

May 19, 1936.

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2,041,600

RADIO SYSTEM

Filed April 5, 1934

5 Sheets-Sheet 1

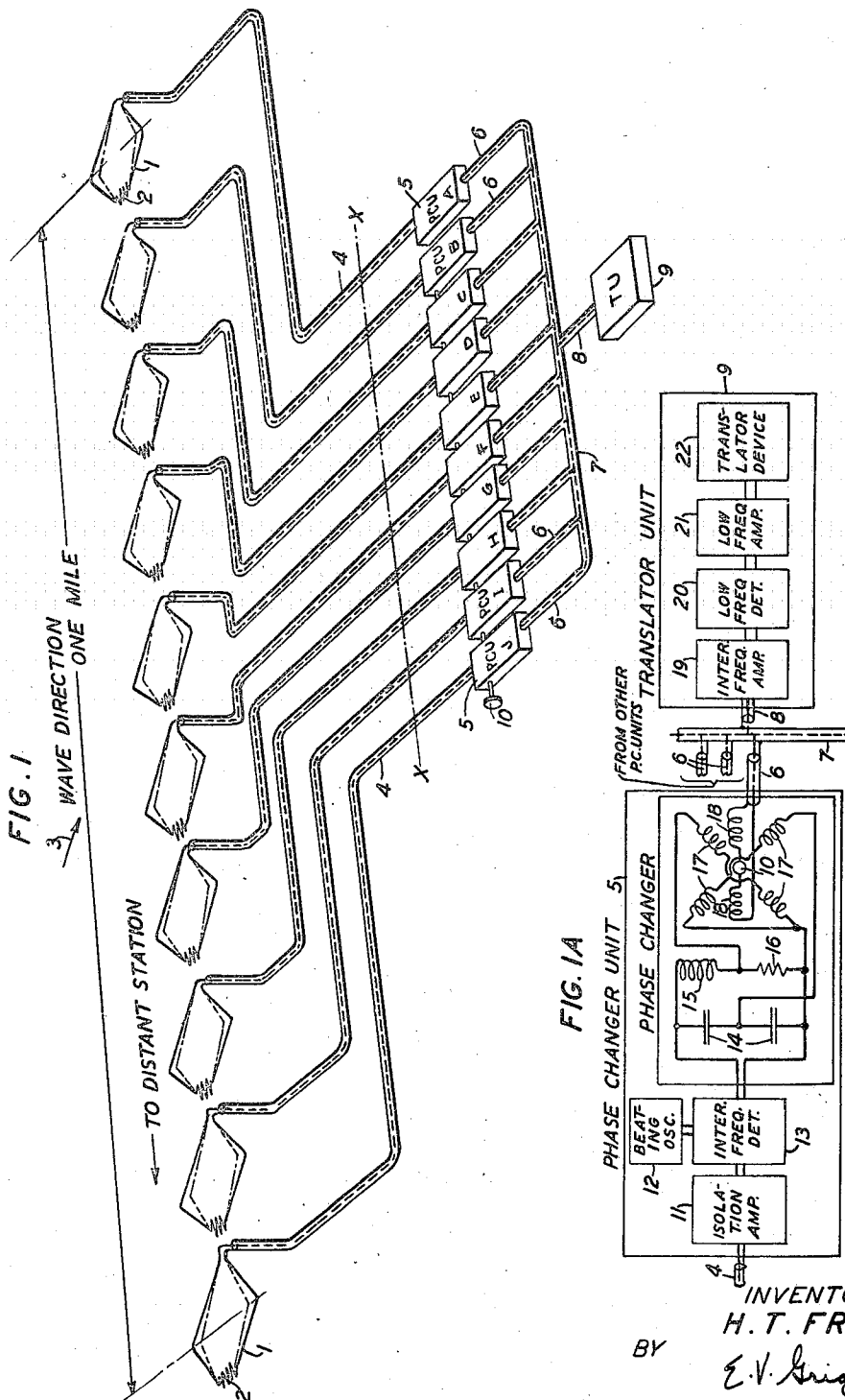


FIG. 1A

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FIG. 1B

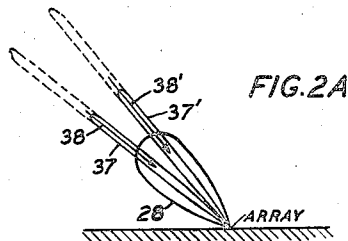
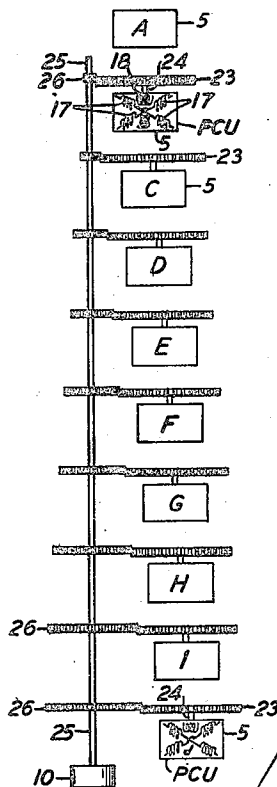


