Dec. 2, 1952 E. D. BLODGETT ET AL 2,620,471

RADIO DIRECTION FINDER

Filed March 28, 1945 2 SHEETS—SHEET 1

Fig. 1.

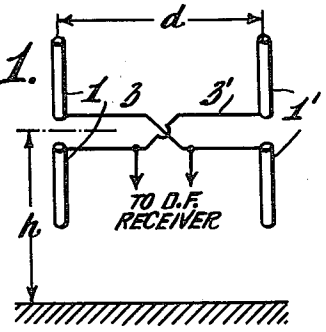


Fig. 2.

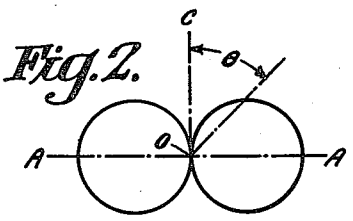


Fig. 3.

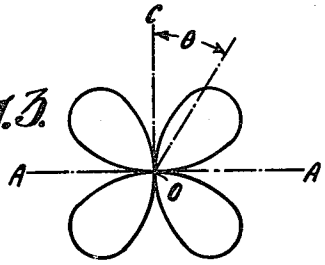


Fig. 4.

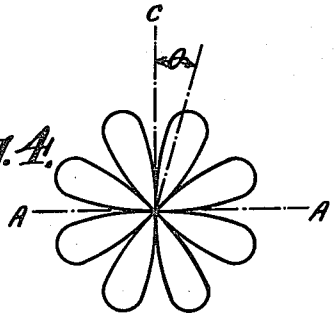


Fig. 5.

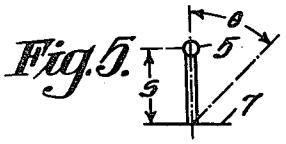


Fig. 6.

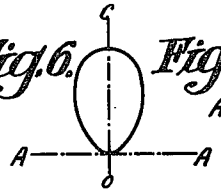


Fig. 7.

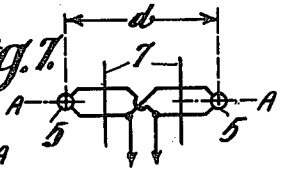


Fig. 8.



Fig. 9.

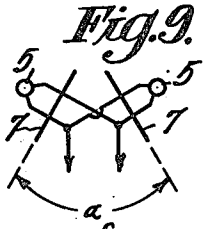


Fig. 10.

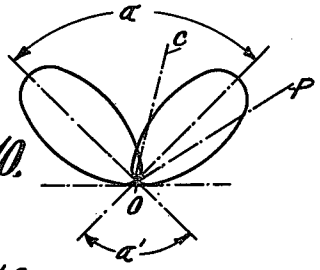


Fig. 11.

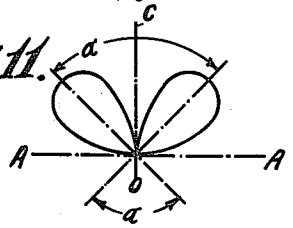


Fig. 16.

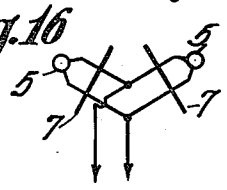
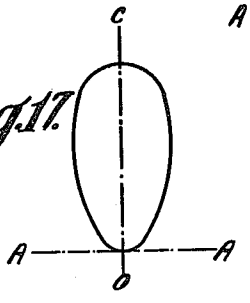


Fig. 17.



INVENTORS
Edward D. Blodgett
& Louis L. Lakatos
BY
C. D. Tuska
ATTORNEY

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Fig. 12.

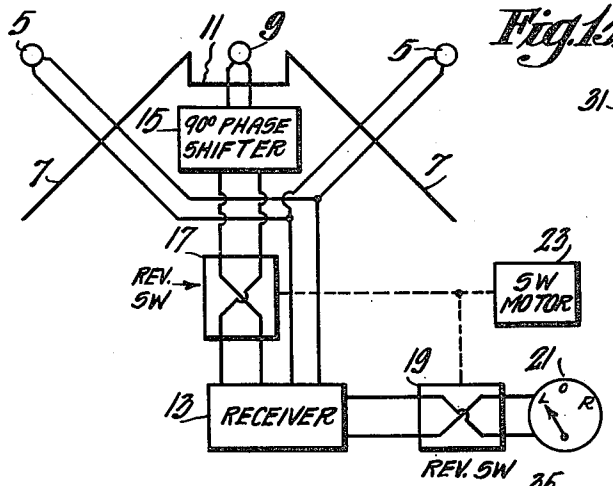


Fig. 13.

