

June 17, 1941.

C. B. H. FELDMAN ET AL

2,245,660

RADIO SYSTEM

Filed Oct. 12, 1938

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FIG. 2

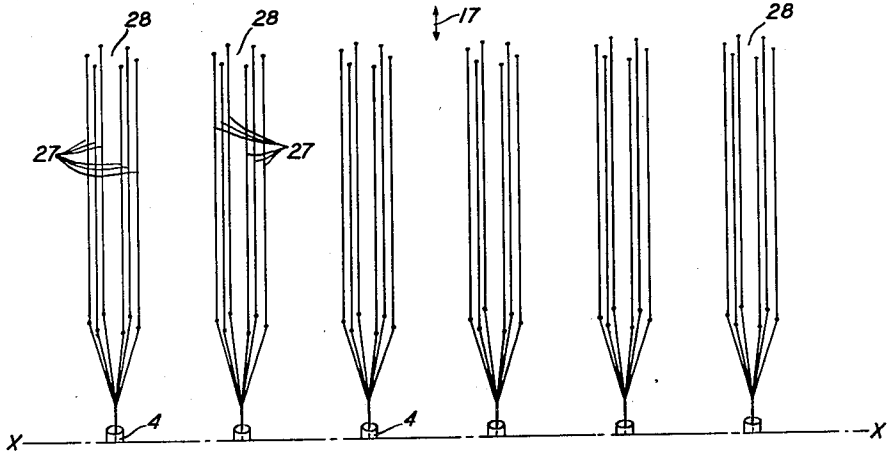


FIG. 2B

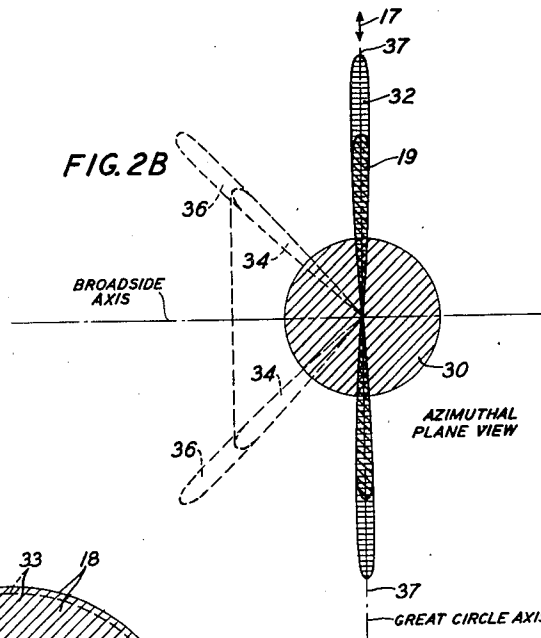
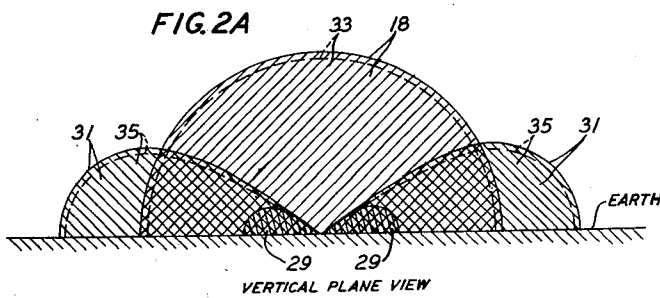


FIG. 2A



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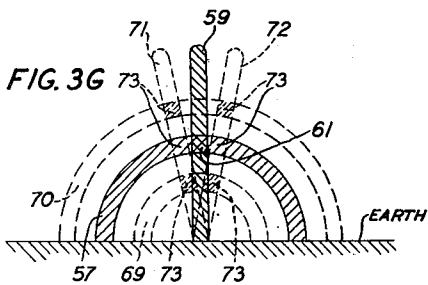
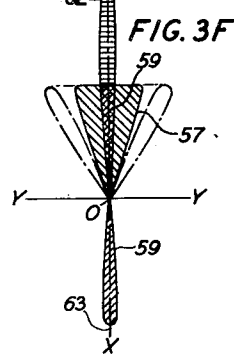
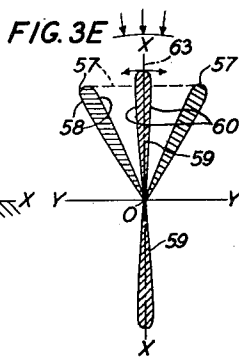
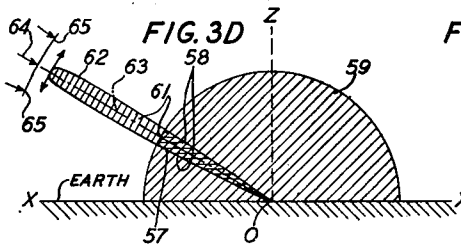
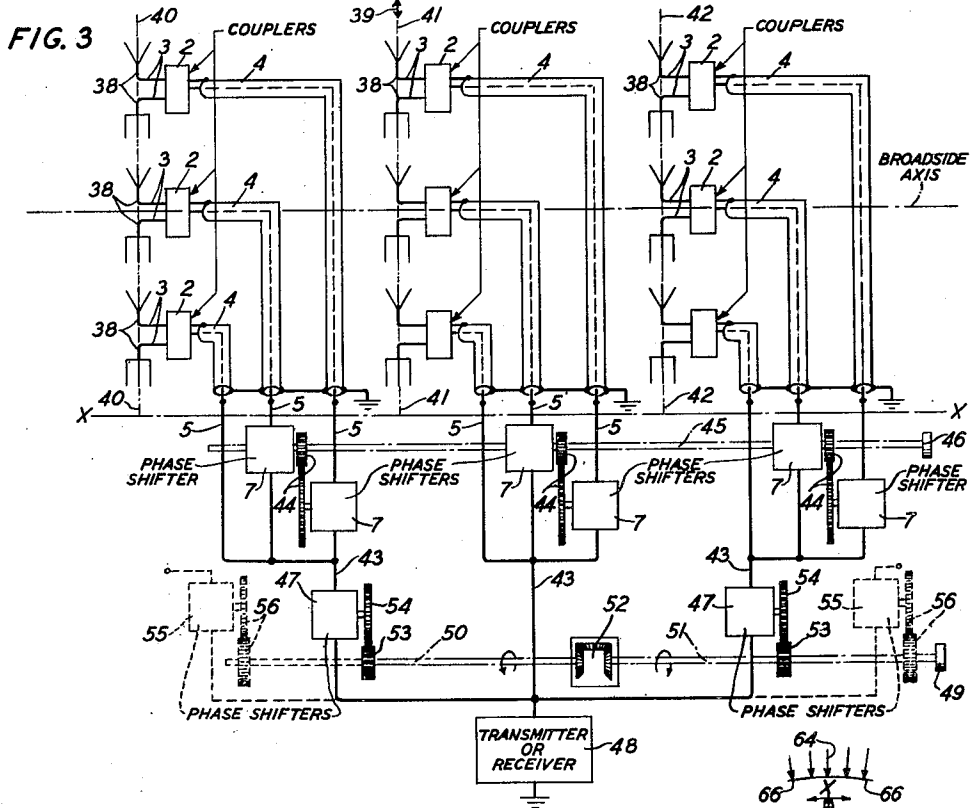
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RADIO SYSTEM

