Jan. 11, 1949. C. A. WARREN 2,458,885

DIRECTIVE ANTENNA SYSTEM

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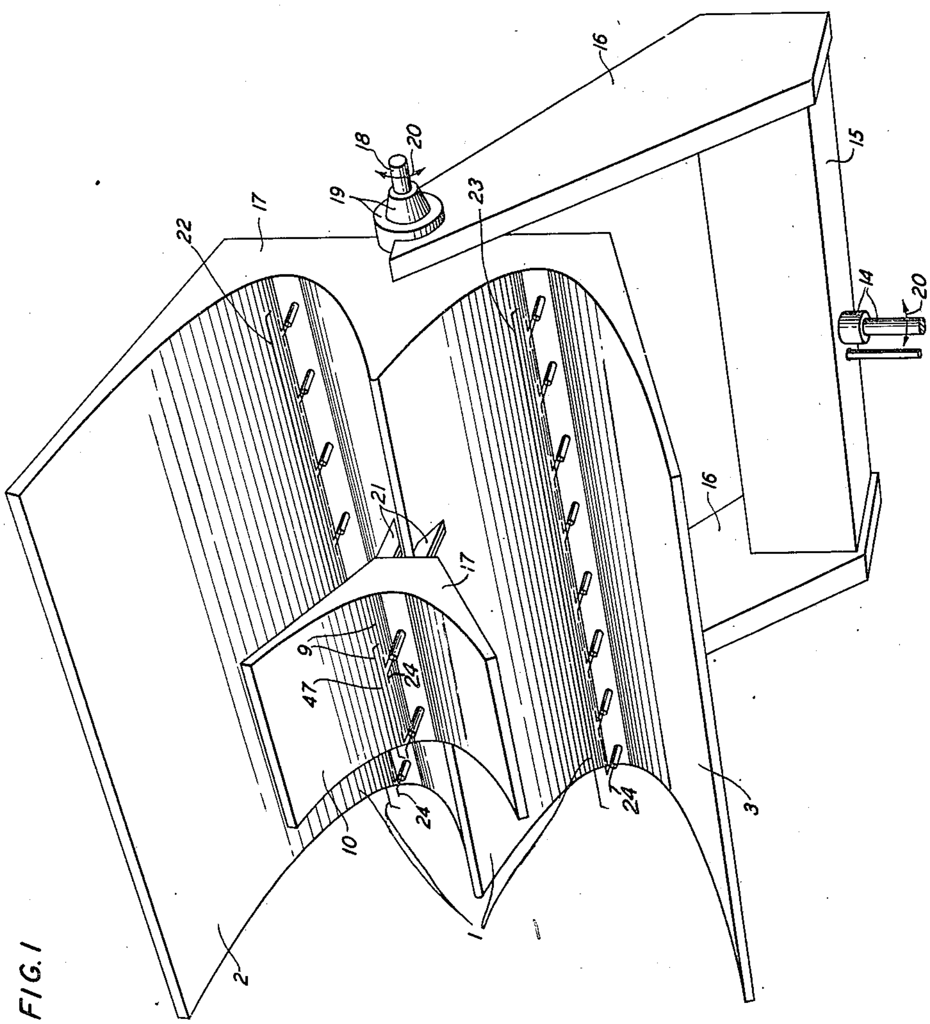

FIG. 1

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FIG. 3
SIDE DIAGRAMATIC VIEW

