March 7, 1967 TETSUO TAMAMA 3,308,465

ANTENNA SYSTEM

Filed May 27, 1963 6 Sheets-Sheet 6

FIG. 9

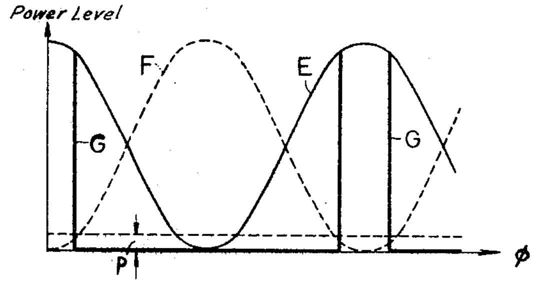
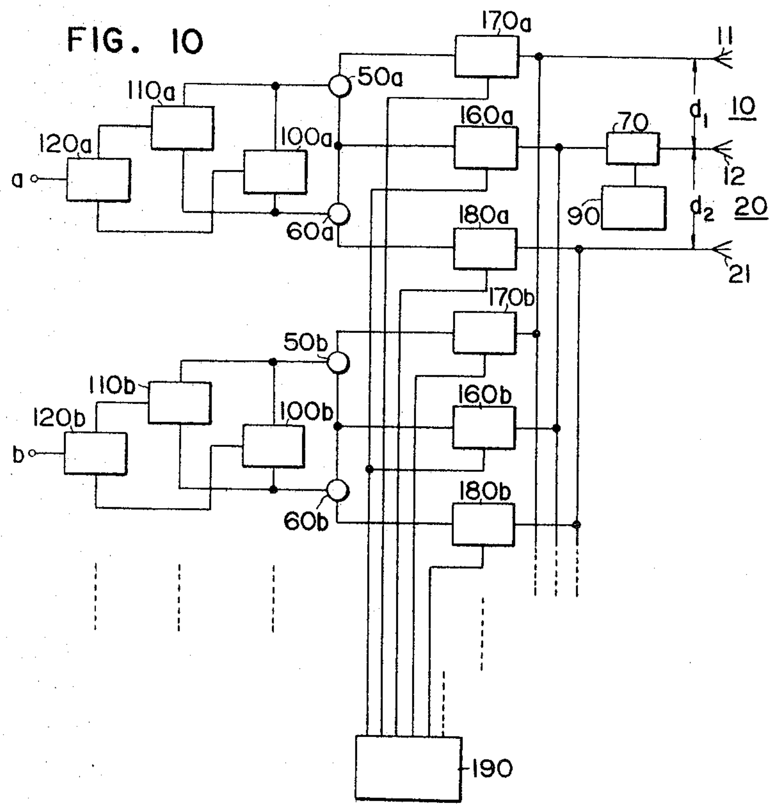


FIG. 10



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ANTENNA SYSTEM

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This invention relates to improvement in antenna systems, and more particularly, to realization of antenna array systems that are capable of electronic beam steering, multi-beaming and beam shaping.

It has been commonly known in the art of antenna or radiator systems for the detection of incoming signal bearings that an antenna array, or an assembly of radiator elements usually of identical characteristics distributed in linear, circular, planar or other alignments, exhibits an overall directivity pattern which is a product of that of each element, known as element pattern, and that inherent to the alignment itself, known as array pattern. It has been further known that this latter pattern can be steered without mechanical motion of any of the elements by introducing suitable amounts of phase difference between signals transmitted by and/or received from each element.

While the above features are regarded as essential assets of an antenna array for search and angle detection of desired objects in the space, it was characterized in the past by several restrictions, most of which stemming from the fact that the inter-element spacing and the number of radiator elements arrayed have direct bearings on the array pattern.

As the element spacing becomes larger than one-half of an employed wavelength, conspicuous side lobes, more correctly known as grating lobes, begin to appear; their number and magnitude being aggrandized as the spacing becomes wider. Consequently the element spacing is restricted to be about or less than one-half the wavelength. Likewise the width of the lobes varies roughly in inverse proportion to the number of radiator elements arrayed.

Those properties have imposed a number of disadvantages over an antenna array, some of which are as follows:

(1) Assuming a manageable number of radiator elements spaced about or less than one-half the wavelength apart, the lobe sharpness is limited, and so is angular detection accuracy.