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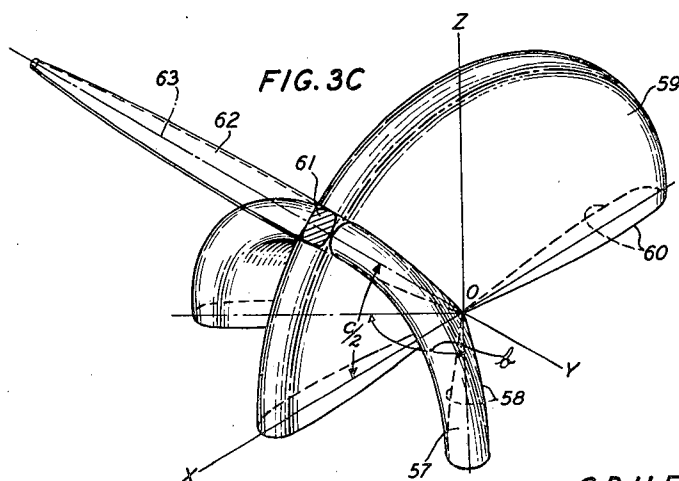
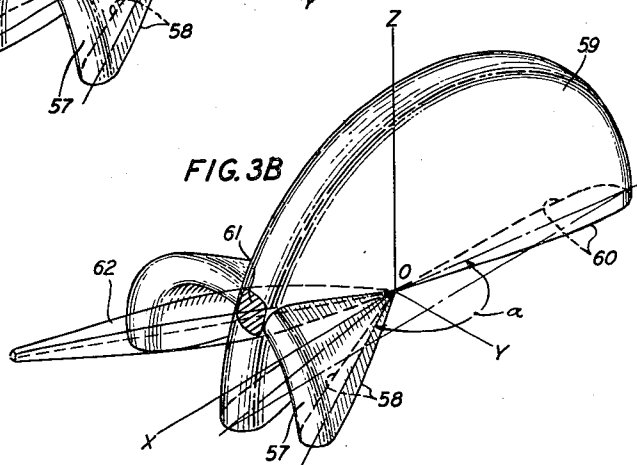
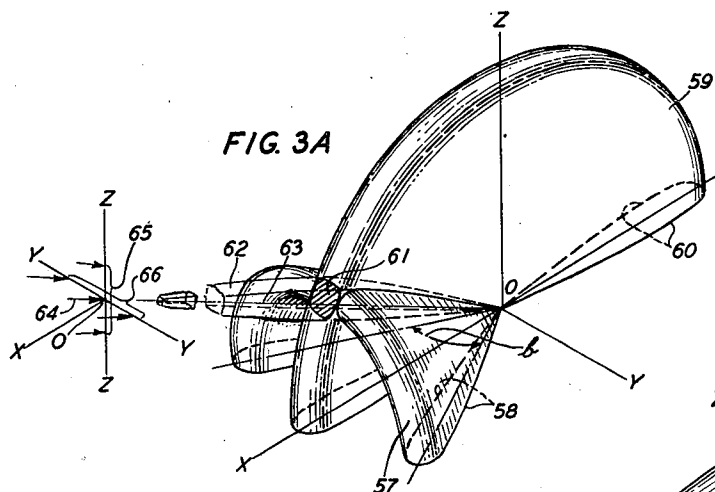
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FIG. 4