FIG. 2
RONT DIAGRAMATIC VIEW

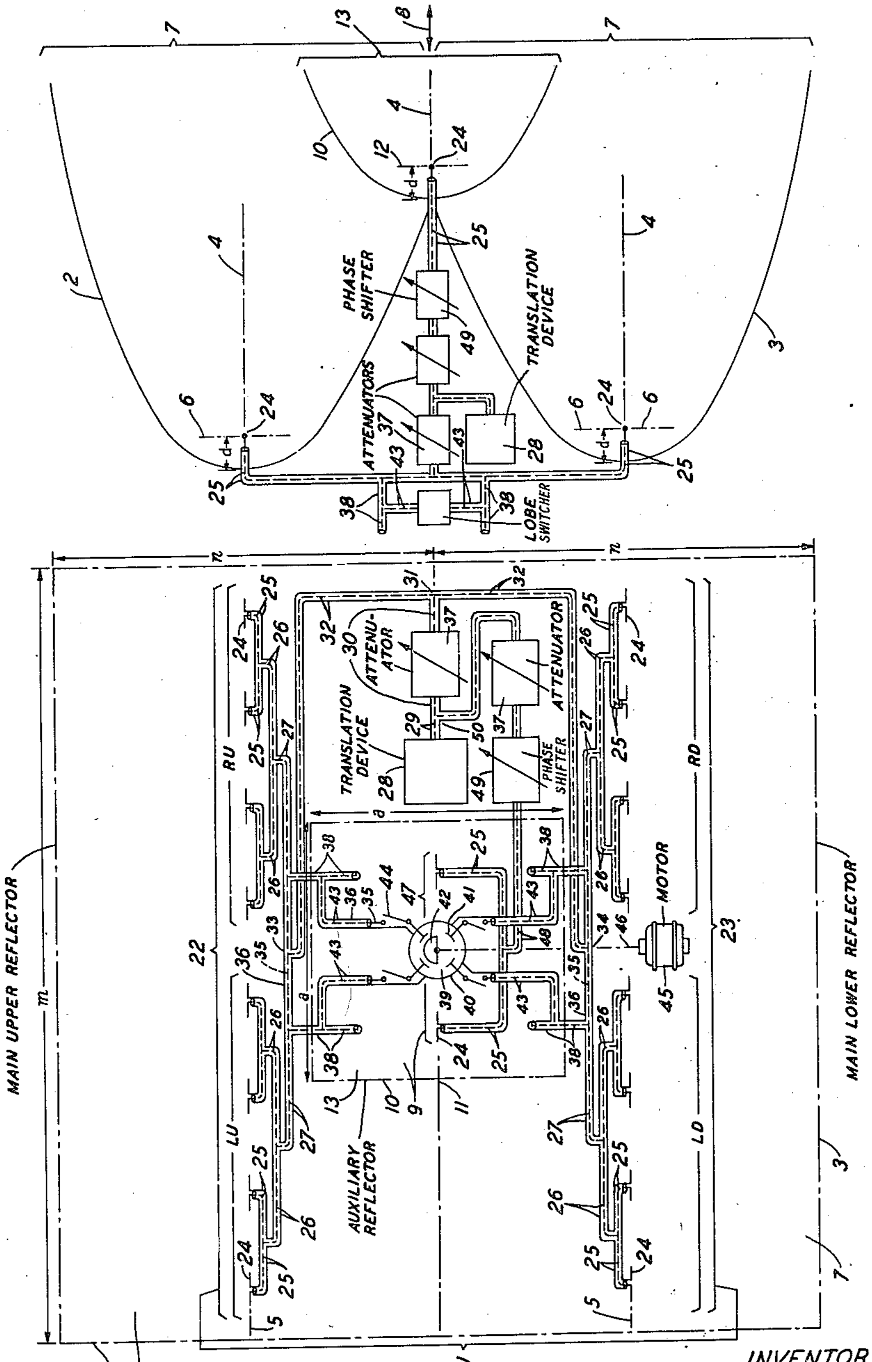

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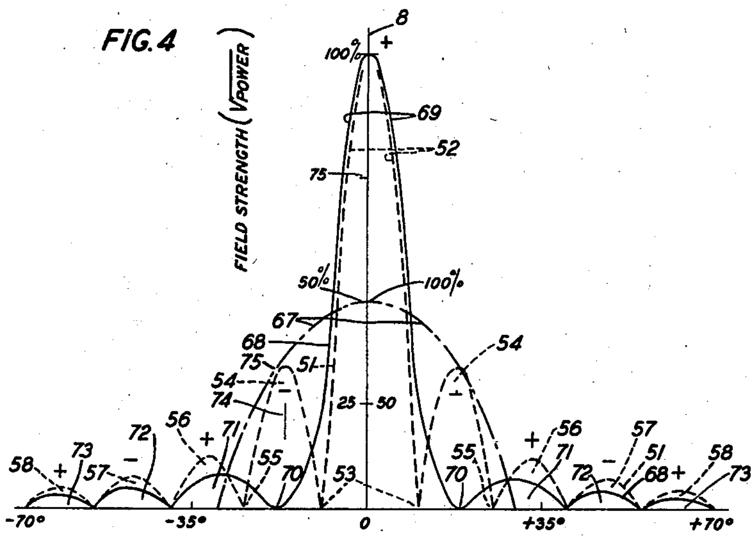
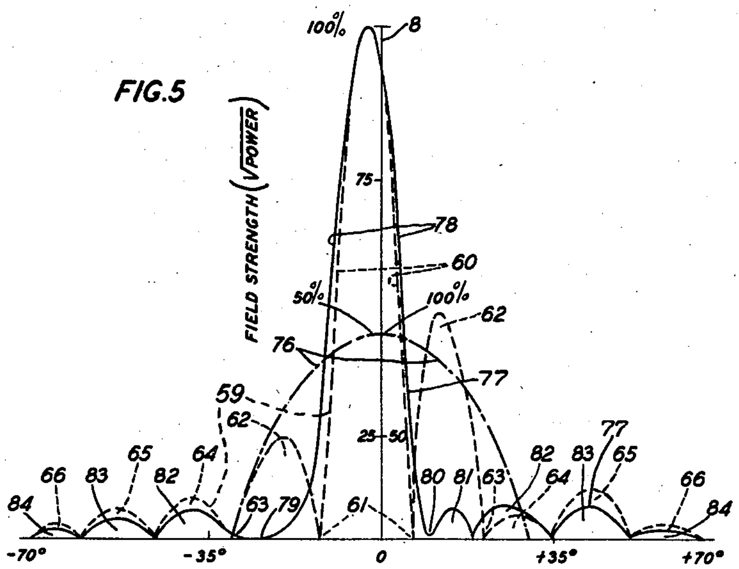