(2) The number of radiator elements required for high angular accuracy can be very large, in some planar array applications the number amounting to tens of thousands.

(3) Due to the small inter-element spacing, little space is left for the apparatus to be installed with each of the radiators, such as transmitters, receivers and phase shifters.

(4) Also due to the lack of space, there is little room for the designer to elaborate on the structure and performance of each radiator.

The primary object of the present invention is to provide the means to overcome these disadvantages by realizing an antenna system that has radiation elements disposed at intervals much larger than one-half of the wavelength and yet is unaffected by the undesired effects of grating lobes, employing two or more arrays of different grating lobe distributions and causing only preselected lobes from each array to coincide in direction.

Another object of the present invention is to provide the means for simple but effective beam shaping technique, by applying which to an antenna array the shape of the lobes can be made substantially sharper than was formerly possible for a given number of arrayed radiator elements.

Let it be understood in the following descriptions that a "lobe" designates a protruding portion of antenna or radiator array directivity which may or may not desirably contribute to the transmission and/or reception, while a "beam" designates a lobe or a set of lobes intentionally selected to perform the desired function of transmission and/or reception.

Again it is well known in the art of searching and detecting devices such as radars that the mutually conflicting demands of faster information rate and higher angular accuracy can only be met by multi-beaming, or generation of plurality of mutually distinguishable beams each independently capable of searching for and detecting the signals from the desired objects.

One of the prior arts of multi-beaming, known as a "defocussed stacked beams" technique, requires a paraboloid reflector equipped with a number of primary feed horns located in a row near the reflector focal point, each more defocussed than the last, causing the same number of beams to be radiated each more off the reflector axis than the last, corresponding to the amount of defocus of each feed horn.

The chief disadvantages of this method are:

(1) Due to the inherent deterioration of beam shape by defocussing, the amount of defocus is limited, and so are the number of beams and angular coverage.

(2) The necessity to provide one transmission and reception channel for each of the beams makes the system structure cumbersome and complicated.

Other multi-beaming techniques shared, more or less, the same sort of disadvantages as described above.

A further object, then, of the present invention is to provide a simple and effective multi-beaming technique which, when applied to the aforementioned system, allows the number of transmission and reception channels to be held to a minimum number while permitting a very large number of undeteriorated beams to be generated.

Before going into the details of the present invention, it will be helpful to review briefly the known art of generating a multi-lobed array pattern from an antenna array.

If we have an antenna array consisting of a plurality of radiator elements spaced a certain distance apart, this distance being much larger than one-half of the employed wavelength, and if appropriate amounts of phase shift are introduced between the radiator elements, it is apparent that the array exhibits a maximum directivity in a direction where the energy related to all radiator elements is added in phase. The directivity pattern in the vicinity of this direction is what is commonly referred to as a lobe.

Denoting the above inter-element distance by d and the phase shift by ψ, the direction ϕ of the nose of the lobe measured from the array broadside is given by

$$\sin \phi=\frac{\lambda}{d}-\frac{\psi}{2\pi}$$

where λ is the employed free-space wavelength.

More generally, if we recall that the phase recurs every 2π radians and that d is much larger than $\lambda/2$, there are apparently more lobes than one. The direction of the nose of the mth lobe from the array broadside, ϕm, is then given by

$$\sin \phi_m=\frac{\lambda}{d}\left(m+\frac{\psi}{2\pi}\right) \qquad (1)$$

where $m=0$, I1, I2, ...

It is clear from the Equation 1 that the angular spacing of the directivity lobes depends on the value of d/λ and that the lobes are steered in angle *en masse* by varying ψ.

The aforementioned objectives of the present invention, then, are achieved approximately as follows:

(1) At least two radiator arrays are employed, each being given a different value of d/λ, so that each array has a multi-lobe directivity of different angular spacing of lobes.

(2) Each of said arrays is provided with one or a plurality of circuit means for introducing predetermined phase differences between said elements.

(3) Means is provided for combining said arrays through said circuit means whereby a preselected lobe of the directivity pattern of one array as produced by the corresponding circuit means coincides in one angular direction with a preselected lobe of each of the directivity pattern(s) of the other array(s) as produced by the corresponding other circuit means, to constitute what will be hereinafter called a "main beam."