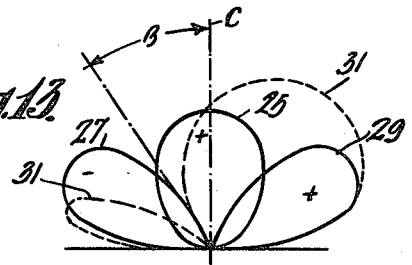


Fig. 14.

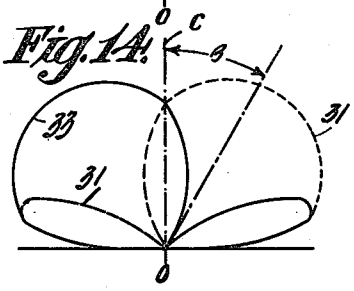
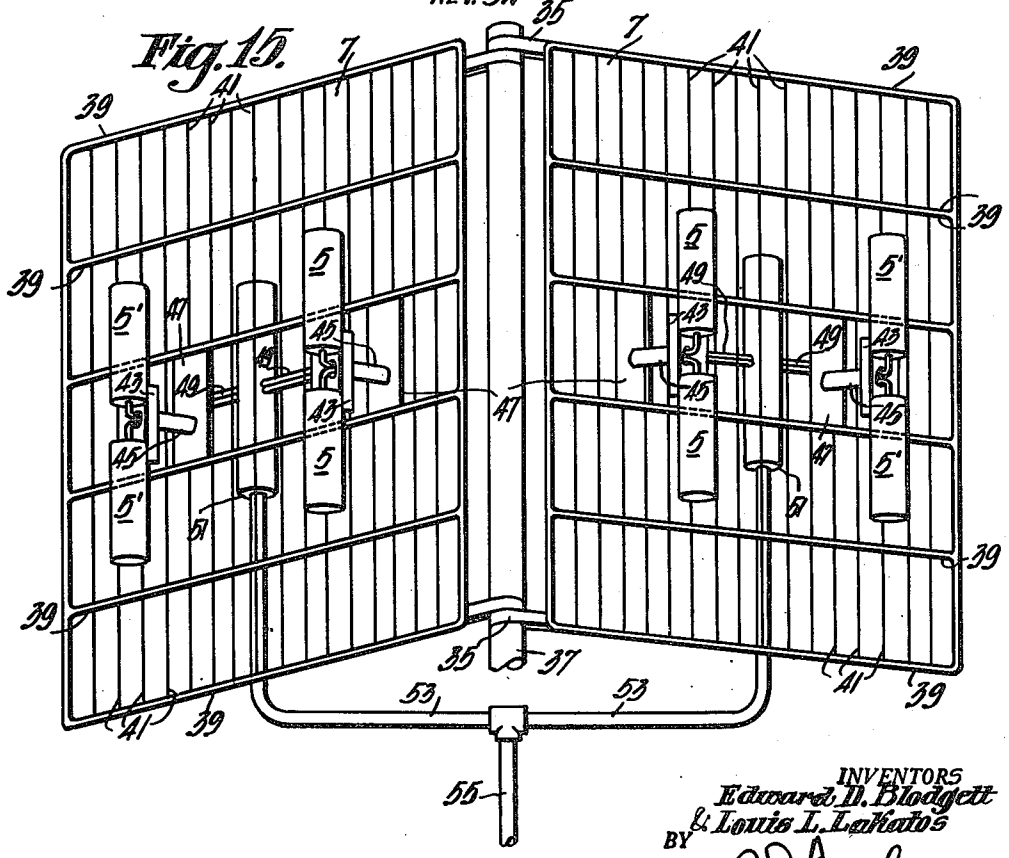


Fig. 15.



INVENTORS
Edward D. Blodgett
& Louis L. Lakatos
BY
C. D. Luska
ATTORNEY

Patented Dec. 2, 1952

2,620,471

UNITED STATES PATENT OFFICE

2,620,471

RADIO DIRECTION FINDER

Edward D. Blodgett, Haddonfield, N. J., and Louis L. Lakatos, Bala Cynwyd, Pa., assignors to Radio Corporation of America, a corporation of Delaware

Application March 28, 1945, Serial No. 585,246

5 Claims. (Cl. 343—113)

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This invention relates to antenna systems, and more particularly to improvements in directional antennas for radio direction finders and the like.