FIG. 2A

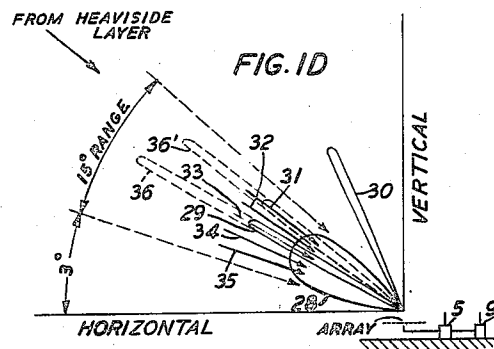


FIG. 1D

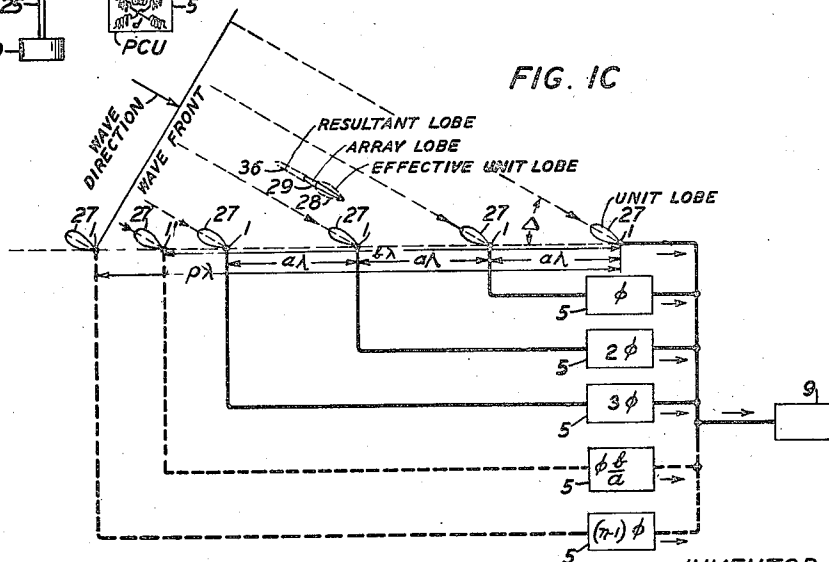


FIG. 1C

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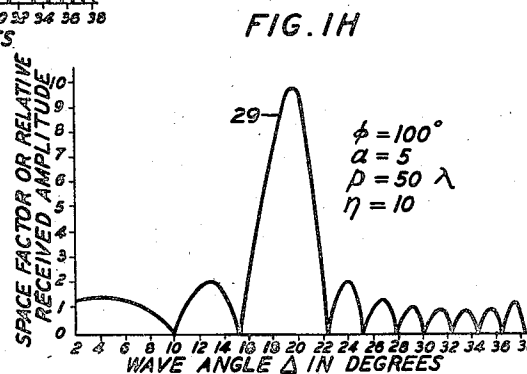
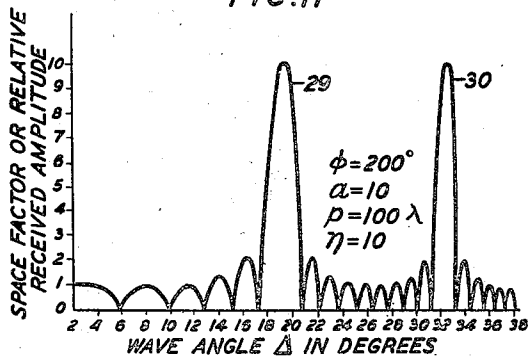
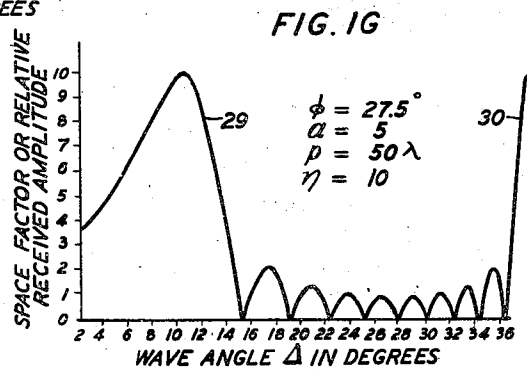
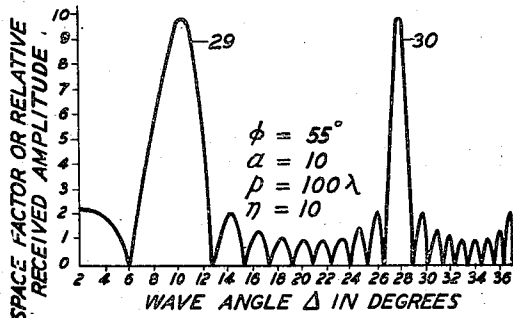
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RADIO SYSTEM

