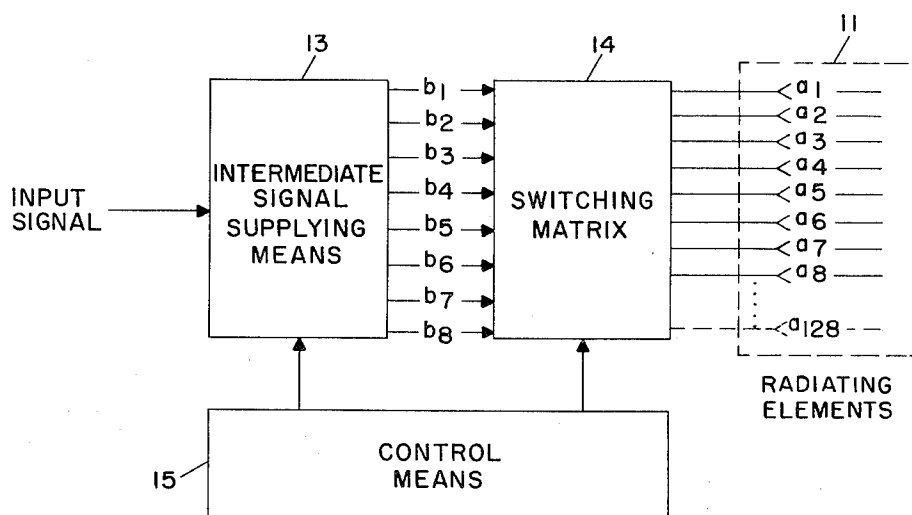


FIG. 2

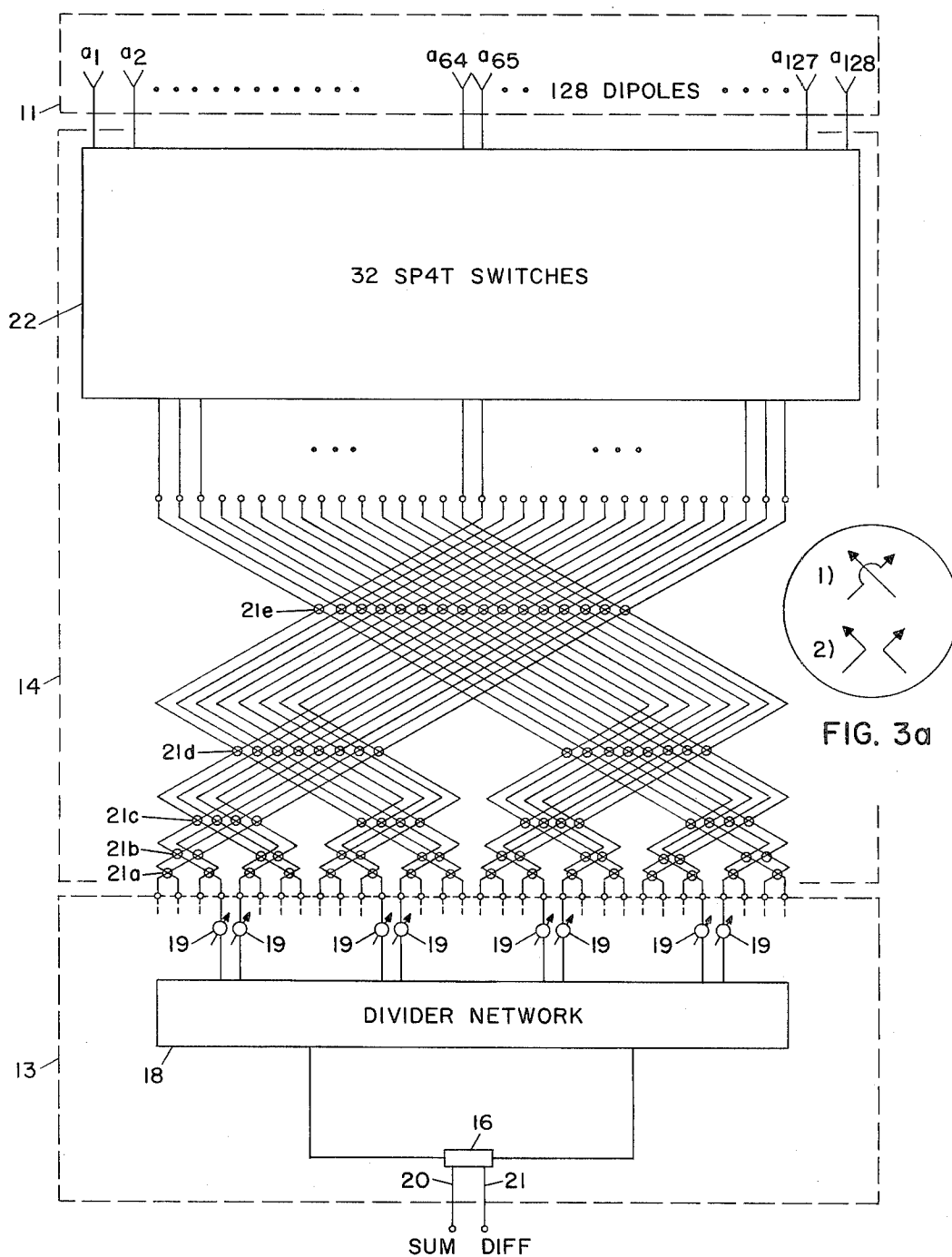


FIG. 3

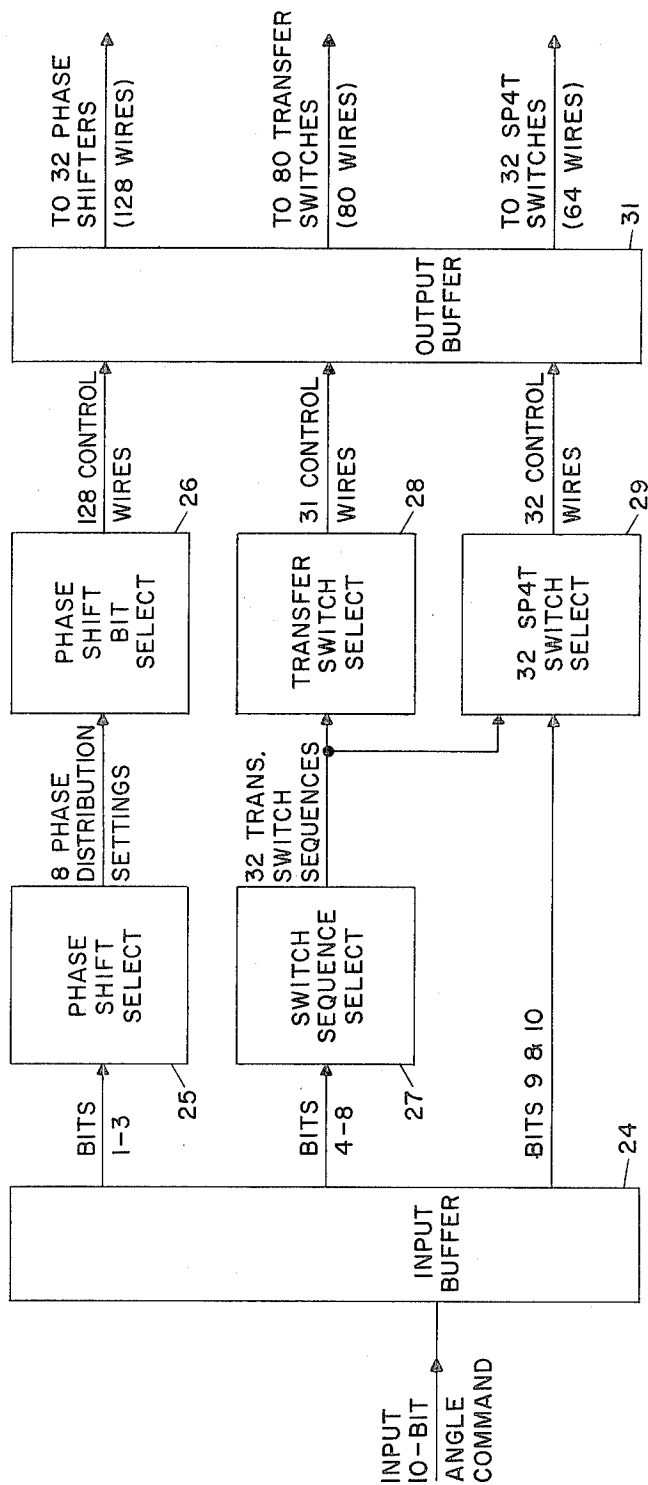


FIG. 4

CYLINDRICAL ARRAY ANTENNA

BACKGROUND OF THE INVENTION

This invention relates to array antennas and more specifically to an electronically steered array capable of radiating a beam which may be steered in coarse and fine increments to selectable beam positions. Antennas capable of radiating such a beam are useful in many situations especially in surveillance and IFF applications where the beam is to be scanned in angular sectors or over a full 360°. In such a case a technique is required to scan the antenna beam, (usually a broad fan beam in elevation) in continuous or at least fine increments in azimuth in a manner which does not introduce beam distortion.

An obvious, and presently used, method for satisfying these requirements is a mechanically rotating antenna. However, mechanical systems have the inherent disadvantages of slow rotational speeds and limited beam agility (ability to scan the beam quickly from one region of space to another).

Electronically scanned antennas overcome the slow speed and beam agility problems of the mechanical antennas but heretofore have proved to be poor analogs of the mechanical antennas in various other respects. For example, one such system has been proposed in which different elements (herein called radiating aperture) of a circular array are illuminated with