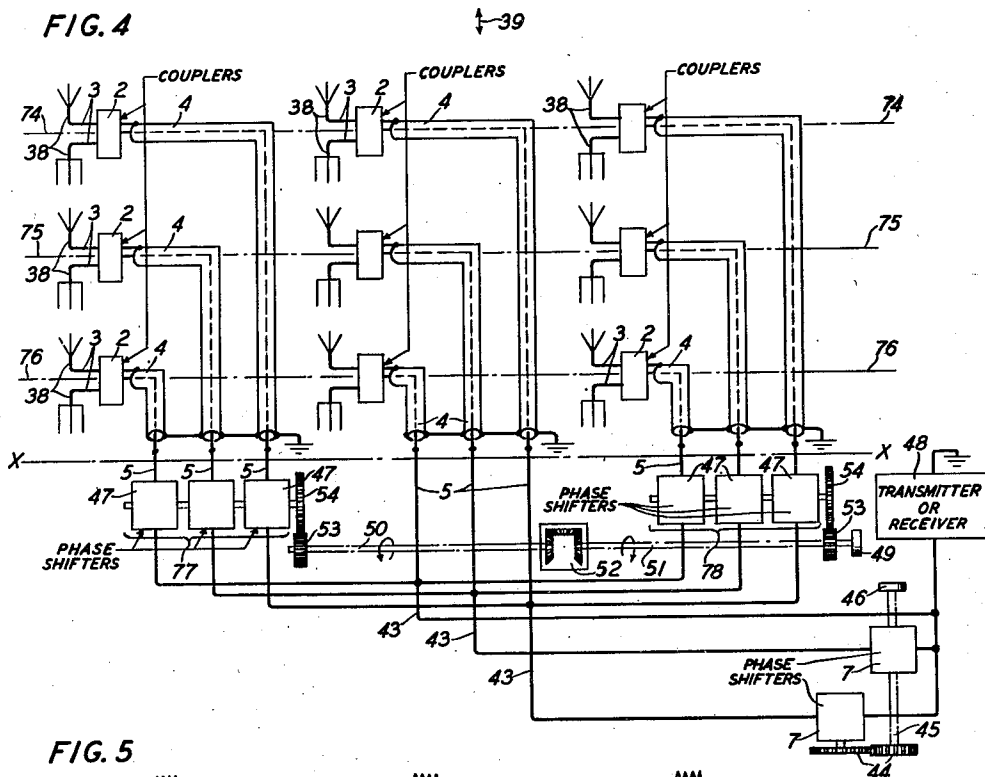
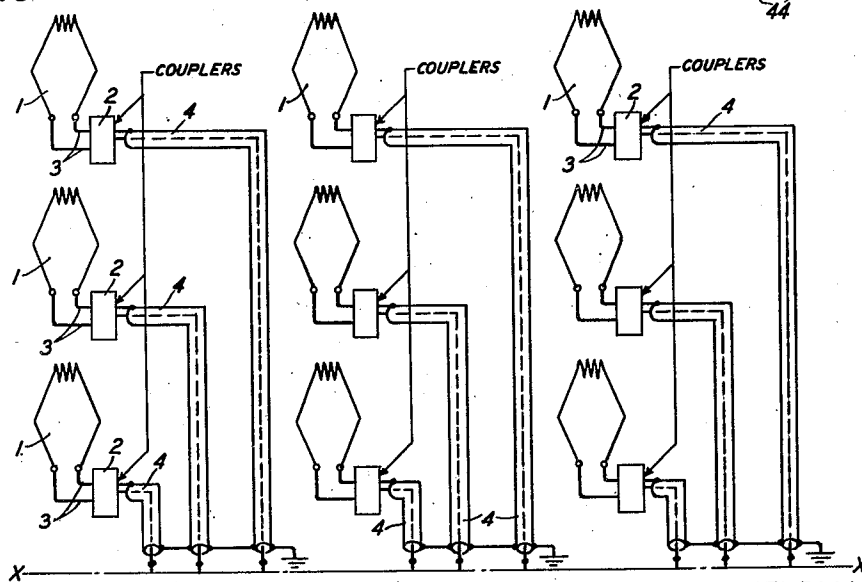


FIG. 5



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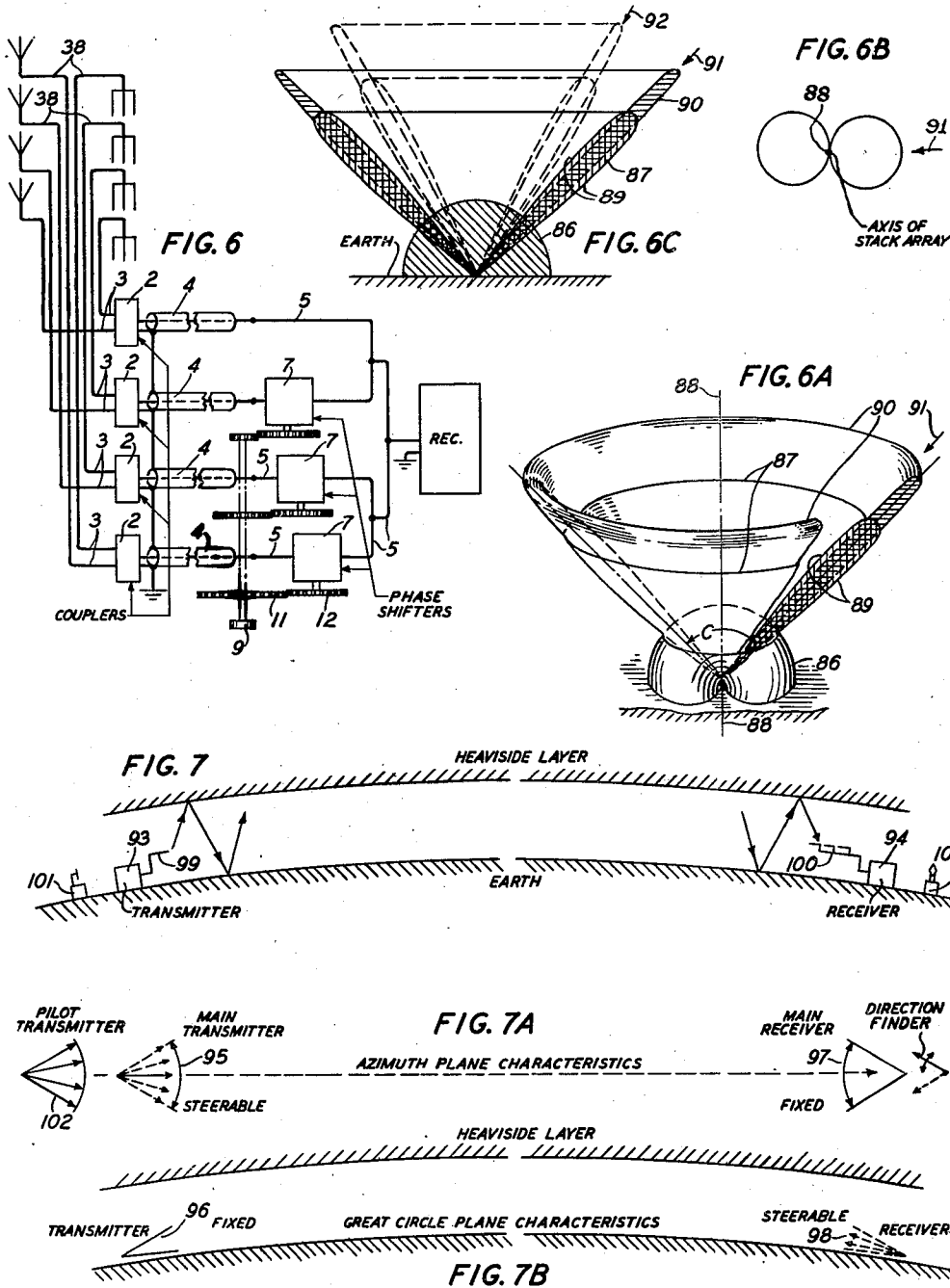
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UNITED STATES PATENT OFFICE

2,245,660

RADIO SYSTEM

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Application October 12, 1938, Serial No. 234,562

12 Claims. (Cl. 250—11)

This invention relates to radio communication systems and more particularly to methods of and means for obtaining controllable and sharp directive transmission and/or reception in such systems.

