

[54] **DUAL CIRCULARLY POLARIZED  
PHASED ARRAY ANTENNA**

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[51] Int. Cl. .... **H01q 21/26**

[58] Field of Search.....**343/797, 798, 799, 800, 876, 343/846, 854**

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[57] **ABSTRACT**

A phased array antenna is provided by stacking two PC boards in a superimposed relationship above the base of a housing for the antenna. Each of these PC boards contain therein a symmetrical arrangement of photo etched or printed mat-strip power division networks and a plurality of radial arrangements each including a plurality of photo etched or printed mat-strip dipole elements having a given angular relationship therebetween. The dipole elements of the radial arrangements on one PC board are orthogonally related to the dipole elements of the radial arrangements on the other PC board. RF switching means control the orthogonally related dipole elements of each of the PC boards that are connected to the power division network so that the phase of the dual circularly polarized radiation pattern can be controlled in quantized steps determined by said given angular relation. The ground plane for the lower PC board is the housing and the ground plane for the radial arrangements of dipole elements on the upper PC board is provided by parallel, space conductive members in a superimposed, parallel relationship with each of the radial arrangements. Each of the power division networks is fed by a double ended balun. The two baluns are in turn fed from a quadrature hybrid.

**15 Claims, 6 Drawing Figures**

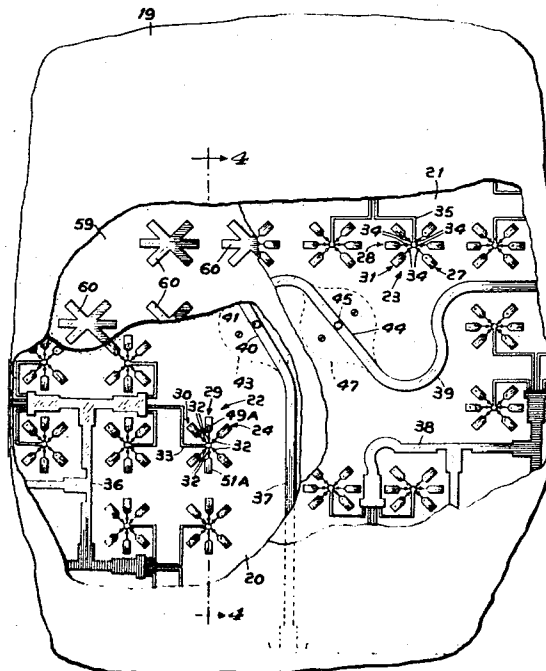


*Fig. 1*

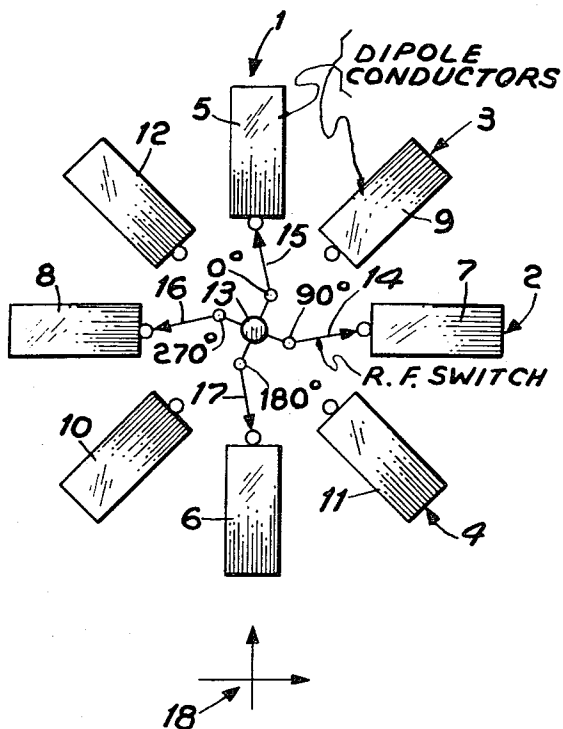


*Fig. 2*

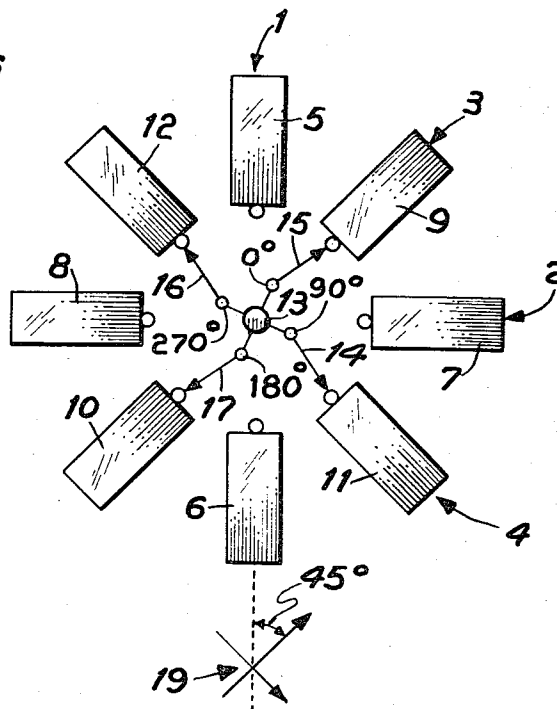
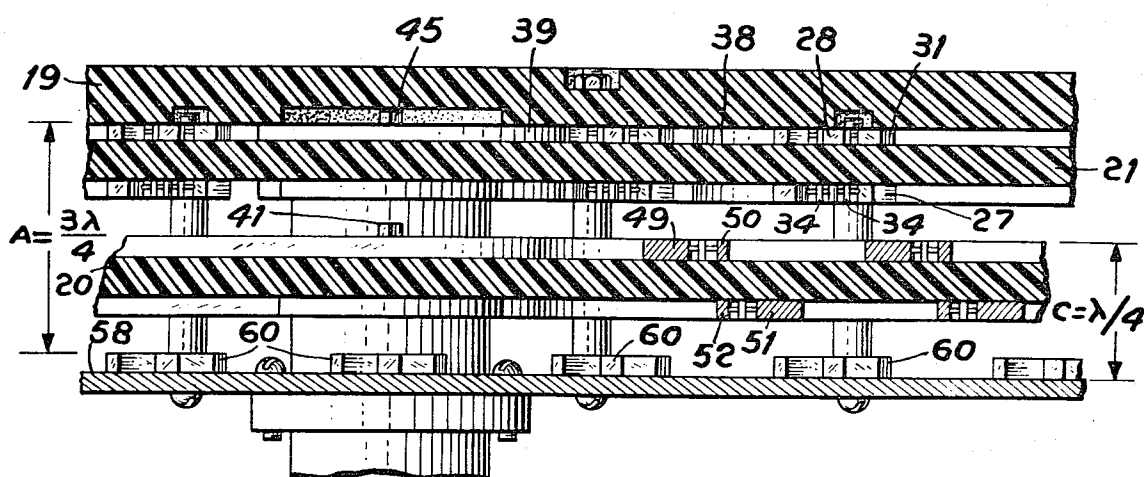
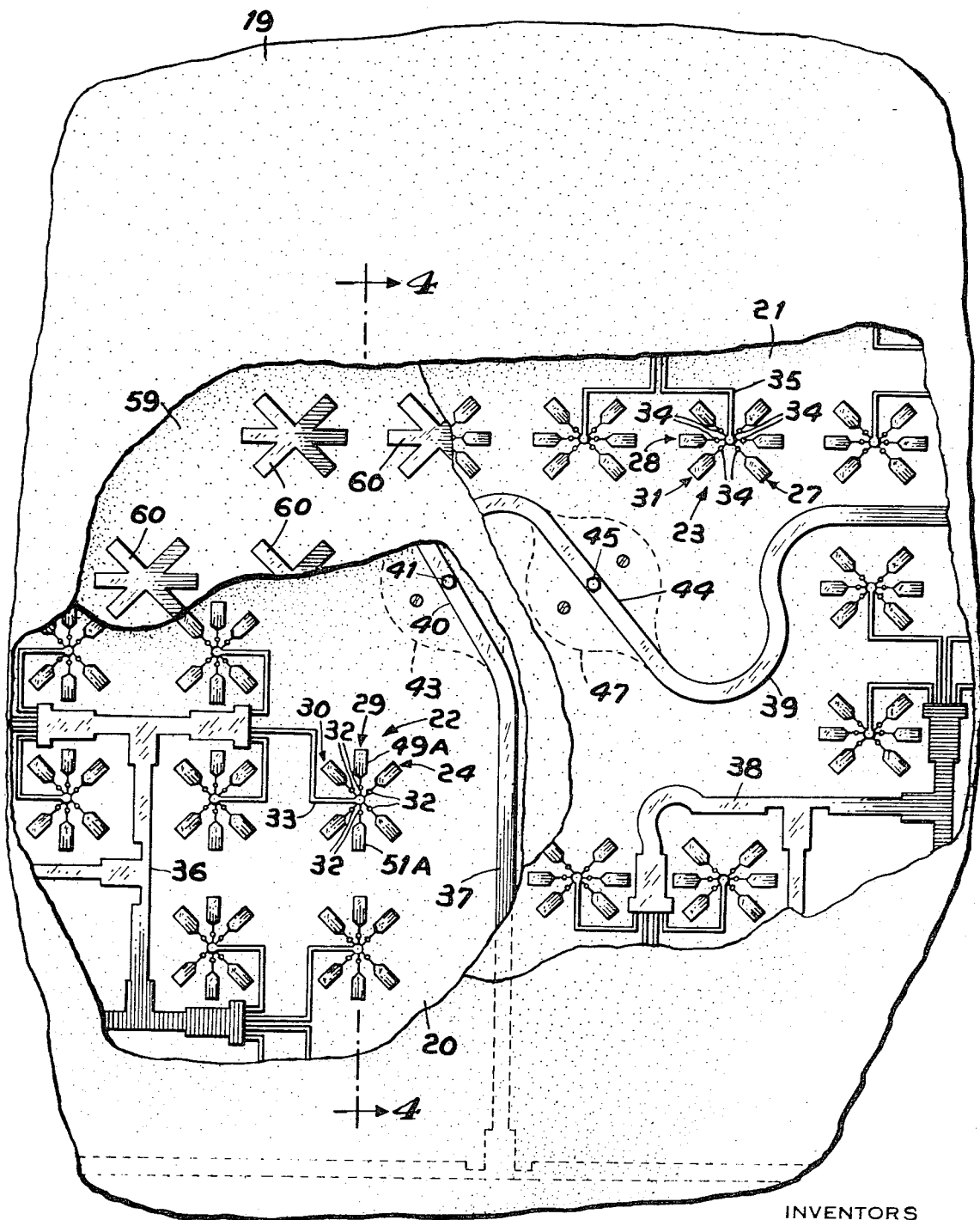