an excitation signal (herein called aperture excitation) through a plurality of switches which are externally controlled. This causes a beam to be radiated only from the illuminated elements in a direction which corresponds to the location of these elements within the array. Such an array is of limited practicality for most modern uses since the beam radiated by the array is not scanned continuously or even in fine increments, as is the mechanical antenna, but is restricted to scanning in relatively large angular increments, the smallest of which is determined by the interelement angular spacing of the array.

Another disadvantage of these "switch only" electronically scanned antennas is that in order to preserve the amplitude distribution of the aperture excitation when switching from one group of elements to another two unattractive methods have been employed. The first is the highly undesirable requirement of supplying all elements illuminated with a uniform excitation, since if a non-uniform excitation was used the amplitude distribution (and therefore the resulting beam) would be destroyed whenever the beam was radiated from a different group of elements. To achieve such a uniform excitation for all beam positions it is necessary to use expensive variable phase shifters for focusing the array after each change in beam position. Obviously this is a severe limitation on prior art systems since there are many situations where it is desirable to provide the array elements with non-uniform excitations, for example in radiating sum and difference patterns simultaneously. The second equally undesirable technique employed by the prior art, which allows non-uniform aperture excitations to be supplied to such arrays is to use a phase shifter and attenuator in combination to retaper the excitations after each change in beam position. Such a technique is excessively lossy, however, causing extremely inefficient operation. Applicant overcomes the problems inherent in both of

these techniques by preserving the order of illumination of the elements (a phrase which is more clearly described hereinafter) when switching between groups of elements thereby leaving his phase shifters for the purpose of beam steering in fine increments a feature heretofore unknown to the art.

It is therefore an object of the invention to provide an array antenna capable of radiating a beam which may be electronically steered to selectable beam positions.

It is a further object of the invention to provide such an array in a cylindrical configuration.

It is still a further object of the invention to provide such an array capable of operation with either a uniform or non-uniform excitation applied to its elements.

It is a still further object of the invention to provide such an array in which compensation for the curvature of the path along which radiating elements lie is accomplished without the use of phase shifters.