As disclosed in Patent 2,076,222 to E. Bruce, April 16, 1937, and Patent 2,041,600 to H. T. Friis, May 19, 1936, it has been proposed to improve radio communication, especially with respect to signal-to-static ratio and fading, by aligning in a given plane, as for example, the vertical or great circle plane containing two widely separated radio stations, the direction of maximum antenna reception at one of two widely separated cooperating stations and the direction of maximum antenna transmission at the other station, with the optimum transmission path between the stations, that is, with the path followed by the strongest of the several incoming waves. It has also been proposed to improve radio communication by confining the reception, assuming diversity operation is not employed, to a single maximum incoming wave regardless of the number of waves established at the receiving station by the transmitting station. While, in long range communication systems, the directional changes of the maximum wave are usually greatest and most frequent in the great circle or vertical plane, directional changes in this wave also occur in the horizontal or azimuthal plane. It therefore appears desirable to align or steer, independently in these two planes, the directions of maximum action of the receiving antenna or transmitting antenna or both. Moreover, it now appears that improved two-point communication may also be obtained by utilizing at the transmitting station an antenna system having a steerable azimuthal directive characteristic and a wide range non-steerable vertical directional characteristic and, at the receiving station cooperating therewith, an antenna system having a steerable vertical plane directional characteristic and a wide range non-steerable azimuthal directive characteristic.

It is one object of this invention to improve point-to-point radio communication.

It is another object of this invention to control or adjust the direction of maximum action of an antenna system, independently, in a plurality of planes.

It is a further object of this invention to secure an antenna array having a sharp, steerable directive characteristic in one plane and a broad non-steerable directive characteristic in a plane perpendicularly related thereto.

It is still another object of this invention to align in a two-point communication system, the maximum direction of action for a transmitting or a receiving antenna array with the optimum transmission path between the cooperating stations, regardless of the orientation or angle with

respect to the horizontal or vertical, of the optimum path.

According to one embodiment of the invention the transmitting or receiving antenna comprises a plurality of end-on antenna subarrays positioned in a broadside array or a plurality of broadside subarrays positioned in an end-on array, each subarray comprising spaced antenna units and having a steerable space factor diagram or directional characteristic. The "space factor characteristic" is termed the "array characteristic" in the above-mentioned Friis patent and is here defined as a portion of the complete directive characteristic of a system comprising a plurality of spaced antenna units, the shape and size of the space factor characteristic for a given direction of transmission or reception being independent of the directive characteristic of each antenna unit and a function of the number of antenna units, the spacing therebetween and the phase relation of the currents in the antenna units. The several subarray characteristics are preferably simultaneously steered or controlled by means of a uni-control knob and the outputs of the several subarrays are connected to a common receiver through individual adjustable phase shifters controlled by a second uni-control knob.

Assuming end-on subarrays arranged in broadside are utilized, the maximum directional cones of the similar space factor directive characteristics for the end-on subarrays are similarly positioned, that is, in effect, superimposed to form an effective subarray or end-on cone and also so positioned or steered that the longest axis of the effective subarray cone coincides with the direction of the maximum incoming wave or the desired direction of the outgoing wave. The flat disc or the maximum shallow cone of the broadside space factor is also steered so as to align with the above-mentioned direction. The effective subarray cone and the broadside cone or disc have a common apex and axes perpendicularly related in the azimuthal or ground plane, whereby the cone and the disc intercept or coextend in space to form an exceedingly sharp cigar-shaped or resultant lobe which may be steered, independently, in the azimuthal and vertical planes and which may be adjusted easily to align with any direction whatsoever incoming or outgoing with respect to the antenna system. If broadside subarrays arranged in an end-on array are employed, the procedure is similar, the broadside flat cones being superimposed to form an effective broadside directive disc or shallow cone. While antenna units each having a non-directional directional characteristic may be used, directional units are preferably employed. The lobes of the directional units should be superimposed to form an effective unit lobe, and

positioned so as to include the normal azimuthal and vertical angular ranges and to coextend with the two space factor cones.

Steerable antenna systems, as described above, may be used at each of the stations constituting a two-point communication system. Satisfactory performance may also be obtained by utilizing at the transmitting station an array arranged for azimuthal steering and comprising antenna units having a relatively broad vertical directional characteristic and by utilizing at the receiving station an array arranged for vertical steering and having a non-directional or a relatively broad horizontal or azimuthal directional characteristic.

The invention will be more fully understood from a perusal of the following specification taken in conjunction with the drawings on which like reference characters denote elements of similar function and on which:

Fig. 1 illustrates an azimuthal plane steerable antenna system comprising a broadside antenna array; and Figs. 1A and 1B, respectively, illustrate the vertical and azimuthal directional characteristics of the system of Fig. 1;

Fig. 2 illustrates a broadside antenna array which may be substituted for the array included in the system illustrated by Fig. 1; and Figs. 2A and 2B illustrate, respectively, the vertical and azimuthal directive characteristics of the system of Fig. 2;

Fig. 3 illustrates an antenna system arranged for independent horizontal and vertical directional steering and comprising non-directional units; Figs. 3A, 3B and 3C illustrative, in perspective, the solid adjustable directional characteristic of the system of Fig. 3, and Figs. 3D, 3E, 3F and 3G are cross-sectional views of the solid characteristic as illustrated by Fig. 3A;

Fig. 4 illustrates an alternative arrangement for steering, horizontally and vertically, the directional characteristic of the array of Fig. 3;

Fig. 5 illustrates an array comprising directional units which may be substituted for the array included in each of Figs. 3 and 4, Fig. 5A illustrates the solid directional characteristic of Fig. 5 and Figs. 5B, 5C and 5D are cross-sectional views of the solid characteristic illustrated by Fig. 5A;

Fig. 6 illustrates an antenna system having a wide non-steerable azimuthal characteristic and arranged for vertical steering; Fig. 6A illustrates the solid directional characteristic of the system of Fig. 6 and Figs. 6B and 6C are cross-sectional views of the solid characteristic illustrated by Fig. 6A;

Fig. 7 illustrates a two-point communication system arranged for cooperative steering; and Figs. 7A and 7B illustrate, respectively, the azimuthal and vertical plane steerable characteristics of the two-point communication system illustrated by Fig. 7.