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FIG. 2

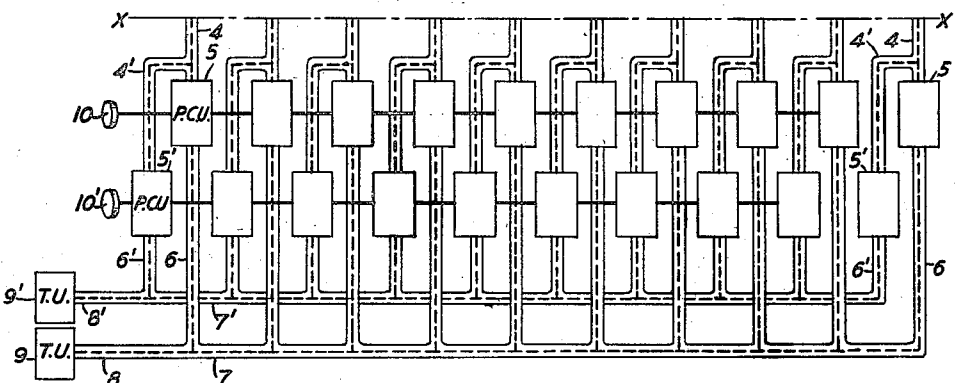


FIG. 3

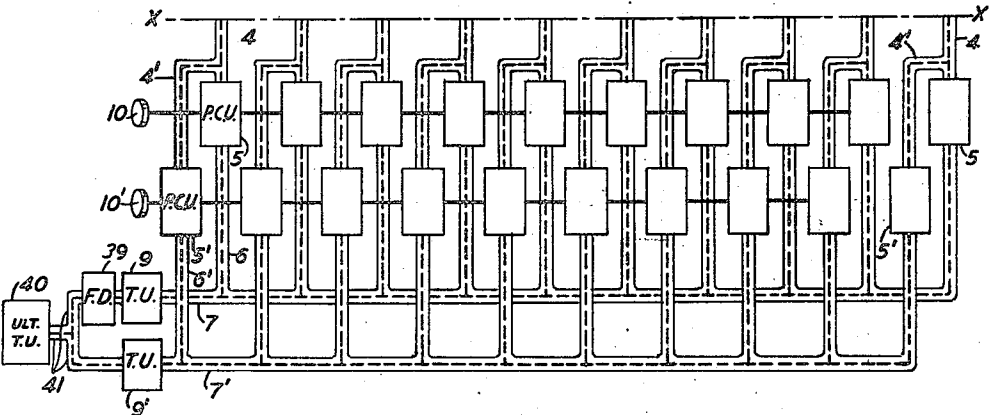
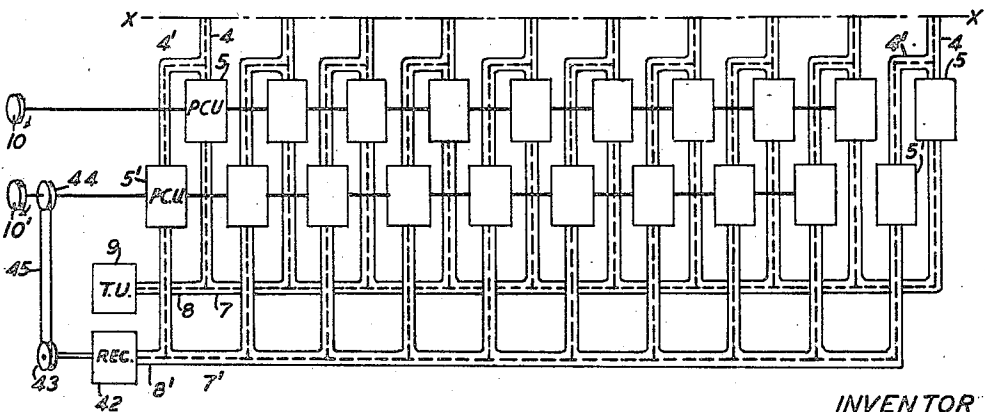