FIG. 4



ON-AXIS THEORETICAL DIRECTIVE PATTERNS

FIG. 5



OFF-AXIS THEORETICAL DIRECTIVE PATTERNS

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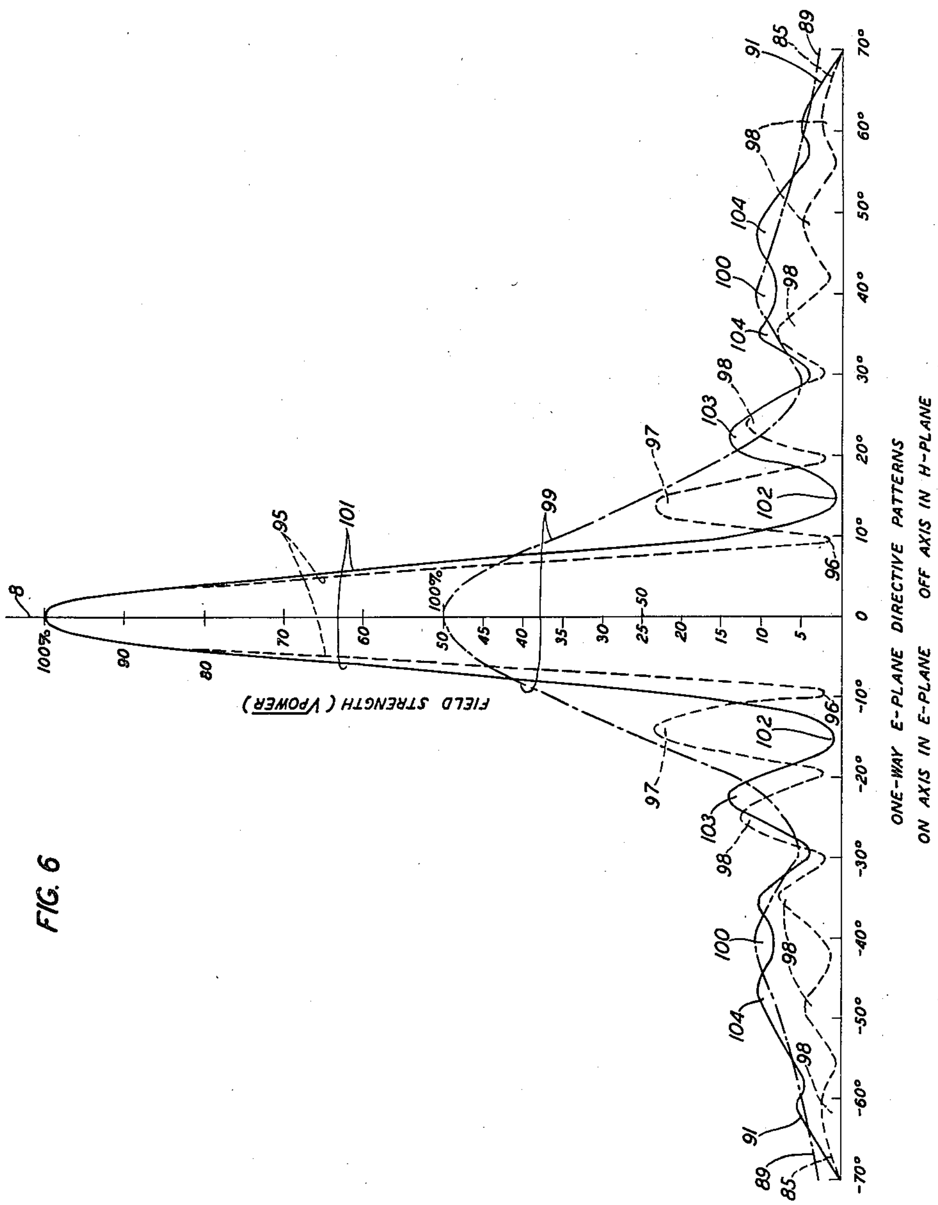