Referring to Fig. 1, reference numerals 1 designate unidirectional rhombic antennas of the type disclosed in the copending application of E. Bruce, Serial No. 513,063, filed February 3, 1931, the rhombics being spaced on the broadside axis "BA", and the spacing being determined by the space factor desired, as disclosed in the above-mentioned Friis patent. The rhombic antenna size and the spacing may be such that the units overlap (as illustrated) in which case the units are preferably also spaced vertically in a staggered manner, the spacing being sufficient to minimize mutual coupling.

Numerals 2 designate antenna couplers one of which is included between each of the balanced lines 3 connected to the rhombic antennas 1 and the associated unbalanced coaxial line 4. The rhombic antenna units are connected by means of the coaxial lines 4 and 5 to the common receiver 6, all except one of the two extreme rhombic units being connected to the receiver 6 through individual adjustable phase shifters 7. Artificial lines 8 are inserted in the intermediate coaxial lines 4 for the purpose of rendering the coaxial lines equal in electrical length. Preferably, the first detectors of the receiver are connected between lines 4 and 5, the coaxial lines 4 being radio frequency lines and the single conductor lines 5 being intermediate frequency lines. As disclosed in the above-mentioned Friis patent the phase shifters are actuated by knob 9 and shaft 10 through an assembly of uniformly graded gears 11 and equal size gears 12, whereby the phase difference between the currents in every pair of adjacent units may be adjusted to the same desired amount. Considering the extreme right-hand rhombic antenna unit as a reference point, rotating the knob 9 in one direction, as for example, clockwise, in the direction of the arrow 13, retards the phases of the remaining antenna currents with respect to that of the reference antenna, whereas rotating the knob counter-clockwise in the direction 14, advances the phases of the remaining antenna current with respect to that of the reference antenna.

Referring to Figs. 1A and 1B, area 15 represents the vertical plane intersection, and area 16 the projection on a horizontal plane of the solid uni-directional maximum lobe, of each rhombic antenna unit, the several whale-shaped unit maximum lobes being considered superimposed and forming an effective unit lobe represented by the same areas 15, 16. The effective unit lobe is positioned so that it includes the normal angular directive range in both the vertical and azimuthal planes of the desired or maximum wave. Assuming the phase shifters 7 are adjusted to produce in-phase antenna currents, the maximum portion or section of the broadside space factor characteristic is wheel or disc-shaped and aligned with direction 17 included in the great circle plane. Area 18 illustrates the vertical plane section and area 19 the horizontal plane section of the broadside space factor disc for this particular adjustment. As indicated in Patent 2,041,600 mentioned above, the superimposed broadside array disc 18, 19 and the effective unit lobe 15, 16 combine to give a sharp resultant lobe, the vertical plane section of which is illustrated by area 20 and the azimuthal plane section by area 21. When the phase shifters 7 are adjusted by means of knob 9 to produce out-of-phase currents, the disc or wheel-shaped space factor changes to a shallow cone. The resultant lobe for the system is then aligned with a direction making an angle with a great circle plane, the shallow cone and the resultant lobe being shifted to the left of the great circle plane upon, for example, clockwise rotation of knob 9 and to the right upon counter-clockwise rotation. In Figs. 1A and 1B areas 22 and 23 shown in dotted lines represent, respectively, the vertical plane and the azimuthal plane sections of the broadside shallow directive cone when the system is adjusted for alignment with direction 26; and numerals 24 and 25 illus-

trate, respectively, the corresponding intersections of the resultant array lobe.

It will thus be seen that the system of Fig. 1 provides a wide horizontal steering range and that electrical steering in the azimuthal plane, over equal ranges on both sides of the great circle plane, of the maximum direction of radiant action of the system, may be easily accomplished by manipulating the uni-control knob 9. If the prevailing azimuthal direction is not in the great circle plane, the broadside array axis may be positioned perpendicular to the vertical plane containing the direction whereby the steering range may be centered on the prevailing azimuthal direction. For example, in transatlantic communication, it has been found that the azimuthal direction is usually several degrees south of the great circle plane and that a more satisfactory steering range may be obtained by constructing or positioning the array so that its steering range is centered on the prevailing southern direction.

Of course, any number of rhombic unit antennas may be utilized in a system of Fig. 1 and the units may be uni-directive, or directive units of a type other than the rhombic type. It should be noted that, while manipulation of knob 9 alters the projection of the maximum array cone or disc on the horizontal and vertical planes, an array containing broadside directional units having their maximum lobes aligned with the in-phase disc-shaped space factor characteristic (as illustrated by Figs. 1, 1A and 1B) is primarily adapted for horizontal or azimuthal steering, whereas an array containing end-on units having their maximum lobes aligned with a sharp or small angle cone space factor characteristic produced by out-of-phase currents is primarily adapted for steering in the vertical or great circle plane, as indicated by Fig. 1C of the Friis Patent 2,041,600 mentioned above.

A wider horizontal steering range may be obtained by replacing the array illustrated in Fig. 1 with the array illustrated by Fig. 2 and comprising vertical antennas. Referring to Figs. 2, 2A and 2B, reference numerals 27 designate vertical antenna elements arranged to form six circular antenna cages 28. The top extremities of the elements 27 of each cage may be connected together or left free and the bottom extremities are connected to the inner conductor of the associated coaxial line 4. The apparatus connected to the six cages is the same as that illustrated below the line X—X in Fig. 1.

Assuming each cage is a half wave-length high, each cage is non-directive in the azimuthal plane and bilateral in the vertical plane, the vertical plane and azimuthal directional characteristics of each cage being represented, respectively, by the areas 29 and 30. As in Figs. 1A and 1B, areas 18 and 19 illustrate, respectively, the intersections of the great circle plane and the azimuthal plane with the directional space factor disc for the array, the phase shifters 7 being adjusted for direction 17. Numerals 31 and 32 designate, respectively, the areas produced by the intersections of the resultant directional lobe of the system with the great circle and azimuthal planes. By manipulating knob 9 the array disc may be changed to a shallow cone and adjusted to the position illustrated by areas 33 and 34. The resultant lobe for the system assumes the vertical plane position represented by area 35 and the azimuthal position represented by area 36. As in the system of Fig. 1 the shallow array cone and

resultant lobe may be steered to the right or left of the great circle axis 37 by proper rotation of knob 9. Thus a 360 degree azimuthal steering range and an extremely wide vertical range are obtained by means of the system of Fig. 2. This particular arrangement is admirably suited for ascertaining the horizontal arrival direction of vertically polarized wave components in a two-point communication system. While Fig. 1 and Fig. 2 have been described as receiving systems, obviously in place of the receiver 6, and associated first detectors, a transmitter may be employed and the direction of transmission may be aligned with any desired path. Any practical number of cages may be employed.