FIG. 4



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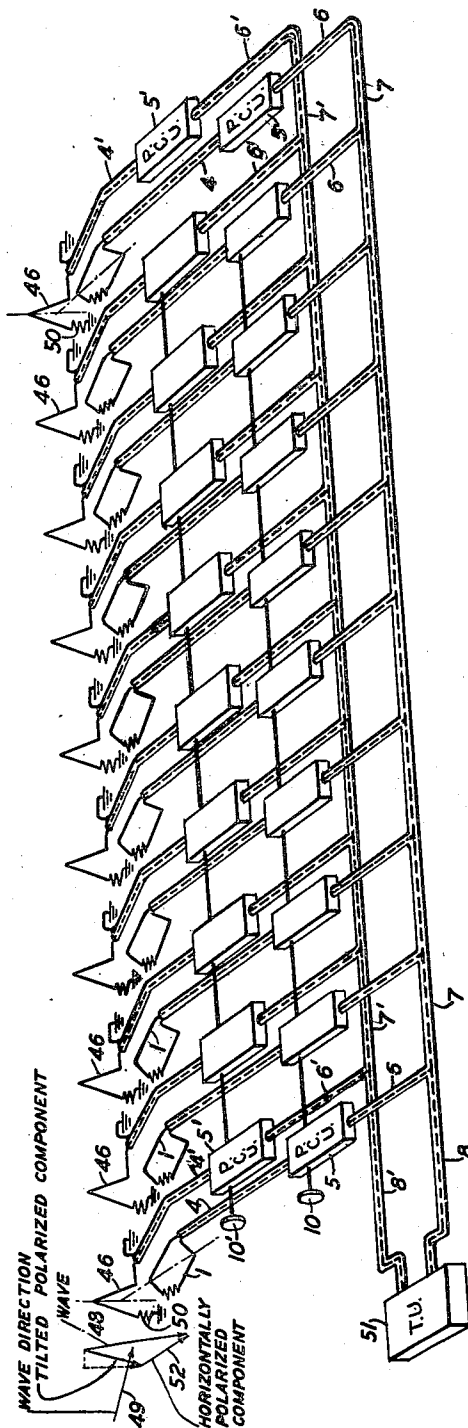
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RADIO SYSTEM

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FIG 5



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UNITED STATES PATENT OFFICE

2,041,600

RADIO SYSTEM

Harald T. Friis, Rumson, N. J., assignor to Bell Telephone Laboratories, Incorporated, New York, N. Y., a corporation of New York

Application April 5, 1934, Serial No. 719,106

18 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.

It is well known in the art that two or more antenna units, such as vertical antenna elements, may be so spaced in a radio system and their currents so related in phase as to produce a fairly sharp transmitting or receiving directive characteristic or diagram, and that the characteristic may be shifted by varying the phase relation of the currents. Radio systems employing this arrangement are described in Patent 1,738,522, G. A. Campbell, December 10, 1929 and in Patent 1,667,792, D. K. Martin, May 1, 1928. Also, it is well known that in such systems the various units may possess either a directional or a non-directional characteristic. Because of economical consideration and other reasons, systems of this nature heretofore proposed have not been used extensively; and it appears desirable to utilize a practical and relatively inexpensive antenna array for the purpose of obtaining an easily controllable directive characteristic which is sharp enough to effect improved communication and specifically, to eliminate both general or radio frequency fading and selective or audio-frequency fading.

It is an object of this invention to obtain a sharper antenna directive major lobe than heretofore obtained.

It is another object to eliminate at all times substantially and regardless of the duration of the communication period, both general and selective fading.

It is a further object of this invention to simultaneously transmit or receive on the same antenna system the same signal in different directions, or different signals in the same or different directions.

It is still another object of this invention to achieve improvement in radio communication in a practical and economically feasible manner.

According to one feature of this invention, the antenna units included in an end-on array each have a very sharp directive lobe critically oriented with respect to the angular propagation range in a given plane. According to another feature of this invention the directive characteristic of the array or span is critically determined by the size of the typical unit directive major lobe and is, in effect, superimposed upon and adjustably related thereto.

In one embodiment of the invention a plurality

of rhombic antenna units, preferably of the steerable type disclosed in the copending application of E. Bruce, Serial No. 684,350, filed August 16, 1933 and assigned to applicant's assignee, are arranged in an end-on array. For a given economic length of the array the spacing and therefore the number of units are so chosen that at any given instant only one major lobe of the array is superimposed in effect on the major lobes of the units, which lobes are similarly directed to include only the wave directions contained in the normal vertical angular range. The unit lobes may be considered as equivalent to a resulting or effective unit lobe. The resultant lobe for the combination is equal to the product along any wave direction or axis of the effective unit lobe and the array lobe and is exceedingly sharp. The several units are connected through separate isolation amplifiers and adjustable phase shifters to the translation device which may be a receiver or transmitter. Throughout the array the phase difference or angle between currents received from or supplied to adjacent units is the same when the elements are uniformly spaced. By adjusting the phase shifters, preferably by means of a single control, the position of the resultant lobe may be varied to select one wave direction, while excluding all other paths including those which differ in length from the selected path by amounts equivalent to radio wavelengths or audio-wavelengths.

The invention will be more readily understood from the following description taken in connection with the drawings on which like reference characters designate elements of similar function, and on which:

Fig. 1 illustrates one embodiment of the invention in which an array comprising ten rhombic antennas is utilized;

Fig. 1A illustrates the details of the phase changer unit and the translator unit which are employed in the system of Fig. 1; Fig. 1B illustrates the details of the uni-control arrangement of the phase changer unit; Fig. 1C is a schematic diagram; Fig. 1D is a polar diagram and Figs. 1E, 1F, 1G and 1H are characteristic curves, all of which are useful for explaining the invention;

Fig. 2 illustrates equipment which may be substituted for that shown below the line XX of Fig. 1, for the purpose of receiving different signals simultaneously;

Fig. 3 illustrates another modification of the system of Fig. 1 which is useful for receiving

simultaneously the same signal over different paths;

Fig. 4 illustrates another modification of Fig. 1 which is useful for insuring optimum reception by the system of Fig. 1;

Fig. 2A is a polar diagram useful for explaining the operation of the systems illustrated by Figs. 2, 3 and 4; and

Fig. 5 illustrates another embodiment of the invention designed for reception of vertically polarized and horizontally polarized wave components.