The principal object of the present invention is to provide improved antennas of the spaced element type of greater angular sensitivity than is achieved by prior art systems.

Another object is to provide antennas of the described type having greater discrimination against signals of undesired polarization than those commonly used.

A further object is to provide antennas of the described type capable of efficient operation through a relatively wide band of frequencies.

The above and other objects will become apparent to those skilled in the art upon consideration of the following description with reference to the accompanying drawings, of which

Figure 1 is a schematic elevation of a prior art antenna system of the so-called "elevated H" Adcock type,

Figure 2 is a polar graph of the usual horizontal directive pattern obtained with antennas of the type shown in Figure 1,

Figures 3 and 4 are polar graphs of the horizontal directive patterns obtained with the antenna of Figure 1 with spacings between the elements of one wavelength and two wavelengths respectively,

Figure 5 is a schematic plan view of an antenna comprising a single dipole and a reflector,

Figure 6 is a polar graph of the horizontal directive pattern of the antenna of Figure 5,

Figure 7 is a schematic view of an antenna system comprising two antennas like that of Figure 5, directed oppositely to each other,

Figure 8 is a polar graph of the horizontal directive pattern of the system of Figure 7,

Figure 9 is a schematic plan view of a system similar to that of Figure 7 but modified to provide differential action between the two elements in accordance with the present invention,

Figure 10 is a polar graph of the field patterns of the individual antennas of the system of Figure 9,

Figure 11 is a polar graph of a horizontal field pattern obtained in the operation of the system of Figure 9,

Figure 12 is a schematic diagram of a modification of the system of Figure 9, including a "sense" antenna and means for periodically varying the directive pattern of the array,

Figure 13 is a polar graph illustrating the horizontal field patterns of the elements of the system of Figure 12, and how the patterns are combined with one polarity relation between the directive antennas and the sense antenna,

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Figure 14 is a polar graph similar to that of Figure 13 but showing the resultant field patterns with the opposite polarity relation between the directive antennas and the sense antenna,

Figure 15 is a perspective view of an antenna like that shown schematically in Figure 9,

Figure 16 is a schematic diagram of a system like that of Figure 9, but with the elements connected additively rather than differentially, and

Figure 17 is a polar graph showing the directive pattern of the system of Figure 16.

An important requirement of an antenna to be used for direction finding is that it must discriminate against signals which are polarized in a manner other than that to which the system is intended to respond. In other words an antenna designed to operate with vertically polarized signals must exhibit as little response as possible to horizontally polarized energy. The more fully this requirement is met, the less the possibility will be erroneous bearing indications on downcoming signals, such as those reflected from the ionosphere or transmitted from a high altitude.

One well known type of antenna which provides relatively little response to signals of undesired polarization is the elevated H Adcock, illustrated in Figure 1. This antenna comprises a pair of vertical dipoles 1 and 1', spaced horizontally from each other a distance d and supported at an elevation h above the earth's surface. The dipoles 1 and 1' are connected together differentially by conductors 3 and 3', and to a radio receiver (not shown).

The elevation h is made as great as possible to avoid unbalance between the upper and lower dipole elements owing to capacitance to ground. The spacing d is ordinarily made appreciably less than one-half wavelength at the highest frequency at which the system is to be used. Referring to Figure 2, the line A—A represents the common vertical plane of the antennas 1 and 1'. A signal arriving from any point on the line OC, perpendicular to A—A and equidistant from the antennas, will induce equal voltages, in phase with each other, in the two dipoles. Due to the differential connection between the antennas, as shown in Figure 1, the two voltages will cancel each other, producing zero resultant output.

A signal arriving from any point on the line A—A on the other hand, will induce voltages of different phases in the two antennas, which vectorially subtracted will provide a maximum output. Similarly, at any angle θ to the line OC,

the output is a function of the direction of arrival of the signal. The polar diagram of the horizontal directive pattern is the well known figure-of-eight curve, having two maxima in opposite directions along the line A—A and two minima along the line OC.

The maxima are quite broad, as is evident from Figure 2, and for this reason are not generally used for direction finding. The minima are much narrower. The direction of signal arrival may be determined by rotating the array until minimum or null signal is received. The line O—C will then indicate the direction.