The present invention will now be further described in connection with the accompanying drawings, throughout which like reference characters indicate like parts, and of which:

FIG. 1 is a circuit diagram in schematic form of an antenna system in accordance with the present invention, comprising two arrays, each consisting of two parallel-fed radiators;

FIG. 2 is a circuit diagram in schematic form of an antenna system in accordance with the present invention, comprising two arrays, each consisting of four series-fed radiators;

FIG. 3 is a circuit diagram in schematic form of an antenna system in accordance with the present invention, comprising two arrays, each consisting of two parallel-fed radiators, but one radiator thereof is used in common with both arrays;

FIG. 4 is a circuit diagram in schematic form of an antenna system equivalent to that of FIG. 3, except that it is used in passive form less transmitter in direction finder application;

FIG. 5 is a circuit diagram in schematic form of an antenna system equivalent to that of FIG. 3, except that it utilizes only one radiator in transmission;

FIG. 6 is a circuit diagram in schematic form of an antenna system equivalent to that of FIG. 5, except that it is equipped with variable phase shifting means to perform electronic beam steering;

FIG. 7 is a circuit diagram in schematic form of an antenna system equivalent to that of FIG. 3, except that it is equipped with means to perform beam shaping;

FIG. 8 is a circuit diagram in schematic form of an antenna system equivalent to that of FIG. 3, except that it is equipped with alternate means to perform beam shaping;

FIG. 9 is a portion of directivity pattern diagram of an antenna array illustrating the principle of beam shaping in accordance with the present invention; and

FIG. 10 is a circuit diagram in schematic form of an antenna system equivalent to that of FIG. 5, except that it is equipped with alternate means of multi-beaming.

Referring now to the drawings for a more detailed understanding of the invention, and in particular, to FIG. 1 thereof, there are shown at **10** and **20** two parallel-fed antenna arrays each consisting of two radiators **11** and **12**, spaced a distance d_1 apart, and **21** and **22**, spaced a distance d_2 apart, respectively. These distances are not identical in proportion to the employed wavelength, and both are larger in magnitude than one-half thereof. Circuit means **30***a*, **30***b*, **30***c* and **30***d*, henceforth to be called "multi-beaming circuits **30***a*, **30***b*, **30***c* and **30***d*," are provided in parallel for the former array **10**, each independently to introduce phase shifts in amounts of ψ_{1a}, ψ_{1b}, ψ_{1c} and ψ_{1d} respectively, between radiators **11** and **12** by means of phase shifting means **31***a*, **31***b*, **31***c* and **31***d*. Likewise circuit means **40***a*, **40***b*, **40***c* and **40***d* are provided in parallel for the latter array **20**, each independently to introduce phase shifts in amounts of ψ_{2a}, ψ_{2b}, ψ_{2c}, and

ψ_{2d} respectively, between radiators **21** and **22**, by means of phase shifting means **41***a*, **41***b*, **41***c* and **41***d*. Each multi-beaming circuit is equipped further with hydrid circuits **50***a*, **50***b*, **50***c*, **50***d*, **60***a*, **60***b*, **60***c* and **60***d* respectively, to divide the transmitted energy to and/or to sum up the received energy from the aforementioned radiators. The energy to be transmitted through these circuits and radiators are supplied by transmitters **90***a*, **90***b*, **90***c* and **90***d*, through duplexers **70***a*, **70***b*, **70***c*, **70***d*, **80***a*, **80***b*, **80***c* and **80***d* which regulate the proper flow of transmitted and received energies, as indicated by the pointers in the drawing. Each apparatus herefore described should be readily recognizable by those skilled in the art as conventional components of such searching and detecting devices as radars.