Referring to Fig. 1, reference numerals 1 designate horizontal rhombic receiving antennas of the type disclosed in the copending application of E. Bruce, mentioned above. The antenna units are not necessarily of this type but may be non-steerable rhombic antennas positioned to receive an angular range in a given plane, or they may be any type directive unit. The rhombic units 1 are arranged in an array extending, preferably, in the plane of the great circle including a distant cooperating station when communication between two stations only is desired. They are equipped with a terminating resistance 2 for the purpose of securing unilateral propagation. Reference numeral 3 represents a typical direction of a signal incoming to the array and included in the plane of the great circle. In one practical and economical embodiment the total length of the array or span is approximately one mile.

Each unit is connected by means of a coaxial line 4 to an individual phase changer unit 5 designated on the drawings PCU and these phase changer units are associated by means of coaxial line 6, coaxial line 7 and coaxial line 8 to the translation unit 9, designated TU which may be a receiver or transmitter or other device. The phase changer units 5 are simultaneously and differently varied by means of the uni-control comprising in part handle 10. For convenience the phase changers are lettered A, B, C, etc. from the right. Phase changer A is in a sense a dummy since it is not adjusted by means of the uni-control handle 10.

Referring to Fig. 1A, reference numeral 11 designates an isolation amplifier and numeral 12 designates a beating oscillator which are connected to the input of the intermediate frequency detector 13. If desired a single beat frequency oscillator 12 common to the several intermediate frequency detectors 13 may be employed. The output of the intermediate frequency detector is connected to a phase changer comprising condensers 14, coil 15, resistance 16, stationary goniometer coils 17 and rotatable goniometer coil 18 associated with handle 10. The translator unit 9 comprises an intermediate frequency amplifier 19 the input of which is associated with the several rotatable goniometer coils 18 and the output of which is connected to the low frequency detector 20. Reference numerals 21 and 22 designate, respectively, a low frequency amplifier and a translation device.

The uni-control phase changer unit illustrated in detail by Fig. 1B comprises a plurality of similar gears 23 each rigidly associated with a different rotatable coil 18 by means of shafts 24. The gears 23 are driven by means of handle 10, main shaft 25 and gears 26. The gears 26 are uniformly graded in size, assuming the antenna units are uniformly spaced, so that the rotatable coils 18 in the phase changers C, D, E, etc. illustrated in Fig. 1 and Fig. 1B rotate upon move-

ment of the handle 10, respectively, twice, three and four times as fast as the rotatable coil in phase changer B. By means of such an arrangement the phase difference between the currents supplied to or received from adjacent antenna units may be conveniently and simultaneously changed from one value, for example, 100°, to another value, for example, 150°. As will be explained later, the position of the major lobe included in the array characteristic is dependent upon the phase difference or angle just described. By changing the phase angle the array characteristic is, in effect, shifted or rotated.

In an array in which the units are not evenly spaced the associated gears 26 are not uniformly graded in size. Referring to Fig. 1C, in a system having either uniformly or non-uniformly spaced units, the phase change obtained for any particular unit, such as unit 1', is equal to the product of the phase angle ϕ between the extreme or first unit and the next adjacent unit and the ratio of the distance between the particular unit and the first unit to the distance between the first and second units, that is,

$$\frac{b\lambda}{a\lambda}$$

When, as illustrated by Fig. 1C the same length difference exists between the adjacent main lines, that is, the antenna-to-phase shifter lines, and said difference corresponds to the antenna unit spacing in the array, the pick-up calibrating coils 18 (Fig. 1B) of the several phase shifters B to J are similarly positioned with respect to the static coils 17 by properly associating gears 23 and 26 in the case of each phase shifter. When the lengths of the main lines do not have the relation illustrated by Fig. 1C and described above, as in the case of the lines 4 in Fig. 1, the phase shifters B to J are each calibrated to compensate for the deviation in line length from the preferred arrangement of Fig. 1C, the calibration being effected in the case of each phase shifter by correctly associating gears 23 and 24 and therefore by correctly associating initially coils 18 and coils 17. The lines 6, 7, 8, 6', 7', 8' and 41 of Figs. 1, 2, 3, 4 and 5 are of negligible length at the intermediate frequencies conveyed.