Referring to Fig. 3, reference numerals 38 designate antenna-counterpoise units each comprising a doublet antenna, and numerals 2, 3 and 4 designate respectively antenna couplers, balanced lines and coaxial lines as already described in connection with Fig. 1. The antenna units are arranged, with respect to the direction 39 in three end-on subarrays 40, 41 and 42; and the three subarrays are arranged in a broadside array. Considering any of the subarrays 40, 41 and 42, all of the antenna units are connected by means of the associated coaxial lines 4 and a single conductor line 5 to a common line conductor 43, individual adjustable phase shifters 7 being included in all except one of the conductors 5. As in Fig. 1 the first detectors (not illustrated) of the receiver are preferably included between the coaxial lines 4 and the single conductor line 5, the coaxial lines 4 being radio frequency lines and the single conductor lines 5 being intermediate frequency lines. As disclosed in the above-mentioned Friis patent the adjacent coaxial lines differ in length an amount equal to the spacing between the antenna units. As also explained in Patent 2,041,600 in the case of each of subarrays 40, 41 and 42 one phase changer is driven directly, and the remaining phase changer indirectly through a gear assembly 44, by shaft 45 and associated uni-control knob 46. Knob 46 is common to the several end-on subarrays, whereby the currents in the adjacent units, in each subarray, may be adjusted to the same desired phase difference and the three end-on subarray cones may be simultaneously adjusted or steered.

Conductor 43 from one of the subarrays, preferably but not necessarily the central subarray in a system comprising an odd number of subarrays, as illustrated, is connected directly, and the remaining conductors 43 connected through adjustable phase shifters 47, to the common receiver 48. The phase shifters 47 are adjusted by means of knob 49 and associated shafts 50 and 51 which are connected together through a differential gear assembly 52, whereby as explained in the copending application of N. J. Pierce and F. A. Polkinghorn, Serial No. 149,824, filed June 23, 1937, they rotate in opposite directions and currents of the same phase difference are obtained from the adjacent antennas. The phase shifters 47 are connected to shafts 50 and 51 through equal size driving gears 53 and equal size driven gears 54.

In the system of Fig. 3, each end-on subarray may comprise any practical number of antenna units and the broadside array may comprise any practical number of end-on subarrays. If additional antenna units are provided in each subarray, the additional phase shifters required should be associated with shaft 45 through a uniformly graded gear arrangement as disclosed in

the above-mentioned Friis patent. Again, if two additional end-on subarrays are provided, the additional phase shifters 55 required are preferably connected to shafts 50 and 51 through a uniformly graded gear arrangement 56 comprising driven gears 54 of the same size as gear 54 and driving gears equal to each other but larger than driving gears 53.

Referring to Fig. 3A, the operation of the system will now be described, it being assumed that the system is used for reception and that the phase shifters 47 produce in-phase currents from the subarrays 40, 41 and 42. The line XO included in the ground plane and in the vertical great circle plane XOZ, represents the end-on array axis and the line YO included in the vertical plane YOZ represents the broadside array axis of the system of Fig. 3, the plane YOZ being perpendicularly related to the plane XOZ. The hollow cone 57 having a wall 58 represents one position of the effective subarray maximum directive cone of the end-on space factor characteristic and the wheel or disc 59 having a thickness or wall 60 illustrates the maximum section or sector of the broadside space factor characteristic. The end-on and the broadside space factor characteristics have a common origin O and perpendicularly related axes coincident, respectively, with the end-on axis XO and the broadside axis YO. As is evident, the two space factors coextend or coexist in the space or volume bounded in part by the surface 61 and they multiply or combine to produce the cigar-shaped resultant lobe 62. The resultant lobe has a longitudinal axis 63 included in the great circle or vertical plane XOZ, a length equal to the product of the two space factors and a cross-section shape similar to surface 61. The end-on space factor phase shifters 7 and the broadside space factor phase shifters 47 are adjusted so that the axis 63 is aligned with the direction 64 of the strongest incoming wave, this direction being included in the great circle plane and also included in the vertical plane wave cluster 65 and the azimuthal plane wave cluster 66. The number of units and/or the spacing therebetween along the two axes may be the same or different; and the end-on and broadside space factors may be the same, or they may differ considerably.

Fig. 3D is a cross-sectional view of the solid representation of Fig. 3A, as seen when one looks at the vertical plane XOZ; Fig. 3E a cross-sectional view seen when one looks at the horizontal plane XOY; Fig. 3F a cross-sectional view as seen when one looks at the oblique plane containing the lobe axis 63 and the broadside axis OY, and the full line representation included in Fig. 3G is a view looking along axis 63 at the surface 61 and toward the center or origin O. As in Fig. 3A, numerals 57, 59 and 62 designate, respectively, the end-on space factor cone, the broadside space factor disc and the resultant cigar-shaped lobe. In Fig. 3F the dot-dash line indicates the intersection of the end-on cone with a horizontal plane.

Assuming it is desired to align the axis 63 of the system lobe 62 with another direction as, for example, a direction represented by one of the arrows shown in Fig. 3A, and other than direction or arrow 64, the end-on phase shifters 7 or the broadside phase shifters 47 or, if necessary, both sets of phase shifters, are adjusted until the alignment desired, as shown by indicators not illustrated, is obtained. If both sets of phase shifters are to be adjusted it is im-