FIG. 6

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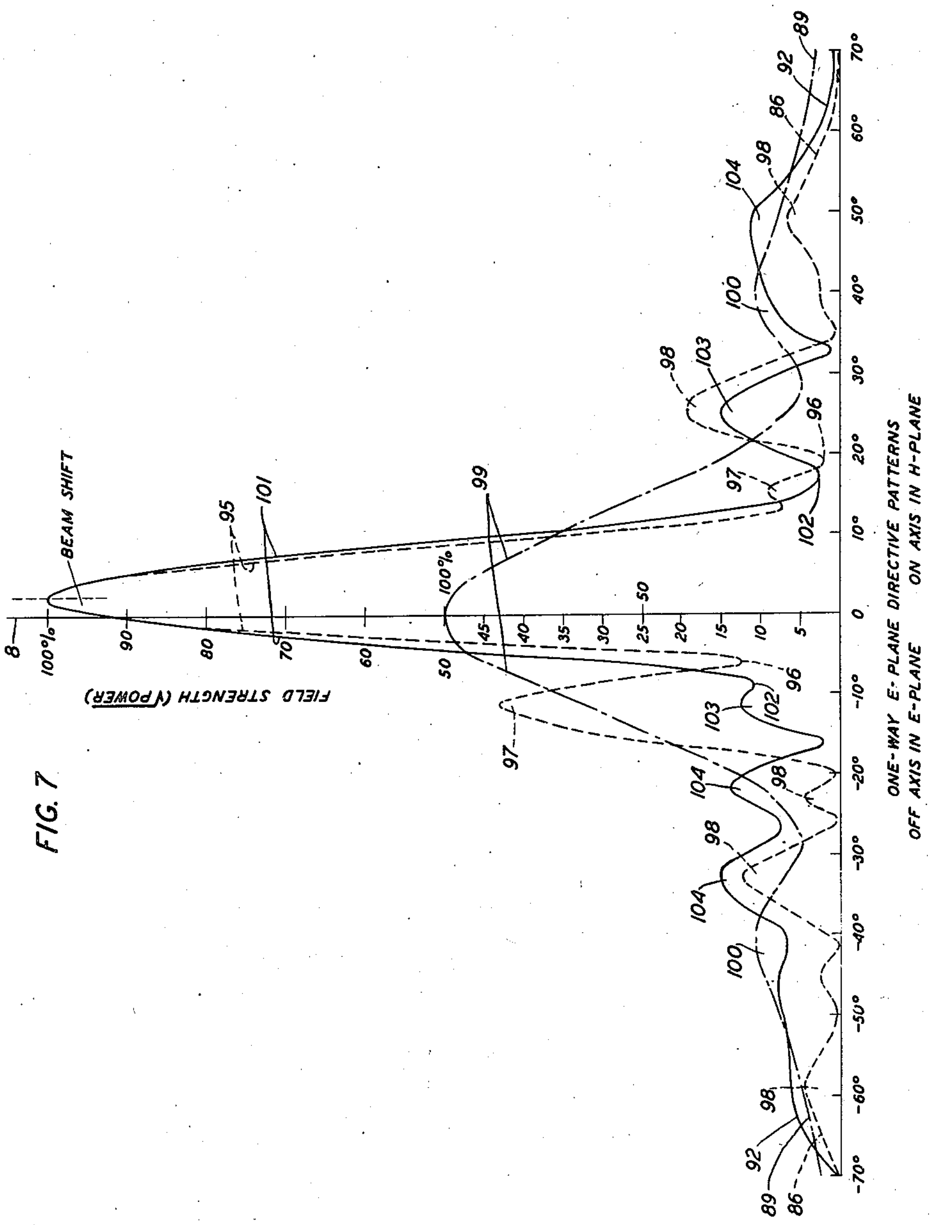