Referring now to Figs. 1C and 1D, the method of obtaining the extremely sharp directive lobe of the invention will be briefly explained. First of all, directive antenna units, such as rhombic units 1, each having a sharp major lobe 27 (see Fig. 1C) are selected. These lobes 27 are similarly positioned or oriented, when the units are arranged in the array, and they may therefore be considered as equivalent to the "effective" unit major lobe 28. The phase shifters render the array directive. The effective unit lobe 28 is oriented for effective operation over a particular angular range, that is, so as to include substantially all wave directions included in the normal angular vertical range. Applicant discovered that the length "pλ" of the array and the phase difference or angle ϕ determine the width of the array major lobes 29 and 30. The length "pλ" of the array or span is chosen, therefore, so as to be economically feasible and at the same time so as to produce the desired narrow array major lobe 29. Applicant next discovered that the spacing between the first major lobe of the array 29 and the next major lobe of the array 30 is determined in part by the spacing designated "aλ" in Fig. 1C between the antenna units and that the lobe spacing increases as the unit spac-

ing decreases. The unit spacing selected is such as to give a spacing between the array lobes greater than the width of lobe 28, that is, it is such that at any particular instant only one major lobe of the array intersects the effective unit lobe 28. In this manner the number of antenna units in the array of chosen length is determined. The phase angle ϕ also determines the position of the array lobes and, specifically, that of the lowest array lobe 29. Thus, in Fig. 1C, the phase angle ϕ determines the wave angle Δ , corresponding to the principal axis of the lowest or first array major lobe 29. By varying the phase angle ϕ array lobe 29 may be caused to sweep across effective unit lobe 28.

Referring now to Figs. 1E and 1F which are calculated diagrams for a one hundred wavelength antenna array and Figs. 1G and 1H which are calculated diagrams for a fifty wavelength antenna array, it will be seen that the width of the first major lobe 29 for the one hundred wavelength antenna, Fig. 1F, is considerably less than the corresponding lobe 29 of the fifty wavelength antenna, Fig. 1H. Also, considering Figs. 1E and 1F, it will be noted that the phase angle ϕ controls the position of the first major lobe; and that the lower the major lobe the greater is its width.

As explained in the above-mentioned copending application of E. Bruce and illustrated by Fig. 3 of that application, waves radiated by a short wave antenna travel over paths of different lengths in reaching the distant receiving station, the earth and Heaviside layer both functioning as reflectors in determining the direction of the various energized paths. Referring again to Figs. 1 and 1D, wave directions 31, 32, 33, 34 and 35 represent incoming paths which originally differ in length from each other by either a large or small amount. The term "path" as used in the application does not signify a line of zero width in a given plane. On the contrary, it describes, and it is here expressly defined as meaning, the course or route, viewed in the solid, followed by a single wave or wave front through space and having at a given point a definite direction. As so defined it is somewhat analogous to the path followed or traced in space by an object in transit, such as the earth or a planet. Referring to Fig. 1D, the wave front projected along a path having at the receiving station a direction 35 is perpendicular to the direction and no doubt has an effective area of several square miles. The wave following the path having the direction 34 is separate and distinct from that traversing the path having a direction 35 not only as regards direction of propagation but also in the ordinary case as regards phase and intensity. Small variabilities in the difference length of these paths as occasioned, for example, by movement of the Heaviside layer, produce selective or general fading. The effective unit lobe 28 is positioned as heretofore explained. For the purpose of eliminating general and selective fading and also for the purpose of obtaining sharper directivity, the major lobe 29 is steered by means of the uni-control handle 10 associated with the adjustable phase shifters 9 so as to exclude all wave directions except wave direction 33, for example. The effect of superimposing the array major lobe 29 on the effective unit lobe 28 is to produce the extremely directive resultant lobe 36. The radii of the resultant lobe 36 are each equal to the product of the corresponding radius of the effective unit lobe 28 and the corresponding radius of the array

lobe 29. Upon a change in the wave direction of the maximum incoming wave the resultant lobe 36 is rotated by means of the uni-control arrangement to assume, for example, the position indicated by the lobe designated by reference numeral 36'. Experiments have indicated that in a long range short wave system there is at the receiver and in a given plane containing the transmitter a prevailing directive range such as that illustrated by Fig. 1D and extending, for example, from 3° to 18° during the summer and a slightly different prevailing range such as one extending from 8° to 22° during the winter. Hence, if the effective unit lobe 28 of the rhombic antennas is not wide enough to include both the summer and winter ranges it would be necessary to reposition the lobe 28 by steering or otherwise. If it be desired to employ the array of Fig. 1 for transmitting purpose it is only necessary to employ a suitable phase changer unit and translation unit in place of those shown in Fig. 1.

Referring to Fig. 2, there is disclosed an arrangement or modification of the system of Fig. 1 which is useful for transmitting or receiving different signals in the same or different directions, the rhombic units having a two-to-one frequency range. The array of Fig. 1 is connected through one set of phase changers 5 to a common receiver 9 and by means of branch lines 4' through a second set of phase changers 5' to a second receiver 9'. The effect of associating two sets of phase changers with the same array is to give, in effect, a double characteristic to the array, each characteristic or diagram being independent of the other. The directive diagram effective at receiver 9 is rotated by means of the uni-control 10 and the array characteristic effective at receiver 9' is rotated by means of control 10'. As indicated in Fig. 2A the major lobe 37 of the array for receiver 9 may be positioned to receive wave direction 38, and the major lobe 38' of the array characteristic for receiver 9' may be positioned to receive wave direction 38'. Lobes 37 and 37' may, of course, be superimposed.