*Fig. 6*



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*Fig. 3*



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*Fig. 4*

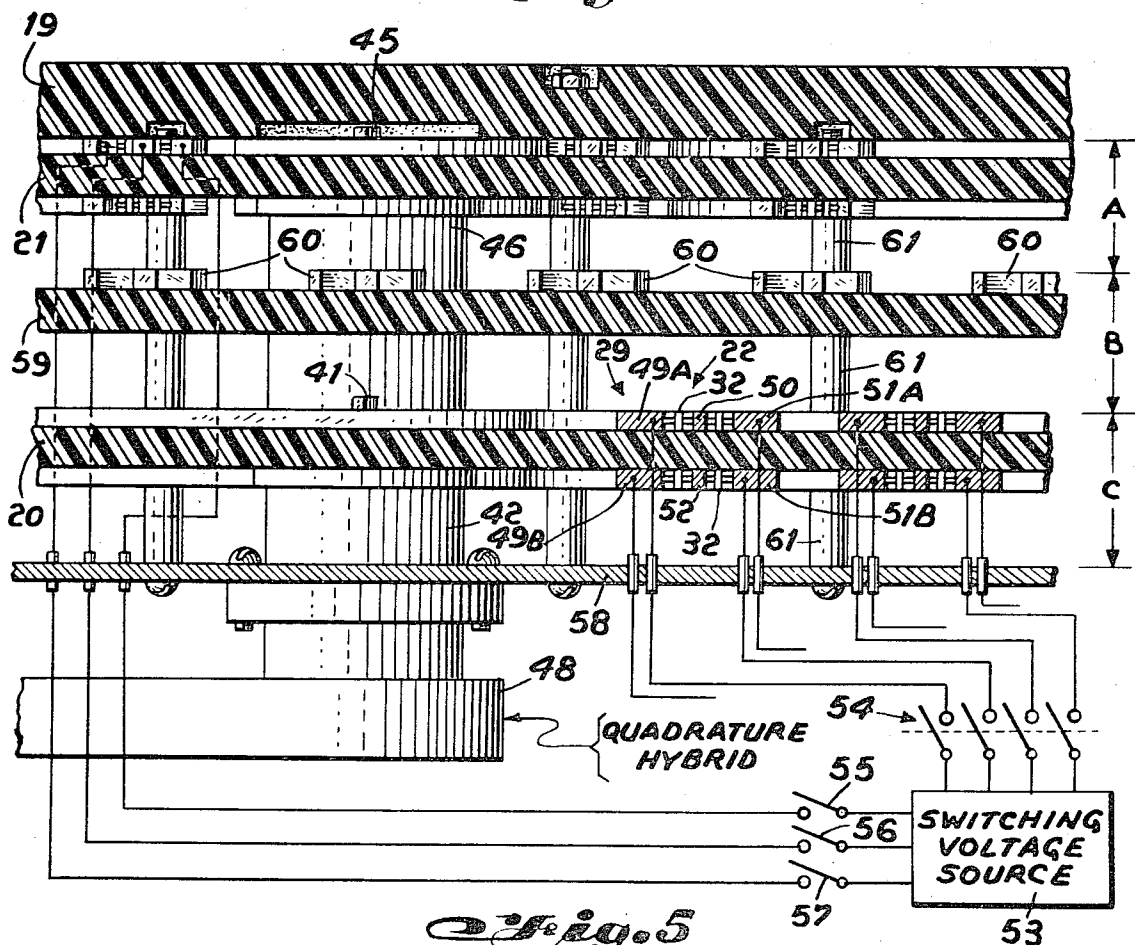
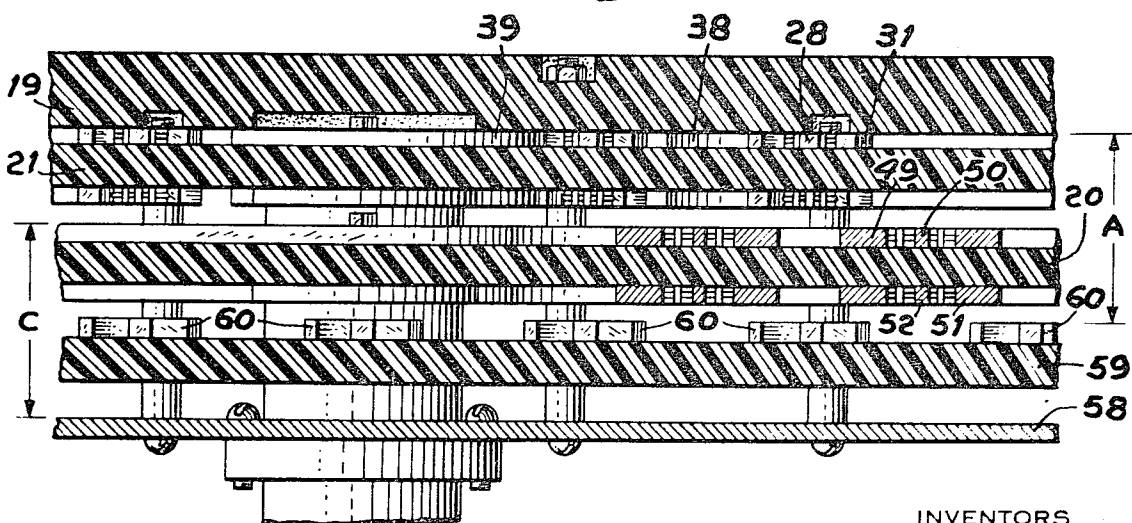