The received energies from each of the arrays **10** and **20**, coming out of the aforementioned duplexers, are fed into coincidence gates **100***a*, **100***b*, **100***c* and **100***d*, the function of which is to close the circuit and yield as its output either one or the other or the sum of both of the two inputs only when both thereof are present, and likewise into power differential gates **110***a*, **110***b*, **110***c* and **110***d*, the function of which is to close the circuit and yield as its output either one or the other or the sum of both of the two inputs only when both thereof are of the identical power level. The function and reason of existence of above gate means are to be studied in a more detailed form elsewhere in this document later. The outputs of these gate means are supplied into switching circuits **120***a*, **120***b*, **120***c* and **120***d*, the function of which is to close the circuit and yield to output terminal means *a*, *b*, *c* and *d* the inputs from the coincidence gate only when the inputs from the power differential gates are present.

In studying the operation of the apparatus heretofore delineated, let it be assumed first that the amounts of phase shifts of the phase shifting means **31***a* and **41***a* are caused to be

$$\psi_{1a}=\psi_{2a}=0 \qquad (2)$$

and, likewise, those of **31***b*, **41***b*, **31***c*, **41***c*, **31***d* and **41***d* to be

$$\frac{\psi_{1b}}{d_1}=\frac{\psi_{2b}}{d_2} \qquad (3)$$

$$\psi_{1c}=2\psi_{1b}, \psi_{2c}=2\psi_{2b} \qquad (4)$$

$$\psi_{1d}=3\psi_{1b}, \psi_{2d}=3\psi_{2b} \qquad (5)$$

By so doing, it is seen from Equation 1 that the array directivity pattern of the system comprising array **10** and multi-beaming circuit **30***a* (hereinafter to be referred to as "pattern at circuit **30***a*") and that of the system comprising array **20** and multi-beaming circuit **40***a* are so directed that, of all the lobes therein, only one each, namely the one that corresponds to the $m=0$ case of Equation 1, has identical bearing while others have not, with the result that any incoming signal covered by this lobe appears at output terminal means *a* while those covered by other lobes do not. Thus a "main beam" is generated, constituted by two particular lobes in patterns at circuits **30***a* and **40***a*; and it can be readily shown from Equation 1 that this beam (which will hereinafter be referred to as "main beam at terminal *a*") is directed to array broadside.

It can be readily found in like manner from Equations 1, 3, 4 and 5 that the second main beam at terminal *b* is generated by patterns at circuits **30***b* and **40***b*, except that it is directed to the following angle to the array broadside:

$$\phi_{ob}=\sin^{-1}\frac{\lambda\psi_{1b}}{2\pi d_1}=\sin^{-1}\frac{\lambda\psi_{2b}}{2\pi d_2} \qquad (6)$$

When ϕ is small this amounts to

$$\phi_{ob}\doteq\frac{\lambda}{2\pi d_1}=\psi_{1b} \qquad (7)$$

Likewise the third main beam at terminal *c* generated by patterns at circuits **30***c* and **40***c* is directed to the angle:

$$\phi_{oc} \doteqdot \frac{\lambda}{2\pi d_1}\psi_{1c} = \frac{\lambda}{2\pi d_1} 2\psi_{1b} \doteqdot 2\phi_{ob} \qquad (8)$$

and, finally, the fourth main beam at terminal *d* by the patterns at circuits **30***d* and **40***d* to the angle:

$$\theta_{od} \doteqdot \frac{\lambda}{2\pi d_1}\psi_{1d} = \frac{\lambda}{2\pi d_1} 3\psi_{1b} \doteqdot 3\phi_{ob} \qquad (9)$$

If we choose, then, the width of the lobe so that the sector of the space to be searched is filled by these four main beams, we now have a device capable of detecting incoming signal bearing simply by discerning the output terminal where the signal output is present.

While the above Equations 2, 3, 4 and 5 are expressed in one representative form only, it can readily be shown that, if we recall that the phase recurs every 2π radians, they are not so limited, but can be written in a more generalized form, as follows:

$$\frac{\psi_{1a}+2\pi m_{1a}}{d_1} = \frac{\psi_{2a}+2\pi m_{2a}}{d_2}$$

$$\frac{\psi_{1b}+2\pi m_{1b}}{d_1} = \frac{\psi_{2b}+2\pi m_{2b}}{d_2}$$

$$\frac{\psi_{1c}+2\pi m_{1c}}{d_1} = \frac{\psi_{2c}+2\pi m_{2c}}{d_2}$$

$$\frac{\psi_{1d}+2\pi m_{1d}}{d_1} = \frac{\psi_{2d}+2\pi m_{2d}}{d_2}$$

where m_{1a}, m_{1b}, . . . are positive or negative integers.