FIG. 7

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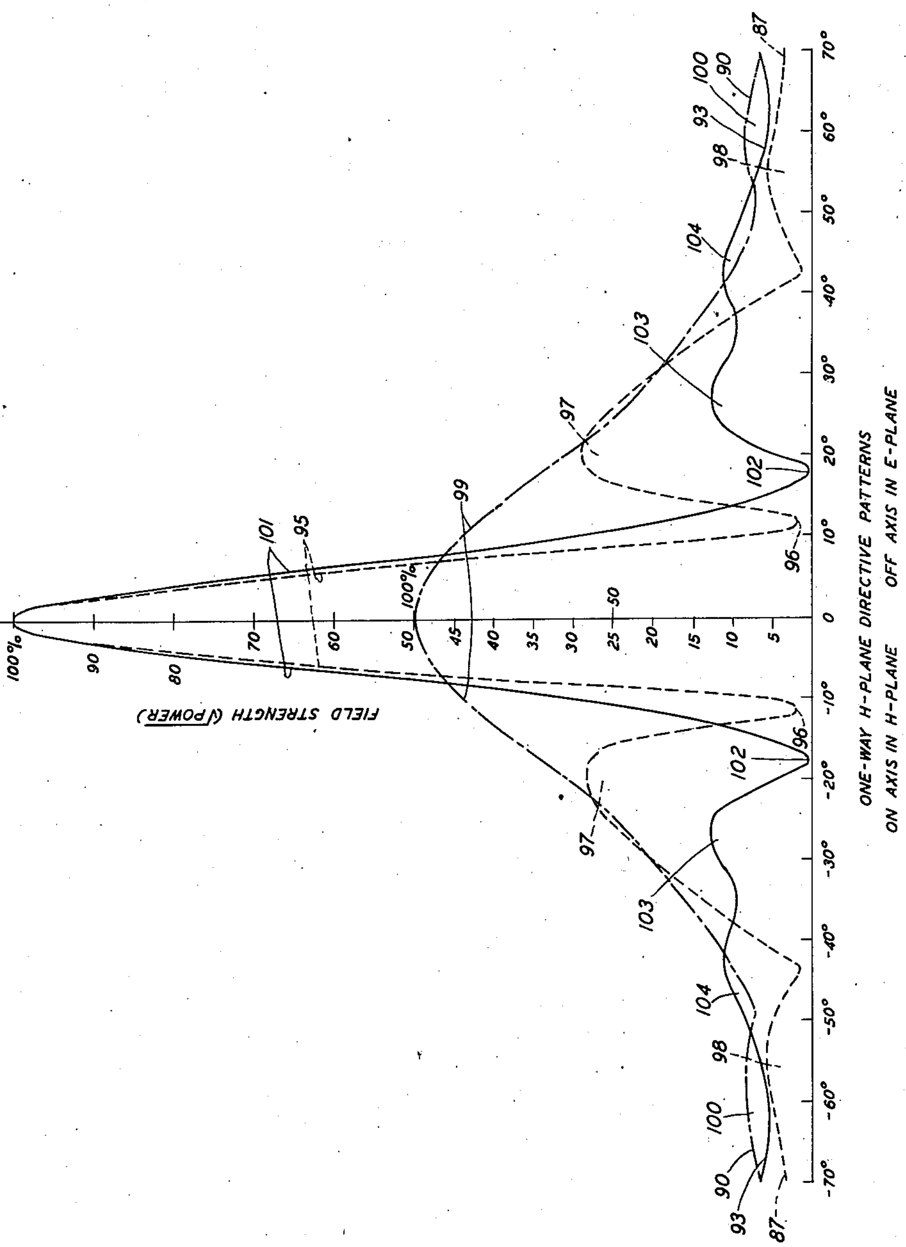
FIG. 8