*Fig. 5*



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# DUAL CIRCULARLY POLARIZED PHASED ARRAY ANTENNA

## BACKGROUND OF THE INVENTION

This invention relates to antennas and more particularly to antennas employing mat-strip and printed circuit techniques.

The term "mat-strip" as employed herein is defined as a photo etched or printed balanced transmission line printed on opposite surfaces of a printed circuit (PC) board in such a manner that both conductors are superimposed, are equal in width and are equal in length. This is in contrast to a stripline transmission line which is an unbalanced transmission line requiring two ground planes one above and one below a single conductive strip and to a microstrip transmission line which consists of a conductive strip above a ground plane having a much greater width than the conductive strip. A microstrip transmission line is analogous to a two wire line in which one of the wires is represented by the image in the ground plane of the wire that is physically present. Another way of expressing what a mat-strip transmission line is is to state that it is a balanced transmission line in which the image wire of a microstrip transmission line has materialized and the ground plane of a microstrip transmission line has been removed.

An antenna dipole element in mat-strip technique consists of one half of the dipole elements (one "wing" or section) being disposed on one surface of a PC board having one end thereof connected to one conductor of a mat-strip transmission line and the other half of the dipole element (the other "wing" or section) being disposed on the other surface of the PC board having one end thereof connected to the other conductor of the same mat-strip transmission line. A ground plane is associated with the dipole elements (it has no function in the mat-strip transmission line) to ensure that the radiation from the dipole element is from one surface of the PC board, namely, the surface of the PC board removed from the ground plane.

U. S. Pat. No. 2,962,716 issued to H. F. Engelmann and assigned to the assignee of the present application discloses therein a linearly polarized antenna array including dipole elements which are parallel fed by a mat-strip transmission line network which, in turn, is fed by a "single ended" balun. The single ended balun includes a coaxial line having its center conductor connected to one conductor of a mat-strip transmission line extending radially in one direction from the center conductor to the antenna feeding power division network while the other conductor of this radially extending mat-strip transmission line is coupled to the outer conductor of the coaxial line. Employing the single ended balun arrangement the power feed to the antenna array is limited by the physical width of the mat-strip transmission line extending in one direction radially from the coaxial line. Also at higher frequencies, such as X-band, the single ended balun arrangement will radiate because an unbalanced line (coax) is connected "single ended" to a balanced line (mat-strip).