The function and the reason of existence of the aforementioned coincidence gates and power differential gates will now be studied. While it is possible for the device heretofore described to detect incoming signal bearing without the aid of said gate means, by appropriately combining the outputs of multi-beaming circuits **30***a,* **30***b,* **30***c,* **30***d,* **40***a,* **40***b,* **40***c* and **40***d,* its capability of adequate detection, upon a careful scrutiny, is found to be limited to the case where there is only one incoming signal in that sector of the space which is simultaneously covered by its main beams. Supposing, for example, the presence of one incoming signal in the direction of one lobe other than that which constitutes the main beam of the pattern at circuit **30***b,* and of another incoming signal in the direction of another lobe other than that which constitutes the main beam of the pattern at circuit **40***b,* then these two signals are combined to appear at the output terminal means *b,* with the result that the user of the device is liable to conclude erroneously that a single incoming signal is present in the direction of the main beam at terminal *b.*

The device illustrated in FIG. 1, therefore, is equipped with apparatus to avoid the above mentioned erroneous operation, the apparatus being coincidence gates **100***a,* **100***b,* **100***c* and **100***d*; power differential gates **110***a,* **110***b,* **110***c* and **110***d*; and switching circuits **120***a,* **120***b,* **120***c* and **120***d.* If two incoming signals are present and are so located as to cause the aforementioned erroneous operation, and if their sources are at different distances from the device, those signals will not pass through the coincidence gates, their time of arrival at the gates being non-coincidental; their appearance at the output terminal means is thereby avoided. If, further, two incoming signals are present and are so located as to cause the erroneous operation, and if their sources are at the same distance from the device, those signals are not likely to pass through the power differential gates, the power level of two separate incoming signals being unlikely to be of exactly the same value; their appearance at the output terminal means is thereby avoided. The device illustrated in FIG. 1, thus, is capable of detecting adequately incoming signal bearings virtually in every foreseeable occasion.

While the present invention has heretofore been described assuming parallel-fed arrays and particular number of arrays, of radiators, of multi-beaming circuits and, hence, of main beams, it will be obvious for those skilled in the art that it is not so limited, but is susceptible of various changes and modifications without departing from the spirit and scope thereof; and especially that the number of main beams radiated is theoretically unlimited.

One such possible modification is illustrated in FIG. 2, referring to which, there are shown at **10** and **20** two series-fed antenna arrays each consisting of four radiators **11**, **12**, **13** and **14**, spaced a distance d_1 apart from each other, and **21**, **22**, **23** and **24**, spaced a distance d_2 apart from each other, respectively. The function of each apparatus therein and operation of the device as a whole will be apparent, after learning that hybrid circuits **51** through **54**, **55***ab* through **58***ab*, **55***cd* through **58***cd*; **61** through **64**, **65***ab* through **68***ab* and **65***cd* through **68***cd* are used to connect arrays to multi-beaming circuits **30***a,* **30***b,* **30***c,* **30***d*; **40***a,* **40***b,* **40***c* and **40***d,* and that certain components corresponding to those of FIG. 1, namely duplexers, transmitters, coincidence gates, power differential gates and switching circuits are represented as single blocks **130***a,* **130***b,* **130***c* and **130***d.*

Several other forms of possible modifications are illustrated in FIGS. 3 through 6, each of which will be briefly described.

FIG. 3 illustrates a modification of FIG. 1, in which radiators **11** and **21** are incorporated into single element **11** which is used in common with both arrays **10** and **20**, and which is advantageous in that the number of required radiator elements are reduced from four to three without seriously affecting the system performance.

FIG. 4 illustrates a modification of FIG. 3, in which duplexers **70***a,* **70***b,* . . . , **80***a,* **80***b,* . . . and transmitters **90***a,* **90***b,* . . . are eliminated, and which is still capable of detecting incoming signal bearing, and which is suitable for passive direction finding application.