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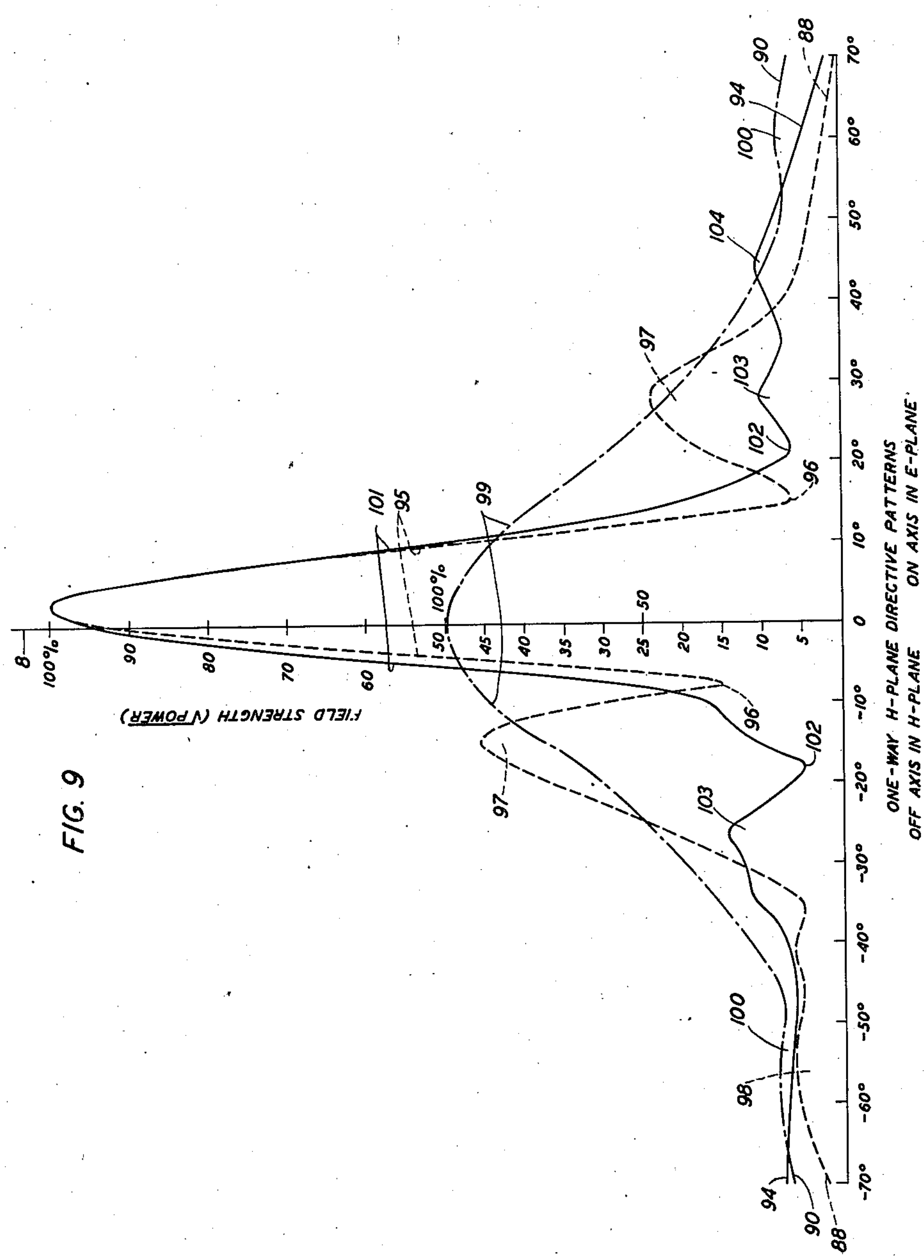