In a copending application of E. J. Perrotti, J. C. Ranghelli and R. A. Felsenheld, Ser. No. 59,404, filed July 30, 1970, now U.S. Pat. No. 3,681,769, discloses a dual circularly polarized antenna array which includes two PC boards stacked in a superimposed relationship

above the bottom of the antenna housing which acts as a ground plane for the lower PC board. Each of these two PC boards contain thereon a symmetrical arrangement of photo etched or printed mat-strip power division networks and dipole elements providing linear polarization, the dipole elements on one PC board being oriented with respect to the dipole elements on the other PC boards to provide orthogonal linear polarization. A ground plane for the dipole elements on the upper PC board is provided by parallel, space conductive members in a superimposed, parallel relationship with the dipole elements of the upper PC boards. The dipole elements and power division networks of the two PC boards and the conductive members forming the ground plane for the upper PC board are so oriented that they are transparent to and from the dipole elements of the two PC board. The symmetrical dipole elements on each of the two PC boards are fed by a balanced, symmetrically branched power division mat-strip network carried by the associated board and a combined balun and power divider coupling an input waveguide to the balanced mat-strip power division network. The input waveguide has its input coupled to a quadrature hybrid. Each combined balun and power divider includes a coaxial transmission line having its center conductor connected directly to a mat-strip conductor extending radially in two directions from the center conductor to the mat-strip network, the radially extending mat-strip conductor having the same width as the mat-strip conductors of the network, and its outer conductor connected to a mat-strip conductor connected to the mat-strip network initially having greater width than the mat-strip conductors of the network than gradually tapered to the same width as the mat-strip conductors. The mat-strip conductors of the network include at the branching locations impedance transformers formed by a predetermined length and a predetermined width different than the given width.

## Summary of the Invention

An object of the present invention is to provide a dual (right and left hand) circularly polarized phased array antenna employing the techniques disclosed in the above-cited copending patent application.

Another object of the present invention is to provide a mat-strip radio frequency energy power division or distribution transmission line network for feeding the antenna elements and the double ended balun arrangement which are substantially identical to those disclosed in detail in the above-cited copending patent application.

A feature of this invention is to provide a dual circularly polarized phased array antenna comprising a plurality of pairs of orthogonally related linearly polarized dipoles, each of said pairs of orthogonally related dipoles being disposed at a given angle with respect to each other and each of said pairs of orthogonally related dipoles having a dual circularly polarized radiation pattern; and switching means coupled to each of the pairs of orthogonally related dipoles to control which of the pairs of orthogonally related dipoles are active ones to enable phase control of the radiation pattern by quantized steps equal to the given angle.

## BRIEF DESCRIPTION OF THE DRAWING

Above-mentioned and other features of objects of this invention will become more apparent by reference to the following description taken in conjunction with the accompanying drawing in which.

FIGS. 1 and 2 illustrations are useful in explaining the operation of the phased array in accordance with the principles of the present invention;

FIG. 3 is a partial top plan section of one embodiment of the dual circularly polarized phase array antenna in accordance with the principles of the present invention having certain portions thereof removed to expose (1) the lower most mat-strip linearly polarized array, (2) the parallel ground planes for the dipole elements of the upper most array and (3) the upper most mat-strip linearly polarized array;

FIG. 4 is a partial cross sectional view of FIG. 3 taken along line 4—4 of FIG. 3;

FIG. 5 is a partial cross sectional view of FIG. 3 taken along line 4—4 illustrating an alternative relative location of the three PC boards in accordance with the principles of this invention; and

FIG. 6 is a partial cross sectional view of FIG. 3 taken along lines 4—4 illustrating an alternative ground plane for the upper most PC board array in accordance with the principles of this invention.

## DESCRIPTION OF THE PREFERRED EMBODIMENT

Referring to FIGS. 1 and 2, there is disclosed in each of these figures a first pair of orthogonally related dipoles 1 and 2 and a second pair of orthogonally related dipoles 3 and 4. Dipole 1 is formed of two sections or wings 5 and 6, dipole 2 is formed of two sections or wings 7 and 8, dipole 3 is formed of two sections or wings 9 and 10 and dipole 4 is formed of two sections or wings 11 and 12. In accordance with the principles of this invention the dual circularly polarized phased array is formed by a plurality of pairs of linearly polarized orthogonally related array, each of which has variable "slant" polarization control and is driven by a quadrature hybrid through a transmission line an end of which is represented at 13. Circular polarization is achieved by exciting the linear polarized antenna elements in pairs such that they are in space quadrature and phase quadrature. Space quadrature is obtained by positioning the linearly polarized elements of a pair in space 90° apart and phase quadrature is obtained by driving the orthogonally related pairs from the outputs of a quadrature hybrid which inherently produces a 90° differential phase between outputs. When the radio frequency (RF) switches 14, 15, 16 and 17 are in the position illustrated in FIG. 1 a certain reference phase of the generated dual circularly polarized radiation pattern is obtained, as indicated, by arrows 18. Phase control of the antenna is obtained by a spatial rotation of each dipole pair about its propagation axis, where the angle of rotation in space equals the phase shift of the radiation pattern. This spatial rotation is obtained by positioning RF switches 14 through 17 as indicated in FIG. 2 which effectively provides a 45° spatial rotation of the pair of dipoles 1 and 2. This results in a 45° phase rotation of the radiation pattern as indicated by arrows 19.