FIG. 5 illustrates a modification of FIG. 3, in which duplexers **70***a,* **70***b,* . . . , **80***a,* **80***b,* . . . and transmitters **90***a,* **90***b,* . . . are eliminated, instead of which a single duplexer **70** and a transmitter **90** are installed directly behind the radiator element **11**; this arrangement is advantageous in that the multi-beaming circuits **30***a,* **30***b,* . . . , **40***a,* **40***b,* . . . and components thereof are not required to withstand the high-power transmission energy.

FIG. 6 illustrates a modification of FIG. 5, in which phase differences between the radiator elements are variable through the use of variable phase shifting means **34** and **44**, by sweeping the phase shift of which the cluster of main beams can be electronically steered *en masse,* with the advantage of increased system flexibility.

Referring now to FIGS. 7 through 9, throughout which the upper case alphabetically characters A through G designate input and/or output signals as well as the terminal means on which the corresponding signals are yielded, a new technique of beam shaping will be described, which enables an array beam shape to be substantially sharper than was formerly possible for a given number of arrayed radiator elements.

It is known in the art of antenna arrays that the array directivity in the vicinity of nose of a lobe changes comparatively slowly with respect to angle, while it has steep inclination in the vicinity of a null. It is further known that in the type of antenna array similar to those illustrated in FIG. 1 and FIGS. 3 through 6, the difference ouput of each hybrid circuit similar to **50***a,* **50***b,* . . . and **60***a,* **60***b,* . . . yields another array directivity pattern that has steep nulls in place of lobes of heretofore discussed array pattern.

FIG. 7 illustrates a device largely similar to that of FIG. 3 but is equipped with beam shaping means which utilize the above phenomenon. The majority of components therein will be readily recognizable in connection with the previous descriptions, except that: (1) Hybrid circuits **50**a, **50**b, . . . and **60**a, **60**b, . . . are equipped with difference output terminal means D, which yield the difference output $D=(A-B)$ of two inputs A and B, in addition to the sum output $C=(A+B)$ on terminal means C which heretofore has been taken simply as hybrid output; and (2) both of these outputs C and D are supplied, through terminal means E and F respectively, into beam shaping circuits **140**a, **140**b, . . . and **150**a, **150**b, . . . which so function as to yield the input E on their output terminal means G only when another input F is smaller than a preselected threshold level P. The effect of beam shaping by means of said beam shaping circuits will be readily understood by referring to FIG. 9, in which E and F designate array patterns with respect to corresponding terminal means and P is said threshold level. As terminal means G yield output identical with E only when F is below P, the resultant pattern at terminal means G is as indicated by curve G in FIG. 9, resultant lobes being substantially sharpened in comparison with the original pattern E, with the advantage of higher angular accuracy and more reliable beam separation in applications when main beams are closely spaced to each other. It is further apparent that by varying said threshold level P, the width of the lobes of pattern G is variable, with a further advantage of an increased system flexibility.

It is apparent that an equivalent beam shaping effect can be achieved by the arrangement illustrated in FIG. 8, in which, into the input terminal means E of the beam shaping circuits **140**a, **140**b, . . . and **150**a, **150**b, . . . are supplied the signals from one of the radiators comprising the arrays **10** and **20**, instead of hybrid sum outputs.

It can be shown also that a comparable beam shaping effect can be achieved by utilizing beam shaping circuits of slightly different function, namely such circuits as to yield on their output terminal means G a signal proportional to the ratio E/F of two inputs E and F only when the said quotient exceeds a preselected threshold level.

While it has been assumed that required amounts of phase shifts for multi-beaming and beam steering are introduced by phase shifting means **31**a, **31**b, . . ., and **41**a, **41**b, . . . in FIGS. 1 through 8 and **34** and **44** in FIGURE 6, it is not necessarily the most desirable procedure to introduce such phase shifts directly to the signal from each of the radiator elements, in view of the possible insertion loss and structural clumsiness of such means as ferrite phase shifters. An alternate means of introducing such phase shifts without the above disadvantages will now be described.

It is known in the art that a set of signals of certain alternating frequency, after being mixed with a corresponding set of another alternating frequency, retains its relative phase; that is, the phase relationships among the initial signals will be conserved through mixing provided the waves to be mixed therewith are of the same constant phase; when the waves to be mixed therewith do have a second set of phase relationships, the phase relationships among the resultant mixed waves are simply the sum of the both. It is therefore possible that, when a certain amount of phase shift is to be introduced between two waves, they can be mixed with two other waves between which exists the required amount of phase difference; then the resultant two mixed waves will possess the desired phase relationship.