In accordance with the invention there is provided an array antenna, capable of radiating a beam which may be steered to selectable beam positions. The antenna includes an aperture comprising a plurality of radiating elements arranged along the perimeter of a predetermined path having a curvature. Also included are means, responsive to a supplied input signal, for developing a predetermined number of intermediate signals suitable for radiation from the elements and having a selected phase distribution. The antenna further includes means for selecting a group of radiating elements from which the intermediate signals are to be radiated. Also included are means for coupling each of the intermediate signals to a different element in the selected group of radiating elements in an independently selectable positional order of illumination on the aperture to cause a beam to be radiated from the group in a direction which is determined by the location of the group along the perimeter and by the phase distribution of the intermediate signals. Finally the antenna includes means for controlling the selection of the group of elements and the selection of the positional order of illumination, thereby providing the ability to steer the beam to different beam positions.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is an illustration of a plurality of radiating elements arranged in a circular configuration and useful in an array antenna built in accordance with the invention;

FIG. 2 is a block diagram illustrating an embodiment of the invention;

FIGS. 3 and 3A are a block and schematic illustration showing one possible interconnection of the intermediate signal supplying means, the switching matrix, and the radiating elements for use in the embodiment of FIG. 2, and

FIG. 4 is a block illustration of one possible control means useful in the embodiment of FIG. 2.

DESCRIPTION AND OPERATION OF THE EMBODIMENTS OF FIGS. 1 & 2

Referring to FIG. 1 there is shown a plurality of radiating elements a_1 through a_n arranged along the perimeter of a predetermined path, shown by circle 10, at a convenient inter-element spacing (for example one-half wavelength). When a selected group of these ele-

ments for example a_1 , a_2 , a_3 and a_4 , are illuminated with an aperture excitation a beam will be radiated from this group and this beam can be steered to different beam positions as will be hereinafter described. Since circle 10 comprises the base of a cylinder it becomes convenient to refer to the plurality of elements arranged as in FIG. 1 as a cylindrical array.

Any suitable type of radiating elements, such as dipoles, may be used for the elements a_1 through a_n , depending on the shape of the beam desired from the array. Each element may be, in fact, replaced by a vertical column of radiating elements thus forming a series of layers of elements one above another in which case the elements will lie along an approximately cylindrical path. The beam radiated by the array of FIG. 1 will have a fan-like shape with the broad portion of the fan in the elevation plane, i.e., perpendicular to the plane of the elements. This type of beam is useful when scanned a full 360° in azimuth in that the position of targets can be monitored within a large volume of space.

Where coverage of less than the full 360° in azimuth is desired, an appropriate number of elements can be omitted from the array of FIG. 1 along the corresponding section of the circle. Many other modifications of the elements and their particular arrangement to produce radiated beams having specific characteristics will be obvious to those skilled in the art. For example, the current path along which the elements lie need not be perfectly circular (or cylindrical in the case where there are layers of elements) but may be shaped to fit the fuselage of an aircraft. It will also be recognized by those skilled in the art that when different types of radiating elements or additional layers of elements similar to those of FIG. 1 are placed one above another the fan portion of the beam can be sufficiently narrowed to create a pencil-type beam.

Turning now to FIG. 2, there is shown in block form an embodiment of the invention that includes an array 11 of 128 radiating elements (labeled a_1 through a_{128}) which may be arranged in a cylindrical configuration as in FIG. 1. Supplied to the apparatus of FIG. 2 is an input electrical signal (either pulse or cw) which may be derived in a transmitter or any other suitable signal generator commonly used for this purpose in connection with conventional array antennas.