Referring to Fig. 3, there is disclosed equipment which may be substituted for that shown below the line XX in Fig. 1, for receiving the same signal over different paths. The receiver 9 is associated with the array of Fig. 1 through one set of phase changers 5 and a second receiver 9' is associated with the same array through phase changers 5'. The reception for receiver 9 is controlled by handle 10 and reception for receiver 9' is controlled by control handle 10'. Receiver 9 is connected to a phase delay 39. Phase delay 39 and receiver 9 are connected to the ultimate receiver 40 by means of transmission lines 41. In the arrangement illustrated receiver 9' is adjusted to receive wave direction 38' of Fig. 2A and receiver 9 is adjusted to receive wave direction 38 of the same signal. Since the wave corresponding to direction 38 arrives before that corresponding to direction 38', the output of receiver 9 is delayed a sufficient amount to render the component waves cumulative in the ultimate translator unit 40.

Fig. 4 illustrates a recording arrangement for determining when the system illustrated by Fig. 1 is adjusted for optimum or maximum reception. In effect, there is added to the system of Fig. 1, 70 branch lines 4', and a set of phase changers 5' which is associated with a recorder 42. The moving paper (not illustrated) of the recorder 42 is caused to move in step, by means of pulleys 43 and 44 and belt 45, with handle 10' associated 75

with phase shifters 5'. Phase changer control handle 10' is turned continuously, either manually or automatically, and the angle with respect to ground of maximum reception, as indicated by the recorder, is observed by the operator. The operator then manipulates handle 10 so that the phase changers 5 are adjusted for the observed angle, whereby maximum energy is delivered to the translator unit 9. Obviously, the recorder may be of any type, as, for example, a cathode ray tube arranged to give a visual indication of the optimum angle.

Referring to Fig. 5, reference numeral 46 designates an end-on array of vertical V type elements such as disclosed in Patent 1,899,410 to E. Bruce, February 28, 1933. These units are positioned to receive the vertically polarized sub-component 47 of the incoming wave 48 which has a wave direction 49. These units are each rendered unilateral by a terminating resistance 50 and they are connected through the simultaneously controlled phase shifters 5' to the common translator unit 51. The antenna units designated by reference numeral 1, as in the case of the system illustrated by Fig. 1, receive the horizontally polarized component 52 of the wave 48. The phase shifters 5 and 5' are adjusted for obtaining extremely sharp resultant lobe and optimum reception of the respective components. These components are properly combined in the translator unit 50. If desirable, components 47 and 52 may belong to different waves.

The curves of Figs. 1C, 1D, 1E, 1F, 1G, 1H and 2A merely illustrate the operation of the invention with respect to communication in a given plane. The directive characteristic of each unit antenna is, in fact, a solid lobe and the characteristic of the array comprises several hollow cones, and consequently the invention may be satisfactorily employed for communication in different horizontal directions, as for example, for communication between a radio station located in New Jersey and stations located in England and Italy or for communication in different directions in any plane.

Although the invention has been explained in connection with certain specific embodiments and component elements, it is to be understood that it is not to be limited to such embodiments and elements. The invention is equally applicable to transmitting as well as receiving systems. Directive antenna units other than the rhombic units and other means for simultaneously operating the phase changers or for rotating the antenna diagram may be employed within the scope of the invention.

What is claimed is:

1. A method of radio communication which comprises energizing a plurality of paths of different lengths in the transmission medium between two stations and receiving at any given instant wave energy propagated along only one of said energized paths through said medium regardless of the proximity of the incoming energized paths.

2. A method of improving radio communication which comprises receiving energy from only a maximum incoming wave regardless of the number of waves incoming from the same cooperating station and changing the direction of reception in accordance with directive changes in said wave.

3. In a radio system, a plurality of unidirectional antennas spaced in a plane containing a cooperating station and positioned for directive

operation over the same angular range in said plane, separate phase changers included between said antennas and a common receiver and means for simultaneously varying said changers.

4. A method of improving radio communication utilizing a plurality of directive antenna units, which comprises placing the units in an array so that the major lobes of their directive characteristics are similarly pointed and include the same set or cluster of incoming wave directions, obtaining a movable directive characteristic or cone for the array, and including in the array cone at all times substantially only one of said incoming wave directions regardless of changes in said wave directions.

5. A method of obtaining sharp directivity in a radio system utilizing a plurality of directive antenna units arranged in a directive array and connected to a translation device, means for moving a directive lobe of each unit, and means for moving a directive characteristic of said array, which comprises moving the unit directive lobes to include in a single plane containing the cooperating station the same angular operating range and moving the major directive lobe or cone of the array characteristic to include a portion of said range.

6. A method of improving radio communication which comprises energizing a plurality of paths of different lengths between two stations, receiving the horizontally polarized components propagated along only one of the paths and the vertically polarized components propagated along only one of the paths, and combining the absorbed components.