The application of the above principle to the present invention will then be readily understood by a brief study of the following in connection with FIG. 10.

FIG. 10 illustrates a device largely similar to that of FIG. 5 except that the phase shifting means **31**a, **31**b, . . . and **41**a, **41**b, . . . are replaced by mixers **170**a, **170**b, . . . and **180**a, **180**b, . . . and that like mixers **160**a, **160**b, . . . are introduced in the path of signal from radiator element **12**. A local oscillator **190** feeds into each of said mixers a set of waves that retain among them phase relationship identical to those required to multi-beaming previously specified in relation to Equations 2 through 5, for example. The further elaboration on the theory of operation of the device of FIG. 10 will now be superfluous, as it is quite similar to that described in connection with FIGS. 1 through 6.

While it has been noted early that the overall directivity pattern of any antenna array is a product of the element pattern and the array pattern, the discussions of the present invention so far have almost entirely concerned themselves with the latter. It is justifiable because, unless the element pattern is unusually sharp in shape and unless in that portion of space where the element pattern changes unusually quickly with respect to angle, the overall pattern is largely determined by the array pattern; the foregoing discussions of the directivity pattern in connection with the present invention are valid without major modifications.

What I claim is:

1. An antenna system comprising two or more radiator arrays disposed in parallel with a single plane and each having inter-element spacings much larger than one-half of the employed wavelength and multi-lobe array directivity of different angular spacing of lobes; means independently to displace angularly the directivity of each of said arrays by introducing suitable amounts of inter-element phase differences in a manner that one and only one lobe from each of said arrays coincides with each other in direction; and means to combine the received signal outputs from each of said arrays in a manner that only such signal as is received from all of said arrays is yielded as its output.

2. An antenna system comprising two or more radiator arrays each consisting of an even number of radiator elements spaced at inter-element spacings of larger than one-half of the employed wavelength and having multi-lobe array directivity of different angular spacing of lobes; means independently to displace angularly the directivity of each of said arrays by introducing suitable amounts of inter-element phase differences in a manner that one and only one lobe from each of said arrays coincides each other in direction; means connected to each of said arrays to yield as output of the corresponding array a signal that attains its maximum magnitude when either the difference of the received signal from one half of the radiator elements of said array and that from another half of the radiator elements thereof is below a preselected threshold level, or the ratio of the sum of the received signal from each radiator element of said array to the difference of the received signal from one half of the radiator elements thereof and that from another half of the radiator elements thereof exceeds a preselected threshold level, provided either the sum of the received signal from each radiator element of said array or received signal from any one of radiator element thereof is present; and means to combine the signal outputs from each of said arrays in a manner that only such signal as received from all of said arrays is yielded as its output.

3. An antenna system comprising two or more radiator arrays each having inter-element spacings of larger than one-half of the employed wavelength and multi-lobe array directivity of different angular spacing of lobes; the means independently to displace angularly the directivity of each of said arrays by introducing suitable amounts of inter-element phase differences in a manner that one and only one lobe from each of said arrays coincides each other in direction; and the means to combine the received signal outputs of each of said arrays in a manner that only such signal as received from all of said arrays simultaneously and at approximately identical power level is yielded as its output.

4. An antenna system comprising two or more radiator arrays each consisting of an even number of radiator elements spaced at inter-element spacings of larger than one-half of the employed wavelength and having multi-lobe

array directivity of different angular spacing of lobes; means independently to displace angularly the directivity of each of said arrays by introducing suitable amounts of inter-element phase differences in a manner that one and only one lobe from each of said arrays coincides each other in direction; means connected to each of said arrays to yield as output of the corresponding array a signal that attains its maximum magnitude when either the difference of received signal of one half of the radiator elements of said array and that of another half of the radiator elements thereof is below a preselected threshold level, or the ratio of the sum of the received signal of each radiator element of said array to the difference of the received signal of one half of the radiator elements thereof and that of another half of the radiator elements thereof exceeds a preselected threshold level, provided either the sum of the received signal of each radiator element of said array or received signal from any one of radiator element thereof is present; and means to combine the signal outputs from each of said arrays in a manner that only such signal as received from all of said arrays simultaneously and at approximately identical power level is yielded as its output.