Block 13 comprises means, responsive to the supplied input signal, for developing a predetermined number of intermediate signals suitable for radiation from the elements in array 11 and having a selected phase distribution. These intermediate signals cooperate to form a complete aperture excitation which can be coupled to a selected group of the radiating elements (the radiating aperture) in array 11 to cause a beam to be radiated therefrom. The number of intermediate signals developed (in this case eight, supplied on lines b_1 through b_8) will determine the number of radiating elements in the selected group (eight) and therefore, the width of the resulting radiated beam, since the coupling means hereinafter described couples each intermediate signal to a different element in the selected group. For example, if the selected group of elements includes a_1 through a_8 , then the signal on line b_1 may be coupled to element a_1 and likewise for b_2 and a_2 etc. This establishes a positional order of illumination for the elements within the group. The aperture excitation formed by the intermediate signals cause a

beam to be radiated from the selected elements and the direction of this beam can be varied by varying the phase distribution i.e., the progressive phase shift between individual intermediate signals of the intermediate signals. Assuming for a moment that this aperture excitation is coupled to the previously mentioned selected group of radiating elements (a_1 through a_8) in a particular order of illumination, (b_1 to a_1 , b_2 to a_2 etc.) then, as is well known in the art, a linear variation of this phase distribution (in fine increments) has the effect of varying the direction of the beam radiated from the group of elements in very fine increments, thus achieving a practical equivalency to the continuous scanning ability of a mechanically rotating antenna which scans the area covered by the radiating aperture.

The switching matrix 14 of FIG. 2 comprises means for selecting a group of elements from which the intermediate signals are to be radiated and means for coupling, in a predetermined order of illumination, each of the intermediate signals to a different element in the selected group of the radiating elements. Matrix 14 is capable of coupling the aperture excitation formed by the eight intermediate signals to any selected group of elements within array 11. Thus, the position of the radiated beam will be partially determined by the location of the selected group in array 11. Selecting different groups of elements around array 11, therefore, achieves a coarse steering of the beam. The minimum coarse steering increment is determined by the inter-element spacing, since the minimum possible change in selecting a new group is to change a single radiating element. For example, if the first selected group included elements a_1 through a_8 , then to advance the beam one coarse steering increment the second group would include elements a_2 through a_9 , and so on. However, since any group may be selected (i.e. the second or subsequently selected group may include elements a_{30} through a_{37}) discontinuous coarse steering is possible, giving arrays constructed in accordance with the invention significant beam steering agility.

Block 15 represents means for controlling the selection of the group of elements and the selection of the phase distribution while preserving the predetermined order of illumination within each selected group. Under the control of unit 15 the beam from array 11 can be steered to different beam positions, with the steering in coarse increments being accomplished by controlling switching matrix 14 so as to select different groups of elements and steering in fine increments being accomplished by controlling unit 13 so as to select different phase distribution for the intermediate signals. Means 15 may be a suitably programmed digital computer, or a special purpose computer or other logic circuitry specially adapted to control units 13 and 14 so as to cause the beam to be steered in continuous or discontinuous increments. Since there are innumerable special purposes for arrays of this type in which the requirements for beam scanning will usually be different, a suitable control means will have to be selected in each case to suit the steering criteria for each array built in accordance with the invention. An example of control means suitable for an array of the type described above and responsive to a supplied beam position 10 bit command signal such as may be derived in existing IFF systems is illustrated in block form in FIG. 4.

In selecting different groups of elements in the array 11, the order of illumination is preserved by control means 15. Thus, if in a first selected group of elements a_1 through a_8 the intermediate signal appearing on line b_1 is coupled to element a_1 , line b_2 to element a_2 and so on, then in the next selected group, such as a_{31} through a_{38} , line b_1 would be coupled to the same corresponding element in this group, namely element a_{31} , and line b_2 to element a_{32} , and so on. This preservation of the order of illumination allows either a uniform or non-uniform aperture excitation to be supplied to matrix 14 since as will be recognized by those skilled in the art, the amplitude distribution of the aperture excitation is likewise preserved when switching to different groups of elements, thus overcoming a major difficulty in the prior art.

Various other advantages of a cylindrical array or the type described above are immediately apparent since the beam agility problems of prior art mechanical scanning systems are overcome by the speed with which an array of the above type can be electronically steered to different beam positions. Furthermore, the failure of prior art systems to approach the ability of the mechanical systems to steer in fine increments is overcome in the above array by varying the phase distribution of the intermediate signals to achieve the desired fine steering.