material which set is adjusted first. Adjustment of phase shifters 47 by knob 49 changes the disc-shaped broadside space factor into a shallow cone having an apex angle α as may be seen by comparing Figs. 3A and 3B. An adjustment of phase shifters 7 by knob 48 changes the apex angle β of the end-on cone, as is apparent from an examination of Figs. 3A and 3C. Fig. 3G illustrates, by way of example, two other positions designated by numerals 68 and 70 of the end-on space factor or cone, two other positions designated by numerals 71 and 72 of the broadside space factor characteristic and four other positions designated by the numerals 73 of the cigar-shaped lobe 62 (or surface 61). It will be noted that a steering adjustment made in one plane changes the steering range in the other plane, that is, an adjustment of the end-on characteristic changes the steering range for the broadside characteristic and vice versa. The horizontal range for the same vertical angle of reception increases as the end-on cone apex angle β increases. Thus, in accordance with the invention, the cigar-shaped lobe of the system of Fig. 3 may be aligned, by vertical and/or horizontal steering with any incoming wave direction or path regardless of the value of the angle between the path and the great circle plane and the value of the angle between the path and the horizontal or azimuthal plane, the number and spacing of the units along the broadside and end-on axes being such that the cross-sectional area of the system lobe is small enough to select one of several wave directions constituting a bundle or bunch of incoming directions. For convenience, the operation of the system of Fig. 3 when used as a receiving system has been described. It should be understood, however, that the system is equally suited for transmitting. When used for transmitting, the first detectors are omitted and the receivers 48 are replaced by a transmitter.

Fig. 4 illustrates a dual steering arrangement which in a sense is the converse of the arrangement of Fig. 3. As in Fig. 3 the several non-directional antenna-counterpoise units 38 are arranged in a rectangle. The connection between the units and the receiver are such, however, that the units form three broadside subarrays 74, 75 and 76 arranged end-on instead of three end-on subarrays 40, 41 and 42 arranged in broadside, as illustrated in Fig. 3. The broadside phase shifters 47 are arranged in the two groups 77 and 78, the right-hand, center and left-hand phase shifters 47 in these groups being connected, respectively, to the units constituting subarrays 74, 75 and 76. The three subarrays are connected by means of conductors 43 to the common second detector in receiver 48. A first detector (not illustrated) is preferably inserted between each coaxial line 4 and the associated single conductor line 5, a phase shifter 7 being included in all except one of the conductors 43. Phase shifters 7 and 47 are controlled, respectively, by the uni-control knobs 46 and 49.

The method of alignment of the cigar-shaped lobe of the array of Fig. 4 is the same as that described above in connection with Fig. 3. In reality, however, the space factor directive characteristics of the three broadside subarrays are simultaneously steered by means of knob 49 to include a desired direction, as for example, direction 39, the three space factors being in effect superimposed to form an effective broadside space factor characteristic for the whole array; and

the end-on space factor is steered by means of knob 46 so as to intercept the effective broadside characteristic and to include the desired direction. Incidentally, the same number of phase shifters are employed in the systems illustrated by Figs. 3 and 4. Figs. 3A, 3B, 3C, 3D, 3E and 3F are applicable to the system of Fig. 4 as well as to the system of Fig. 3. Directive antenna units, of course, may be employed in the system of Figs. 3 and 4 instead of the non-directive units 38, for the purpose of securing a more satisfactory resultant lobe. For example, Fig. 5 illustrates an array comprising rhombic units which may be substituted for the array shown above the line X—X in each of Figs. 3 and 4. When directive units are used the directional characteristic or the system lobe equals the product of the broadside space factor characteristic, the end-on space factor characteristic and the directive characteristic of the unit, as is indicated by Figs. 5A, 5B, 5C and 5D.

Referring to the solid characteristic illustrated by Fig. 5A and the cross-sectional views by Figs. 5B, 5C and 5D of the solid characteristic, reference numeral 79 designates the solid uni-directive whale-shaped characteristic of each rhombic antenna, the rhombics being positioned so that their lobes each include the normal operating great circle and azimuthal wave cluster ranges. Numeral 62 denotes the cigar-shaped lobe (also illustrated in Fig. 3A) derived from the two space factors and numeral 80 illustrates the product of resultant lobes 62 and 79, when the system is adjusted for alignment with direction 84, included in the great circle plane XOZ at an angle 81 with the horizontal. The lobes 62 and 80 may be steered as indicated by the dotted line representation of these lobes, vertically for alignment with another direction, such as direction 82 included in the great circle plane or horizontally for alignment with another direction having the same elevation angle 81 as, for example, direction 83 or both horizontally and vertically for alignment with a still different direction 84.

The view of Fig. 5B taken on the vertical or great circle plane XOZ and the view Fig. 5C taken on the oblique plane LMOPQ are believed to be self-explanatory. Fig. 5D illustrates a view looking along axis 63 toward the origin O. It may be noted that the vertical plane and azimuthal steering range of the resultant lobe 80 are dependent upon the size and shape of the cross-sectional area 85 of the unit lobe 79 as indicated in Fig. 5D.

Referring to Fig. 6, the antenna-counterpoise units 38 are arranged one above the other in the same vertical plane to form a "stack" array. The units may be oriented for utilization of either horizontally polarized or vertically polarized waves and if desired directive units may be employed in place of the non-directive units. As in Fig. 1, the units are connected by means of lines 3, 4 and 5 to the receiver, all except one of the lines 5 being equipped with a phase shifter 7. Also, as in Fig. 1, the phase shifters are adjusted by means of knob 9 through uniformly graded gears 11 and equal size gears 12.

Assuming each unit antenna in the system of Fig. 6 is a horizontal doublet positioned perpendicular to the great circle plane, the useful unit directive characteristic above ground in the above plane is a semicircle as shown by the perspective view Fig. 6A and the vertical plane view Fig. 6C; and it is a figure 8 in the azimuthal plane as shown by Fig. 6A and the horizontal plane view, Fig. 6B. The space factor characteristic is a hol-

low cone 87 having a vertical axis 88 and a wall 89. The unit characteristic and cone combine to produce the resultant cone 90 which is aligned with direction 91. The common apex angle α of the two cones 87 and 90 may be changed by means of knob 9 and phase shifter 7, whereby vertical steering over a maximum range (180 degrees) in any azimuthal plane is provided. In Fig. 6C the cone shown in dotted lines illustrates the position of the space factor characteristic when it is aligned with direction 92. Of course, the space factor characteristic of the stack array is affected by the presence of the ground surface, the amount being related to the height of the array above the ground. This factor must be taken into account in actual practice, in accordance with the manner well known in the art.