The sharpness of the null may be increased by increasing the spacing d, so that the phase difference between the voltages induced in the two antennas is greater for a given angle θ between the plane of the antennas and the wave front of the signal. When this is done, however, it is found that the pattern breaks up into more lobes, giving four minima and four maxima with a spacing of one wavelength, as shown in Figure 3, and eight lobes, as shown in Figure 4, with a spacing of two wavelengths. Thus, although the null points are much sharper, the ambiguity of three or more undesired nulls is substituted for the single reciprocal null shown in Figure 2. Furthermore, while the reciprocal null of Figure 2 may be determined by use of an auxiliary sense antenna in the well known manner, application of this method to patterns of the types of Figures 3 and 4 will only reduce the ambiguity by one-half, leaving at least two nulls which cannot be differentiated from one another.

The present invention contemplates the use of reflectors with the spaced antenna elements, so arranged as to prevent the appearance of undesired nulls. Referring to Figure 5, a vertical antenna element **5** is supported parallel to and a distance s in front of a flat reflector **7**. The horizontal directive pattern, in polar coordinates, is

$$r=\cos\left(\frac{2\pi s}{\lambda}\sin\theta\right)$$

where r is the relative response at an angle θ to the line OC perpendicular to the plane of the reflector **7**, and λ is the wavelength. This pattern is shown in Figure 6 for $s=\lambda/4$.

If two structures like that of Figure 5 are placed back-to-back, as shown in Figure 7, and connected either differentially, as shown, or additively, to a common utilization circuit, the directive pattern will be a figure-of-eight (see Figure 8) consisting of two lobes similar to the pattern of Figure 6. It is to be noted that the pattern shown in Figure 8 does not result from differential action between the antennas, as does the pattern of Figure 2, but is merely the sum of two independent patterns. Consequently, the spacing d in the system of Figure 7 has no effect on the shape of the pattern. The pattern is also independent of any phase difference introduced in the connecting means between the two antennas. The reason for this is that only one or the other of the antennas responds to a signal from a particular direction, no matter what that direction is.

Referring to Figure 9, the two reflectors **7** are placed at an angle α with respect to each other, with the antennas **5** outside. This causes the corresponding directive lobes to be at the angle α with respect to each other, as shown in Figure 10. It is evident that the lobes now intersect through their portions which lie within the angle α. A signal arriving along the line OC, lying within the angle α, will induce a voltage in each antenna. A signal arriving along a line OP, outside the angle α, will act only on one antenna. Within the opposite angle α', neither antenna will respond. With the antennas differentially connected, as shown in Figure 9, a signal arriving from any direction within the angle α will produce a differential output which is zero at the intersection of the two lobes. The resulting directional pattern of the array of Figure 9 is shown in Figure 11.

The pattern of Figure 11 actually has two nulls, one from the forward direction and the other in the region α'. However there is no ambiguity because the back null extends over the entire angle α', while the forward null is very sharp. There is no definite limit to the spacing which may be used between the two antennas. If the distance is made such as to produce a large number of lobes without the reflectors, the angle α should be adjusted to include only part of the two desired lobes. The sharpness of the resulting null is approximately that of the multiple lobed pattern.

Under some conditions it is desirable to provide an indication of the direction in which the antenna array should be rotated to bring the null upon a signal being received. This may be done by means of an auxiliary antenna, connected like the "sense" antenna of the conventional L—R indicator type of radio compass. Referring to Figure 12, an auxiliary antenna **9** is provided between the directive antennas **5**. This antenna may also be provided with a reflector **11**. The antennas **5** are differentially connected, as in the system of Figure 9 to a common utilization circuit, in this case a radio receiver **13**. The antenna **9** is coupled to the receiver **13** through a 90° phase shifter **15** and a reversing switch **17**. The output circuit of the receiver is applied through a second reversing switch **19** to a meter **21**. The switches **17** and **19** are arranged to operate together, as indicated by the dash line connection therebetween, and may be operated periodically by a motor **23**.