Another advantage of the above array is that since a complete aperture excitation is generated by means 13, with means 14 only coupling this excitation to different groups of elements, necessary compensation for the curvature of the array can be achieved simply and inexpensively unlike the various prior art systems. One method of compensating for the curvature of the array is illustrated in FIG. 2, where lines b_1 through b_8 , used to supply the intermediate signals to the switching matrix 14, can be transmission lines of differing lengths whose delays are chosen to compensate for the curvature of the cylinder. Since this curvature is constant and the order of illumination of elements is preserved, once the initial choice of line lengths is made the length of the lines b_1 through b_8 need not be changed thereafter to achieve compensation for all beam positions because the compensation required for the elements of one group (a_1 through a_8 , for example) is the same for the corresponding elements of any other selected group (a_{31} through a_{38} , for example).

DESCRIPTION AND OPERATION OF THE EMBODIMENTS OF FIGS. 3 & 4

FIG. 3 shows in block and schematic form specific embodiments of intermediate signal supplying means 13 and switching matrix 14. Unit 13 is shown as consisting of an input hybrid junction 16 having two outputs which are connected to a power divider network 18. The divider network 18 is in turn connected to 32 electronically controlled phase shifters 19 (although only 8 such phase shifters are shown for clarity) resulting in 32 individual output lines from unit 13. On each output line there is provided an intermediate signal and therefore in normal operation the aforementioned selected groups of radiating elements will consist of 32 out of 128 elements.

In operation, a suitable input signal may be fed to the sum port 20 of hybrid 16 to obtain a low side lobe sum pattern from the array by illuminating an entire 32 element radiating aperture of the array 11 in phase. A dif-

ference pattern may be obtained by feeding the input signal to the difference port 21 of hybrid 16, thereby illuminating one-half of the radiating aperture, in this case 16 radiating elements 180° out of phase with the other half.

Divider network 18 may be of conventional design which provides a symmetrical in-phase tapered amplitude distribution for the 32 signals fed to the phase shifters (when radiating sum patterns). Within this divider network there may be introduced fixed transmission line lengths (similar to lines b_1 through b_8) to provide an alternate method for compensating for the curvature of the array, therefore leaving the phase shifters 19 for the purpose of beam steering. Phase shifters 19 introduce a phase shift into each intermediate signal, to create a selected phase distribution across the 32 intermediate signals which determines the direction of the beam radiated from a selected group of 32 elements, thus achieving the requisite fine steering. The phase shift provided by each phase shifter 19 is controlled by control means 15 to provide a series of selectable linear phase distributions which in this case by way of example is assumed to be eight. Each individual phase shifter is conveniently chosen as a digital 4 bit (4 input lines control the phase shift of each phase shifter) diode phase shifter giving a 360° total phase shift in 22.5° increments, thus each individual phase shifter can provide 16 different phase shifts, however, when combined with the other phase shifters in the system there is provided a group of intermediate signals with 8 possible different phase distributions.

Coupling means 14 is shown as a switching matrix consisting of 80 transfer switches $21_a - 21_e$ and a bank of 32 SP4T (single pole four throw) switches 22. Shown in FIG. 3a are alternate states for the transfer switches which may be individually selected by the control means 15 to supply a particular intermediate signal to a particular SP4T switch in bank 22 thereby selecting the positional order of illumination by which the intermediate signals are coupled to the selected radiating elements independent of the selection of the radiating elements. The 32 SP4T switches 22 comprise means for selecting a group of elements from which the intermediate signals are to be radiated. A simple connection of the SP4T switches 22 then permits the 32 outputs of the transfer switches to be connected to a group of 32 radiating elements designated by the control means 15. Since the aperture excitation at the input to the matrix is complete and need only be routed to the selected group of 32 elements to cause a beam to be radiated, the switching matrix couples the intermediate signals to the elements in array 11 by equal length paths thus ensuring that the aperture excitation created by means 13 will not be distorted in the matrix.