7. A method of improving radio communication utilizing a plurality of directive units each connected to two receivers through separate phase changers, which comprises absorbing on each unit energy from the same two directions, conducting the energy received from one direction to one receiver and the energy received from the other direction to the other receiver, and combining the outputs of the receivers.

8. A method of improving radio communication utilizing a plurality of directive antenna units arranged in an end-on array, the maximum lobe of the directive characteristic of each of which is not wider than the operating range, means for moving each unit lobe and means for rotating the array directive characteristic, which comprises employing for a given array length a sufficient number of units to insure a spacing between adjacent major lobes or cones of the array directive characteristic greater than the angular range, positioning the unit lobes so as to include substantially all wave directions in said range, rotating the array characteristic to include in one of its major directive lobes or cones the direction of the wave of maximum intensity, and upon a directive change in said wave direction again rotating said characteristic to include in one of its major directive lobes or cones the direction corresponding to the wave of maximum intensity.

9. A method of simultaneously receiving different signals without fading utilizing a plurality of directive antenna units arranged in an array, means for rotating the array directive characteristic for one signal, a second means for rotating the array directive characteristic for another signal, and two receivers, which comprises receiving on each unit differently directed waves of the first mentioned signal differently directed waves of the second signal, rotating the first

mentioned characteristic so that its major lobe includes the direction of only one of the first mentioned waves, rotating the second mentioned characteristic so that its major lobe includes the direction of only one of the second mentioned waves, supplying the energy absorbed from the first mentioned wave to one receiver and that absorbed from the second mentioned wave to another receiver.

10 10. A method of simultaneously receiving the same signal over transmission paths of different length utilizing a plurality of directive antenna units arranged in an array having a plurality of directive characteristics, separate means for rotating each characteristic, a phase delayer, and
15 a receiver, which comprises directing waves on each unit waves having directions corresponding to each path, including one direction in a major lobe of one characteristic and another direction in a major lobe of another characteristic, delaying the wave arriving over the shorter path an amount sufficient to produce an in-phase relation between the received waves and combining the waves in the receiver.

20 11. A method of improving radio communication utilizing a plurality of directive units arranged in an end-on array having a plurality of directive characteristics, the major lobe of the directive characteristic of each unit being positioned to include only a given angular receiving range, means connected to a wave intensity recorder for rotating one array directive characteristic and means connected to a receiver for rotating another array directive characteristic,
30 which comprises determining the position of the first mentioned directive characteristic of the array which gives maximum reception and rotating the second mentioned directive characteristic of the array to the determined position.

40 12. In combination, a plurality of antennas each connected through a separate coaxial line to a translation device, a phase changer included in each line, each changer having a movable element for varying the phase adjustment and means for simultaneously and differently varying said elements comprising similar size gears
45 connected to said elements and different size gears mounted on a common shaft and associated with said first mentioned gears.

50 13. In combination an antenna array comprising a plurality of elements spaced in the plane of propagation of a radio wave and connected to a translation device, a different phase changer included between each of at least two elements and the translation device, means for simultaneously varying each of the said phase changers an amount proportional to the spacing between the associated element and an extreme element of said array.

60 14. In combination, an antenna array comprising a plurality of elements spaced in the plane

of propagation of a radio wave and connected to a translation device, a different adjustable phase changer included between the device and each of several elements excluding an extreme element, gear means for simultaneously and differently adjusting said phase changers, the phase change produced upon actuation of said means by any particular phase changer being proportional to

$$\phi \frac{a}{b}, \text{ where } \frac{b}{a}$$

10 equals the ratio of the spacing between said extreme element and the element associated with said particular element phase changer to the spacing between said extreme element and the element adjacent thereto, and ϕ equals the phase angle between currents corresponding to the two last mentioned elements.

15 15. In a radio system, an end-on array comprising a plurality of rhombic antenna units spaced in a plane containing a cooperating station, each unit comprising side elements each having a length greater than one half of an operating wave length, separate phase changers included between said units and a common receiver, and means for simultaneously adjusting said phase changers.

20 16. In a radio communication system, an end-on array comprising a plurality of directive units, a receiver, a different phase changer included between each unit and the receiver, and means for simultaneously varying said phase shifters, said units being positioned for directive operation over the same angular range in a single plane containing a cooperating station, and said phase shifters being adjusted to render the array operative over a portion of said range.

25 17. In a radio communication system, an end-on array comprising a plurality of directive antenna units oriented to receive vertically polarized waves, a second end on array comprising a plurality of directive antenna units oriented to receive horizontally polarized waves, the axes of said array being included, substantially, in a plane containing a cooperating station, two sets of adjustable phase shifters, two receivers, and an ultimate receiver connected to said two receivers, the first mentioned array being connected through one set of phase shifters to one receiver and the second mentioned array being connected through the other set of phase shifters to the second receiver.

30 18. In a radio receiving system, an end-on array comprising a plurality of rhombic antenna units oriented for effective operation over the same angular range, two sets of adjustable phase shifters each uni-controlled and connected to said array, a recorder connected to one set of phase shifters, and a receiver connected to the other set.

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