Referring to Figure 13, the directive pattern of the antenna **9** is a single lobe **25** of the type shown in Figure 6. The pattern of the antennas **5** comprises the two lobes **27** and **29**. Since the antennas **5** are differentially connected, the lobes **27** and **29** are of opposite polarities, i. e. a signal received in the lobe **27** will produce a voltage at the receiver **13** 180° out of phase with the voltage the same signal would produce if received in the lobe **29**. The voltage induced in the "sense" antenna **9** is 90° out of phase with the vector difference of the voltages induced in the two antennas **5**. After passing through the phase shifter **15**, the sense voltage will be in phase with that of one of the antennas **5**, for example the one on the right, and 180° out of phase with that of the other antenna **5**. This voltage is added in the receiver **13** to the combined output of the antennas **5**, providing a resultant directive pattern which is unsymmetrical as shown by the dash line curve **31** of Figure 13. The null of the pattern represented by the curve **31** is displaced to the left of the null of the antennas **5**, by an angle β.

Now if the connection of the antenna **9** to the receiver **13** is reversed, the output of the sense antenna will add to the left hand lobe and subtract from the right hand lobe providing the pattern shown by the curve **33** in Figure 14. The null of this pattern is displaced by an angle β

to the right of the center line. The curve 31 is reproduced in Figure 14 for comparison with the curve 33.

The output of the receiver 13 is applied to the meter 21 through the switch 19. When the pattern 33 appears, the meter is energized for deflection to the left, and when the pattern 31 is present, the meter is energized for deflection to the right. The switches 17 and 19 are operated at a sufficiently rapid rate for the inertia of the meter (and the electrical inertia of its associated circuits) to cause integration of the receiver output pulses corresponding to the signals alternately picked up with the patterns 31 and 33. Thus if the received signal arrives along the line O—C (Figure 14) the successive pulses of receiver output are equal and the meter 21 reads zero. If the signal arrives along a line to the left of O—C, the pulses corresponding to the connection for the pattern 33 are greater, and the meter 21 is deflected toward the left. Similarly, a signal arriving from the right of the line O—C causes the meter 21 to deflect to the right.

The arrays shown schematically in Figures 9 and 12 are not necessarily limited to one antenna element for each reflector. In fact it has been found preferable in practice to use two or more horizontally spaced elements with each reflector, with the elements of each group (associated with one reflector) interconnected to provide a single-lobe directive pattern similar to that of Figure 9, but narrower.

Referring to Figure 15, a pair of reflectors 7 are mounted by metal straps 35 upon a vertical mast 37. The reflectors 7 are disposed in vertical planes at an angle α with respect to each other, as described above. The reflectors 7 comprise rectangular networks of metal tubing 39, supporting and connecting together a large number of vertical wires 41. A pair of vertical dipoles 5 and 5' are supported on blocks 43 of insulation at the ends of tubular members 45, which are in turn secured to plates 47 fastened to the reflector.

Transmission lines 49 are connected to the respective elements of the dipoles 5 and 5', and extend through the tubular members 45 to a line balance converter 51 behind the reflector 7. The converter 51 is not shown in detail, but may be of any known type, such as that described on page 855 of Radio Engineers Handbook, by F. E. Terman, published in 1943 by McGraw Hill Book Company. The upper element of the dipole 5 is connected to the same balanced terminal of the convertor 51 as the upper element of the dipole 5', and the lower elements of the dipoles 5 and 5' are connected together to the other balanced terminal of the convertor 51. The connections of the dipoles 5 and 5' to the convertor 51 of the left hand array are opposite to the corresponding connections of the right hand array. The unbalanced output lines 53 of the convertors 51 are connected together near the mast 37, and to a main downlead line 55.

The horizontal spacing between the elements 5 and 5' of each pair is preferably somewhat more than one-half wavelength at the mean frequency of operation. The dipoles are spaced approximately one-quarter wavelength from the reflectors 7, and are about one-half wavelength long over all at mid-band. The elements are of large diameter (approximately $\frac{1}{15}$ wavelength) to provide broad resonance characteristics in order to minimize variations of antenna impedance with frequency. The line balance convertor 51 is preferably of the reactance-compensated type.

Although the invention has been described as embodied in radio direction finder systems, it will be evident to those skilled in the art that the described antennas may be used with advantages for other purposes such as directive transmission, for example. For transmission it is found preferable to connect the spaced elements additively rather than differentially, as shown in Figure 16. This provides directive patterns of the type shown in Figure 17. The beam is sharper than that which would result if the elements 5, 5' were not shielded from each other by the screens 7.