The switching matrix in response to control means 15 may for example couple the 32 intermediate signals to any 32 consecutive elements of the 128 radiating elements in array 11 in the aforementioned order of illumination. Therefore, there are 128 different coarse beam positions available 2.8° apart. Additionally, for each coarse beam position effected by matrix 14 there are eight fine beam positions effected by unit 13 by varying the phase distribution of the intermediate signals to eight different linear phase distributions as previously described, making a total of 1,024 beam positions available 0.35° apart.

Turning now to FIG. 4 there is shown one embodiment of control means 15 specially suited for operation with the array system of FIG. 3. In this embodiment a predetermined command signal is used to control the state of the switches in matrix 14 and the phase shifters in means 13. The three smallest bits (1-3) will provide the information necessary to determine which of eight possible phase distributions are to be selected, with control for the individual phase shifters being provided by logic circuitry 24, 25, 26 and 31 in a manner which will be recognized by those skilled in the art. The next five larger bits (4-8) will provide the information necessary to determine the settings of the 80 transfer switches and in combination with bits 9 and 10, the settings of the 32 SP4T switches through logic circuitry 24, 27, 28, 29 and 31. Bits 4-10 therefore provide information to select between 128 beam positions. It will be recognized by those skilled in the art that since there are only 128 different beam positions utilized (since there are only 128 elements in the array) and, while the use of 80 transfer switches would give the possibility of many more beam positions, for simplicity, the logic circuitry shown is adapted to control these transfer switches in sequences and combinations since many of them will receive the same command for any one selected beam position.

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.

What is claimed is:

1. An array antenna, capable of radiating a beam which may be steered in coarse and fine increments to selectable beam positions, comprising:

an aperture comprising a plurality of radiating elements arranged along the perimeter of a predetermined path having a curvature;

means, responsive to a supplied input signal, for developing a predetermined number of intermediate signals, suitable for radiation from said elements and having a selected phase distribution;

means for selecting a group of said radiating elements from which said intermediate signals are to be radiated;

means for coupling each of said intermediate signals to a different element in said selected group of radiating elements in an independently selectable positional order of illumination on said aperture to cause a beam to be radiated from said group in a direction which is determined by the location of said group along said perimeter and by the phase distribution selected for said intermediate signals;

and means for controlling the selection of said group of elements, the selection of said phase distribution and the selection of said positional order of illumination, thereby providing the ability to steer said beam to different beam positions, steering in coarse increments being accomplished by selecting different groups of elements along said perimeter and steering in fine increments being accomplished by selecting different phase distributions for said intermediate signals.

2. Apparatus in accordance with claim 1, wherein said plurality of radiating elements includes at least one layer of such elements arranged in a cylindrical configuration

to achieve 360° azimuth coverage from the array.

3. Apparatus in accordance with claim 1 wherein said predetermined path is approximately circular.

4. Apparatus in accordance with claim 3 wherein said coupling means comprises a plurality of electronically controlled switches arranged in a switching matrix.

5. A cylindrical array antenna, capable of radiating a beam which may be steered in coarse and fine increments to selectable beam positions, comprising:

An aperture comprising a plurality of radiating elements arranged along the perimeter of an approximately cylindrical path having a curvature;

means, responsive to a supplied input signal and including a predetermined number of electronically controlled phase shifters, for developing a corresponding number of intermediate signals suitable for radiation from said elements and having a selected phase distribution;

means, including a plurality of electronically controlled switches, for selecting a number of said radiating elements equal to the number of said intermediate signals and from which said intermediate signals are to be radiated;

means, including a plurality of electronically controlled switches, for coupling each of said intermediate signals to a different element in said selected group of radiating elements in an independently selectable positional order of illumination on said aperture to cause a beam to be radiated from said group in a direction which is determined by the location of said group along said perimeter and by the phase distribution selected for said intermediate signals;

and means for controlling the state of said switches and the amount of phase shift caused by each of said phase shifters, to control the selection of said group of elements, the selection of said phase distribution and the selection of said positional order of illumination, thereby providing the ability to steer said beam to different beam positions, steering in coarse increments being accomplished by selecting different groups of elements along said perimeter and steering in fine increments being accomplished by selecting different phase distributions for said intermediate signals.