As illustrated in FIG. 2 a 45° differential phase rotation of the radiation pattern is obtained by having the pair of orthogonally related antennas disposed at a 45° angle with respect to each other. The phase quantization or angle of rotation of the radiation pattern is determined by the number of dipoles employed where an increase in the number of orthogonally related pairs of dipoles will reduce the angle between the dipole pairs. For instance, in the illustration of FIG. 1 there are four dipoles from which there are eight possible pairs of orthogonally polarized dipoles which provides three bits of phase quantization or eight angles of rotation. If eight dipoles were employed the angle between the orthogonally related dipole pairs would be 22.5° and there would be four bits of phase quantization shifts or sixteen steps or angles that the dipole pairs could be rotated to. If 16 dipoles were employed the angle between the dipoles would be 11.25° and the number of steps of phase quantization shifts would be equal to 32.

The degree values shown in FIGS. 1 and 2 represent the instantaneous phases of signals as provided by the quadrature hybrid. The RF switches 14—18 are shown as ideal switches. In actual practice the RF switch would be realized by semiconductor devices, such as PIN diodes, or mechanical devices, such as reed type switches. The phased array of this invention can be realized in a number of ways, the most convenient of which is to print the RF energy distribution transmission line together with the array of dipole elements employing mat-strip techniques similar to that disclosed in the above-cited copending application. Either one PC board with all of the orthogonally related pairs of dipoles or two PC boards each contain one linearly polarized element each pair of linearly polarized orthogonally related elements can be employed.

Referring to FIGS. 3 and 4, there is illustrated in a partial top plane view embodiment of a dual circularly polarized phased array antenna in accordance with the principles of this invention which incorporates the techniques for the dipole elements, RF energy distribution system and combined power divider-balun arrangement as disclosed in the above-cited copending patent application.

The embodiment illustrated incorporates a stack or sandwich type arrangement of PC type linearly polarized arrays and associated ground planes to enable the achievement of a circularly polarized phased array antenna when energy is appropriately coupled thereto in accordance with the principles of this invention. The antenna includes a radome 19 and a PC board 20 having printed thereon in a symmetrical arrangement one of the dipole elements of each of a plurality of pairs of dipole elements and a PC board 21 having printed thereon in a symmetrical arrangement the other dipole element of a plurality of pairs of dipole elements to enable the spatial rotation about the propagation axis of the dipole pairs to thereby provide a phase shift of the circularly polarized radiation pattern.

The one dipole element of the plurality of pairs of dipole elements on each of the PC boards 20 and 21 arranged in radial arrangements such as illustrated at 22 and 23, respectively. Dipole 24 in one radial arrangement on PC board 20, such as arrangement 22,

cooperates with dipole element 27 in one radial arrangement on PC board 21, such as radial arrangement 23, to form a first pair of orthogonally related dipole elements. Dipole element 28 of arrangement 23 cooperates with dipole element 29 of radial arrangement 22 to provide a second pair of orthogonally related dipole elements. Dipole element 30 of arrangement 22 cooperates with dipole element 31 of arrangement 23 to provide a third pair of orthogonally related dipole elements. It is to be understood that while the above description is made with respect to two widely spaced radial arrangements the cooperative association between the orthogonally related dipole pairs would be between two radial arrangements which are positioned closer together than that illustrated, preferable in the adjacent grids of the two PC boards 20 and 21. The term "grids" has reference to the lines defining the location of the radial arrangements on either of the PC boards 20 and 21.

The remainder of each of the radial arrangements, such as arrangement 22, includes an RF switch, for instances a PIN diode 32 connected between each wing of a dipole element and a mat-strip transmission line section 33. Arrangement 23 has a similar arrangement of semiconductor diodes 34 coupled as illustrated to mat-strip transmission line section 35. Each of the radial arrangements on PC board 20 contain the same elements and are arranged as described with respect to arrangement 22. Each of the radial arrangements on PC board 21 also incorporates the same components and are arranged as described with respect to arrangement 23.

Energy is fed to the transmission line sections 33 and 35 of the two PC boards 20 and 21 by means of interconnected mat-strip type transmission lines having impedance transformers in the form of different width conductors in a manner similar to that taught in the above-cited copending patent application. A portion of the RF energy distribution system is shown in FIG. 3 on PC board 20 and includes the mat-strip transmission line sections 36 and 37 interconnected as fully taught in the above-cited copending patent application. PC board 21 likewise includes an RF energy distribution system including mat-strip transmission line sections 38 and 39. A combined double ended balun and power divider is included to feed power to the energy distribution system contained on each of the PC boards 20 and 21. With respect to PC board 20 the combined power divider and double ended balun includes the upper mat-strip conductor 40 having a width equal to the transmission conductor 37 coupled to the center conductor 41 of coaxial line 42. The outer conductor of coaxial line 42 is connected to the lower mat-strip conductor 43 which has a width greater than the width of conductor 37 of the energy distribution system. Similarly with respect to PC board 21 the combined power divider and double ended balun includes conductor 44 connected to the center conductor 45 of coaxial line 46 and the larger width conductor 47 is connected to the outer conductor of coaxial line 46. The input to coaxial lines 42 and 46 are provided by quadrature hybrid 48.