Summarizing briefly, the invention has been described as an improved type of directive antenna system including spaced differentially connected elements, with reflectors arranged so that the directive pattern of one group intersects but does not coincide with that of the other, oppositely connected group. Thus each group alone responds throughout a respective wide azimuth angle, and both groups respond differentially throughout a common narrow azimuth angle. This arrangement provides extremely sharp directivity without the introduction of undesired directive lobes.

We claim as our invention:

1. In a radio direction finder operable over a wide band of frequencies, a pair of rectangular planar reflector members pivotally joined together at adjacent edges, at least one dipole antenna element mounted upon and located centrally in front of each of said planar reflector members, voltage amplitude responsive indicator means, and means to couple said dipole antenna elements to said indicator means in opposition to each other, said reflector members being angularly adjusted to substantially shield said dipole antenna elements one from the other and to cause the directive field patterns of the directive antennas formed by said reflector members and the dipole antenna elements mounted thereon to overlap.

2. A radio dirction finder operable over a wide band of frequencies, including voltage amplitude responsive indicator means, a pair of simultaneously effective directive antennas including plane reflector members arranged behind each of said antennas, said antennas and associated reflectors being arranged at an angle with respect to each other at which the directive axes of said antennas diverge appreciably and the directive field patterns thereof overlap over a relatively small angle only, said antennas being arranged at distances from said reflectors at which the latter substantially shield the antennas one from the other, whereby the spacing between antenna elements has substantially no effect on the resultant field patterns, and means coupling said antennas in opposition to said indicator means, a sense antenna arranged between said reflectors and substantially shielded from said directive antennas, means coupling said sense antenna to said indicator in phase quadrature with respect to said directive antennas, and periodic switch means connected cyclically to reverse the connections of said directive antennas with respect to those of said sense antenna.

3. A radio direction finder operable over a wide band of frequencies, including voltage amplitude responsive indicator means, a pair of simultaneously effective directive antennas in-

cluding plane reflector members arranged behind each of said antennas, said antennas and associated reflectors being arranged at an angle at which the directive axes of said antennas diverge appreciably and the field patterns thereof overlap over a relatively small angle only, said reflectors having dimensions at which the directive antennas are substantially shielded one from the other, whereby the spacing between antenna elements has substantially no effect on the resultant field patterns, and means coupling said antennas in opposition to said indicator means, a sense antenna located between said reflectors to be substantially shielded from said directive antennas, means coupling said sense antenna to said indicator means in phase quadrature with respect to said directive antennas, and periodic switch means connected cyclically to reverse the connections of said direction antennas with respect to those of said sense antenna.

4. In a radio direction finder operable over a wide band of frequencies, at least three simultaneously effective antenna elements arranged substantially parallel to each other on a given line, two plane reflector members arranged behind said antenna elements, said plane reflector members being arranged at angles with respect to each other at which the axes of the directive antennas formed by the outermost antenna elements and the adjacent plane reflector members diverge appreciably and the directive field patterns thereof overlap over a relatively small angle only, the foremost edges of said plane reflector members being located to substantially shield the antenna elements one from the other without substantially reducing the effectiveness of the innermost antenna element, whereby the spacing between antenna elements has substantially no effect on the resultant directional field patterns, amplitude responsive indicator means, means coupling said outermost antenna elements in opposition to said indicator means, means coupling the innermost antenna element to said indicator means in phase quadrature with respect to said outermost antennas, and periodic switch means connected cyclically to reverse the connections of said outermost antenna elements with respect to those of said innermost antenna.

5. In a radio direction finder operable over a wide band of frequencies, at least three antenna elements arranged substantially parallel to each other on a given line, two plane reflector members arranged behind said antenna elements, said plane reflector members being arranged at angles with respect to each other at which the axes of the directive antennas formed by the outermost antenna elements and the adjacent plane reflector members diverge appreciably and the directive field patterns thereof overlap over a relatively small angle only, the foremost edges of said plane reflector members being located to substantially shield the antenna elements one from the other without substantially reducing the effectiveness of the innermost antenna element whereby the spacing between antenna elements has substantially no effect on the resultant directional field patterns, a common utilization circuit, means coupling said outermost antenna elements in opposition to said common utilization circuit, means coupling the innermost antenna element to said common utilization circuit in phase quadrature with respect to said outermost antennas.

EDWARD D. BLODGETT.
LOUIS L. LAKATOS.

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