6. Apparatus in accordance with claim 5 wherein said control means comprises logic circuit means, responsive to a predetermined supplied beam position command signal, for controlling the state of said switches and the phase shift caused by each phase shifter to control the selection of said group of elements and the selection of said phase distribution so as to steer said beam to the beam position specified in said command signal.

7. Apparatus in accordance with claim 6 wherein said intermediate signal supplying means further comprises a plurality of transmission line lengths each for adjusting the phase of one of said intermediate signals by a fixed amount to compensate for the curvature of said cylindrical path.

8. Apparatus in accordance with claim 7 wherein said radiating elements include a plurality of layers of such elements each arranged in a circular configuration.

9. A cylindrical array antenna, capable of radiating a beam which may be steered in coarse and fine increments to selectable beam positions, comprising:

an aperture comprising a plurality of radiating elements uniformly spaced along the perimeter of a circle and including at least one layer of such elements arranged to achieve 360° azimuth coverage from the array;

means, responsive to a supplied input signal and including a power divider network and a predetermined number of electronically controlled phase shifters fed by said power divider network, for developing a corresponding predetermined number of intermediate electrical signals suitable for radiation from said elements and having a selected phase distribution;

a plurality of transmission line lengths, each for adjusting the phase of one of said intermediate signals by a fixed amount to compensate for the curvature of said cylindrical path;

means, including a plurality of electronically controlled switches, for selecting a number of said radiating elements equal to the number of said intermediate signals and from which said intermediate signals are to be radiated;

an electronically controlled solid state switching matrix for coupling, in an independently selectable positional order of illumination on said aperture, each of said adjusted intermediate signals to a different element in said selected group of radiating elements, to cause a beam to be radiated from said group in a direction which is determined by the location of said group along said perimeter and by the phase distribution of said intermediate signals;

and logic circuit means, responsive to a supplied beam position command signal, for controlling the state of said electronically controlled switches, the state of said switching matrix and the amount of phase shift caused by each phase shifter, to control the selection of said group of elements, the selection of said positional order of illumination and the selection of said phase distribution respectively, thereby providing the ability to steer said beam to different beam positions in a full 360°, steering in coarse increments being accomplished by selecting different groups of elements along said perimeter and steering in fine increments being accomplished

by varying the phase distribution of said intermediate signals.

10. An array antenna, capable of radiating a beam which may be steered to selectable beam positions, comprising:

an aperture comprising a plurality of radiating elements arranged along the perimeter of a predetermined cylindrical path having a curvature;

means, responsive to a supply input signal, for developing a predetermined number of intermediate signals, suitable for radiation from said elements and having a selected phase distribution;

means for selecting a group of said radiating elements from which said intermediate signals are to be radiated;

means for coupling each of said intermediate signals to a different element in said selected group of radiating elements in an independently selectable positional order of illumination on said aperture to cause a beam to be radiated from said group in a direction which is determined by the location of said group along said perimeter and by the phase distribution of said intermediate signals;

and means for controlling the selection of said group of elements and the selection of said positional order of illumination, thereby providing the ability to steer said beam to different beam positions.

11. Apparatus in accordance with claim 10, wherein said plurality of radiating elements includes at least one layer of such elements arranged in a cylindrical configuration to achieve 360° azimuth coverage from the array.

12. Apparatus in accordance with claim 10, wherein said predetermined path is approximately circular.

13. Apparatus in accordance with claim 12, wherein said coupling means comprises a plurality of electronically controlled switches arranged in a switching matrix.

14. Apparatus in accordance with claim 13, wherein said intermediate signal supplying means further comprises a plurality of transmission line lengths each for adjusting the phase of one of said intermediate signals by a fixed amount to compensate for the curvature of said cylindrical path.

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