Referring particularly to FIG. 4, a portion of the radial arrangement 22 is illustrated in cross section illustrating that dipole element 29 includes a section 49A

on the upper surface of PC board 20 and a section 51B on the lower surface of PC board 20. Section 49 is connected by a diode 32 to the upper conductor of transmission line section 33. Section 51 is connected by a diode 32 to the lower conductor 52 of transmission line section 33. An alternate arrangement uses dipole wing 51A on the upper surface and dipole wing 49B on the lower surface to form a dipole element which has the same radial orientation as dipole 49A-51B but is inverted electrically, i.e., 180° shifted in phase. It should be pointed out here that the upper and lower conductors 50 and 52 of transmission line section 33 serve as the voltage return path for the switching voltage supplied from source 53 which is selectively coupled by some form of switching arrangement, such as ganged switches 54, to make active those dipole elements having the same orientation on PC board 20 and in turn the appropriate operation of ganged switches coupled to source 53 to assure that the switching voltage is provided to the properly oriented dipole element on PC board 21 to be compatible with the selected dipole element of the array on PC board 20 to provide the desired orthogonally related dipole elements. Switches 55, 56 and 57 represent one switch of a plurality of ganged switches, each of the ganged switches being coupled to the wings of the dipole elements on PC board having the same orientation.

The ground plane for the radial arrangements of the dipole elements on PC board 20 is the bottom wall 58 of the housing containing the antenna. On the other hand, the ground plane for the diode elements contained in the radial arrangements on PC board 21 is provided by a third PC board 59 having photo etched or printed thereon conductive members 60 which are parallel to and in a superimposed relationship to the radial arrangement of dipole elements on PC board 21. The stacked arrangement and the spacing between the PC boards contained therein are provided by spacers 61 fastened in position by an appropriate nut and bolt. The spacing between the ground plane 58 and the array on PC board 20 is a dimension C equal to  $\lambda/4$ . Likewise, the spacing between the array on PC board 21 and the ground plane provided by conductive members 60 is a dimension A equal to  $\lambda/4$ . The values given hereinabove for the dimensions A and C are nominal values for the operating frequency range of the antenna.

Due to the presence to the ground plane formed by members 60 disposed between the radial arrangements contained on PC boards 20 and 21, the dimension B is not critical and, therefore, close tolerances do not have to be maintained in the process of manufacturing the antenna of this invention. This is due to the fact that the wave velocity both in free space and in the coaxial balun structure are nearly equal. Thus, the quadrature phasing necessary to derive circular polarization is not significantly altered by the dimension B.

Referring to FIG. 5, there is disclosed therein an alternative position of the ground plane conductors 60 carried by PC board 59 with respect to radial arrangement of dipole elements carried by PC board 21. In this arrangement PC board 59 is disposed between the housing or ground plane 58 and the PC board 20. In this arrangement, the dimension A and the dimension C are again equal to  $\lambda/4$  and will result in a more com-

pack stack or sandwich of the PC boards and their associated ground planes.

Referring to FIG. 6, there is illustrated an alternative arrangement for the ground plane of the radial arrangement of dipole elements on PC board 21 which eliminates PC board 59. This is accomplished by appropriately positioning conductive members 60, in the manner described in connecting with FIG. 4, on the surface of the ground plane 58. In this instance, the dimension C is equal to  $\lambda/4$  and the dimension A is equal to  $3\lambda/4$ .

The antenna of this invention provides a construction which is a compact sandwich construction, is extremely rugged, is inexpensive and is of minimal thickness. Another advantage is that both the upper and lower PC boards containing the radial arrangements 22 and 23 and the RF energy distribution network can be fabricated by PC techniques employing the same art work. As a result, the phase errors introduced by the printed radial arrangements and the distribution networks is minimized when using the modular concept to build larger antennas and in addition, the manufacture costs are minimized especially if many modules are to be constructed.

While we have described above the principles of our invention in connection with specific apparatus, it is to be clearly understood that this description is made only by way of example and not as a limitation to the scope of our invention as set forth in the objects thereof and in the accompanying claims.

We claim:

1. A dual circularly polarized phased array antenna comprising:

a plurality of pairs of orthogonally related linearly polarized dipoles, each of said pairs of orthogonally related dipoles being disposed at a given angle with respect to each other and each of said pairs of orthogonally related dipoles having a dual circularly polarized radiation pattern;

switching means coupled to each of said pairs of orthogonally related dipoles to control which of said pairs of orthogonally related dipoles are the active ones to enable phase control of said radiation pattern by quantized steps equal to said given angle; and

a radio frequency energy transmission line having an end in juxtaposition to said plurality of said pairs of orthogonally related dipoles and said switching means;

each dipole of said pairs of orthogonally related dipoles including two spaced sections;

said plurality of said pairs of orthogonally related dipoles being disposed such that said spaced sections are spaced from and radially extending from said end of said transmission line; and

said switching means including a radio frequency switch means coupled between each of said spaced sections and said end of said transmission line.