5. An antenna system comprising two or more radiator arrays each having inter-element spacings of larger than one-half of the employed wavelength and multi-lobe array directivity of different angular spacing of lobes; a plurality of circuits connected in parallel to each of said arrays, each of said circuits having the means independently to displace angularly the directivity of each of said arrays by introducing suitable amounts of inter-element phase differences; and means to combine the received signal outputs from said arrays through said circuits so that one circuit output per array is combined in a manner that one and only one lobe from each of said arrays coincides each other in direction, the circuits being so provided and the combinations so chosen that the directions of said directionally coinciding lobes be unique and unduplicated for each combination of said circuits, so that each of said combinations yields as its output only such signal as received from all of said arrays.

6. An antenna system comprising two or more radiator arrays each consisting of an even number of radiator elements spaced at inter-element spacings of larger than one-half of the employed wavelength and having multi-lobe array directivity of different angular spacing of lobes; a plurality of circuits connected in parallel to each of said arrays, each of said circuits having the means independently to displace angularly the directivity of each of said arrays by introducing suitable amounts of inter-element phase differences; means connected to each of said circuits to yield as output of the corresponding circuit a signal that attains its maximum magnitude when either the difference of the received signal from one half of the radiator elements of corresponding array and that from another half of the radiator elements thereof is below a preselected threshold level, or the ratio of the sum of the received signal from each radiator element of said array to the difference of the received signal from one half of the radiator elements thereof and that from another half of the radiator elements thereof exceeds a preselected threshold level, provided either the sum of the received signal from each radiator element of said array or received signal from any one of radiator element thereof is present; and means to combine the signal outputs from said arrays through said circuits so that one circuit output per array is combined in a manner that one and only one lobe from each of said arrays coincides each other in direction, the circuits being so provided and the combinations so chosen that the directions of said directionally coinciding lobes be unique and unduplicated for each combination of said circuits, so that each of said combinations yields as its output only such signal as received from all of said arrays.

7. An antenna system comprising two or more radiator arrays each having inter-element spacings of larger than one-half of the employed wavelength and multi-lobe array directivity of different angular spacing of lobes; a plurality of circuits connected in parallel to each of said arrays, each of said circuits having the means independently to displace angularly the directivity of each of said arrays by introducing suitable amounts of inter-element phase differences; and means to combine the received signal outputs from said arrays through said circuits so that one circuit output per array is combined in a manner that one and only one lobe from each of said arrays coincides each other in direction, the circuits being so provided and the combinations so chosen that the directions of said directionally coinciding lobes be unique and unduplicated for each combination of said circuits, so that each of said combinations yields as its output only such signal as received from all of said arrays simultaneously and at approximately identical power level.

8. An antenna system comprising two or more radiator arrays each consisting of an even number of radiator elements spaced at inter-element spacings of larger than one-half of the employed wavelength and having multi-lobe array directivity of different angular spacing of lobes; a plurality of circuits connected in parallel to each of said arrays, each of said circuits having the means independently to displace angularly the directivity of each of said arrays by introducing suitable amounts of inter-element phase differences; means connected to each of said circuits to yield as output of the corresponding circuit a signal that attains its maximum magnitude when either the difference of the received signal from one half of the radiator elements of corresponding array and that from another half of the radiator elements thereof is below a preselected threshold level, or the ratio of the sum of the received signal from each radiator element of said array to the difference of the received signal from one half of the radiator elements thereof and that from another half of the radiator elements thereof exceeds a preselected threshold level, provided either the sum of the received signal from each radiator element of said array or received signal from any one of radiator element thereof is present; and means to combine the signal outputs from said arrays through said circuits so that one circuit output per array is combined in a manner that one and only one lobe from each of said arrays coincides each other in direction, the circuits being so provided and the combinations so chosen that the directions of said directionally coinciding lobes be unique and unduplicated for each combination of said circuits, so that each of said combination yields as its output only such signal as received from all of said arrays simultaneously and at approximately identical power level.

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