Fig. 7 illustrates a two-point long range communication system, reference numerals 93 and 94 designating, respectively, a transmission station and a receiving station widely separated therefrom as, for example, a transmitting station located in England and a receiving station located in the United States. In such a long range system, it has been found that the maximum wave directive changes in the azimuthal plane occur relatively infrequently, that is, every several hours, whereas the maximum wave directive changes in the great circle plane connecting the cooperating stations occur frequently, that is, every few minutes. Consequently, and as illustrated by Figs. 7A and 7B, an antenna system having a wide range steerable characteristic 95 in the azimuthal plane and a fixed great circle directive range 96 may be employed at the transmitting station; and an antenna system having a fixed azimuthal directive range 97 and a wide range steerable characteristic 98 in the vertical or great circle plane may be employed at the receiving station. To illustrate, at the transmitter an antenna system 99 such as illustrated by Fig. 1 and at the receiver an antenna system 100 such as illustrated by Friis Patent 2,041,600 or Figs. 2 or 6 of the present application, may be employed. Preferably, a pilot transmitter 101 having a non-directive or wide azimuthal range 102 is used at the transmitting station and an azimuthal direction finder 103 is employed at the receiving station.

In operation, the pilot transmitter 101 energizes all the normal azimuthal paths connecting the two widely separated stations and the receiver control operator determines by means of the direction finder the azimuthal direction of the maximum wave 1. The transmitter control operator then steers the direction of greatest transmission of the main high power transmitter 93 so as to coincide with the optimum prevailing azimuthal path as indicated to him over a pilot channel by the receiver control operator, and the receiver operator adjusts the characteristic of the receiving antenna 97 so that its direction of maximum action is aligned with the optimum great circle path of the wave.

Although the invention has been disclosed in connection with certain specific embodiments, it should be understood that it is not to be limited to these embodiments since other apparatus and equipment may be satisfactorily employed without exceeding the scope of the invention.

What is claimed is:

1. A method of radio communication between two stations, utilizing at one station a transmitting system comprising an antenna having a relatively large fixed vertical directive range and

means for steering the azimuthal plane direction of maximum action of said antenna over a given range and, at the other station, a receiving system comprising an antenna having a relatively large fixed azimuthal directive range and means for steering the vertical plane direction of maximum action of said antenna, which comprises positioning the transmitting and receiving antennas so that their azimuthal directive ranges are directed toward each other substantially, steering the azimuthal plane direction of maximum action of the transmitting antenna so as to coincide with the optimum azimuthal path between said stations, and steering the vertical plane direction of maximum action of the receiving antenna so that it coincides with the optimum path between said stations.

2. A method of long range communication utilizing at the transmitting station an antenna array having in a given plane a movable direction of maximum action, and at the receiving station an antenna array having in different planes movable directions of maximum action, which comprises aligning at the transmitting station the direction, in said first-mentioned given plane, of maximum radiant action of said transmitting array with the optimum transmission path in said plane, and aligning at the receiving station the directions of maximum radiant action of said receiving array, in said different planes, with said path.

3. A method of communication utilizing an antenna array comprising a plurality of antenna subarrays spaced in a given direction and each comprising a plurality of antenna units spaced in another direction, said array and said subarrays each having a unidirectional space factor characteristic, and means for moving the space factor directive characteristic of each subarray and for moving the space factor directive characteristic of the array, which comprises adjusting the characteristic of each subarray to include the same path and adjusting the characteristic for the array to include the same path.

4. A method of radio communication between two stations, utilizing at the receiving station an antenna array comprising a plurality of directive antenna units and having two independently adjustable space factor directive characteristics each characteristic having a direction of maximum radiant action, the axes of said space factor characteristics being perpendicularly related in the horizontal plane, which comprises positioning the units so that their directive characteristics or lobes include the normal azimuthal and vertical plane incoming directive ranges of the waves propagated by the transmitting station, and aligning the direction of maximum radiant action of each space factor characteristic with the direction or path of the strongest incoming wave included in said ranges.

5. A method of communication which comprises transmitting energy from a transmitting station to a receiving station equally along a large number of different paths in the same plane, ascertaining at the receiving station the path of the maximum incoming wave, transmitting from the transmitting station a maximum amount of energy along the ascertained path, and receiving energy at the receiving station propagated along only the ascertained path, substantially.

6. In a two-point communication system, a

transmitting station comprising a directive antenna array having a steerable azimuthal maximum direction of action and a relatively wide vertical directive range, a receiving station co-operating with the first-mentioned station and comprising a directive antenna having a vertical plane steerable direction of maximum action and a relatively wide fixed azimuthal directive range, the maximum azimuthal directions of action of said transmitting and receiving antennas being directed toward each other, substantially.

7. In combination, an antenna system comprising at least three antenna units two of which are positioned in a broadside array and two in an end-on array, means for moving the directive characteristic of the end-on array and means independent thereof for moving the directive characteristic of the broad-side array.

8. In a two-point radio system, a transmitting station comprising a broad-side directionally steerable antenna array, a receiving station comprising an end-on directionally steerable antenna array, said broad-side array having its axis perpendicularly related to the great circle plane containing said stations and said end-on array having its axis included in said plane.

9. In combination, a radio antenna array comprising a plurality of antenna subarrays spaced in a given direction and each comprising a plurality of antenna units spaced in another direction, said array and said subarrays each having a space factor directive characteristic, means for simultaneously moving the space factor directive characteristic of each subarray, and means for moving the space factor directive characteristic of the entire array.

10. A two dimensional antenna array comprising antenna units spaced along two angularly related directions or axes, a plurality of phase shifters, a translation device, said units being connected through separate phase shifters to said device whereby said array has a pair of space factor directive characteristics each related to a different array axis, said characteristics being positioned so that portions thereof coextend in space and are aligned with the optimum path of wave propagation.

11. In combination, a two-dimensional antenna array comprising at least four antenna units arranged to form with respect to a given vertical plane of wave propagation a pair of parallel end-on subarrays and a pair of broad-side subarrays, each subarray comprising at least two spaced antenna units, a plurality of phase shifters, a translation device connected to all said units, a first phase shifter being included between the device and all the units in one subarray, a second phase shifter being included between said first phase shifter and one of the last-mentioned units, and a third phase shifter included between said device and an antenna unit in the other similar subarray.

12. In combination, a translation device, a stack antenna array comprising a plurality of antenna units arranged one above the other, and means comprising individual phase shifters connecting said units to said device for obtaining a steerable space factor characteristic for said array, whereby a vertical steering range including high elevation angles is obtained.

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