2. An antenna according to claim 1, wherein each of said radio frequency switch means includes a semiconductor device.

3. An antenna according to claim 2, wherein each of said semiconductor device includes a PIN diode.

4. A dual circularly polarized phased array antenna comprising:

a plurality of pairs of orthogonally related linearly polarized dipoles, each of said pairs of orthogonally related dipoles being disposed at a given angle with respect to each other and each of said pairs of orthogonally related dipoles having a dual circularly polarized radiation pattern;

switching means coupled to each of said pairs of orthogonally related dipoles to control which of said pairs of orthogonally related dipoles are the active ones to enable phase control of said radiation pattern by quantized steps equal to said given angle;

a first printed circuit board containing thereon in printed circuit form one dipole of each of said plurality of said pairs of orthogonally related dipoles and a first associated portion of said switching means;

a second printed circuit board containing thereon in printed circuit form the other dipole of each of said plurality of said pairs of orthogonally related dipoles and a second associated portion of said switching means;

a first ground plane associated with said first printed circuit board; and

a second ground plane associated with said second printed circuit board;

the contents of said first and second printed circuit board and said first and second ground planes being disposed in a parallel, stacked, non-interfering relationship to provide said dual circularly polarized phase controlled radiation pattern.

5. An antenna according to claim 4, wherein said first ground plane includes

the metallic bottom wall of the housing for said antenna; and

said second ground plane includes

a third printed circuit board containing thereon a metallic member superimposed with respect to said other dipoles, said third printed circuit board being disposed between said first and second printed circuit board.

6. An antenna according to claim 4, wherein said first ground plane includes

the metallic bottom wall of the housing of said antenna; and

said second ground plane includes

a third printed circuit board containing thereon a metallic member superimposed with respect to said other dipoles, said third printed circuit board being disposed between said bottom wall and said first printed circuit board.

7. An antenna according to claim 4, wherein said first ground plane includes

the metallic bottom wall of the housing of said antenna; and

said second ground plane includes

a raised metallic member disposed on said bottom wall superimposed with respect to said other dipoles.

8. An antenna according to claim 4, wherein said dipoles disposed on each of said first and second printed circuit boards have a mat-strip configuration.

9. An antenna according to claim 4, further including

a first printed circuit radio frequency energy transmission line section disposed on said first printed circuit board, said first section having an end in juxtaposition to each of said one dipoles and said first portion of said switching means; and

a second printed circuit radio frequency energy transmission line second disposed on said second printed circuit board, said first section having an end in juxtaposition to each of said other dipoles and said second portion of said switching means; and wherein

each of said one dipoles including

two spaced sections disposed in spaced relation with an extending radially from said end of said first transmission line section;

each of said other dipoles including

two spaced sections disposed in spaced relation with and extending radially from said end of said second transmission line section;

said first portion of said switching means includes

a first radio frequency switch means coupled between each of said spaced sections of each of said one dipoles and said end of said first transmission line section; and

said second portion of said switching means includes

a second radio frequency switch means coupled between each of said spaced sections of each of said other dipoles and said end of second transmission line section.

10. An antenna according to claim 9, wherein said first and second transmission line sections have a mat-strip configuration;

said spaced sections of each of said one dipoles have a mat-strip configuration; and

said spaced sections of each of said other dipoles have a mat-strip configuration.

11. An antenna according to claim 9, wherein the radial relationship between said two spaced sections of each of said one dipoles and said end of said first transmission line section and said first portion of said switching means form a first radial arrangement;

the radial relationship between said two spaced sections of each of said other dipoles and said end of

said second transmission line section and said second portion of said switching means form a second radial arrangement;

said first printed circuit board includes

a plurality of said first radial arrangements symmetrically disposed thereon; and

said second printed circuit board includes

a plurality of said second radial arrangement symmetrically disposed thereon; and further including

a first radio frequency energy distribution system coupled to said first transmission line section of each of said plurality of

said first radial arrangement; and

a second radio frequency energy distribution system coupled to said second transmission line section of each of said plurality of said second radial arrangement.

12. An antenna according to claim 11, wherein both said first and second distribution systems include

interconnected printed circuit radio frequency transmission lines of the mat-strip type disposed on the associated one of said first and second printed circuit boards.

13. An antenna according to claim 11, wherein each of said first and second distribution systems include

interconnected radio frequency transmission lines of the printed circuit mat-strip type disposed on the associated one of said first and second printed circuit boards, and

a double ended balun coupled to said interconnected transmission lines.

14. An antenna according to claim 13, further including

a quadrature hybrid coupled to said double ended baluns.

15. An antenna according to claim 14, wherein each of said first and second switch means includes

a semiconductor device; and further including

a source of switching voltage selectively coupled to each of said semiconductor devices to control the phase of said radiation pattern.

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