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FIG. 13

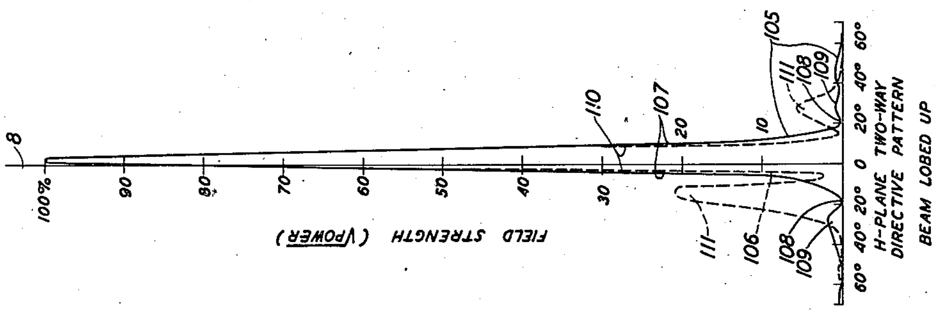


FIG. 12

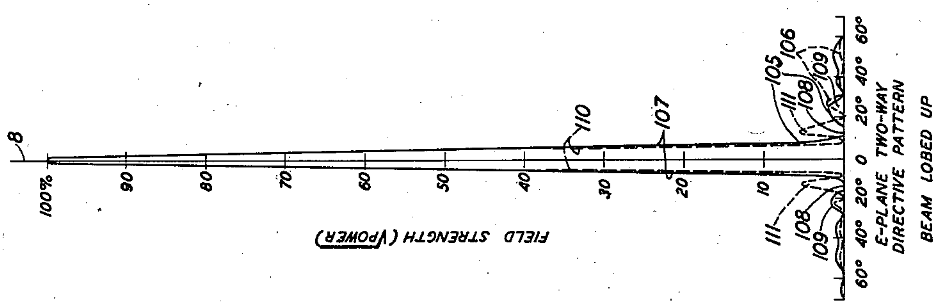


FIG. 11

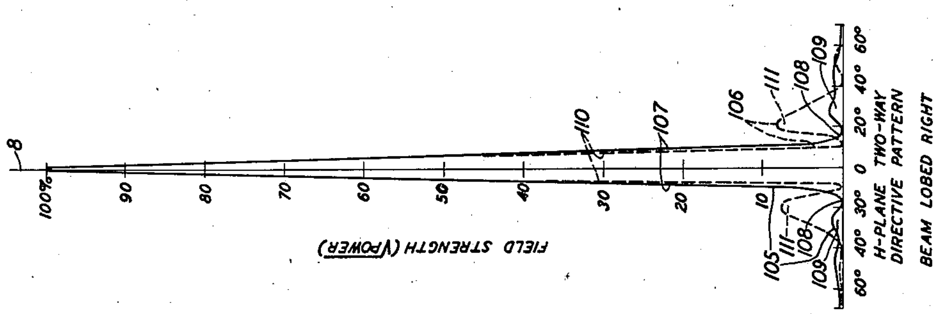
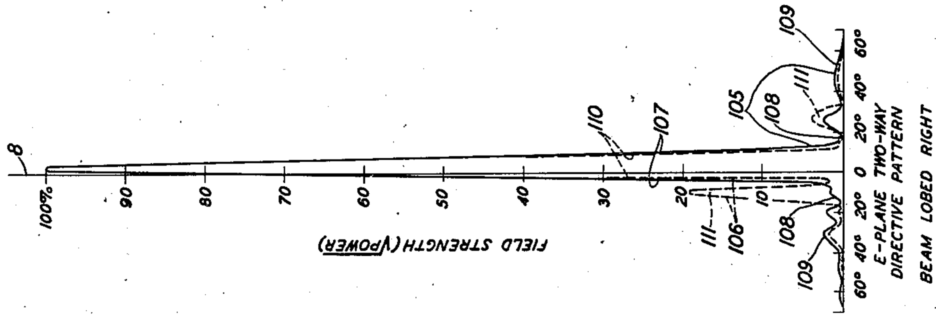


FIG. 10



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Patented Jan. 11, 1949

2,458,885

UNITED STATES PATENT OFFICE

2,458,885

DIRECTIVE ANTENNA SYSTEM

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Application December 15, 1944, Serial No. 568,248

16 Claims. (Cl. 250—33.65)

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This invention relates to antenna systems and particularly to directive antenna systems.

As is known, various methods and arrangements have been proposed for reducing the minor lobes in the directive pattern of an antenna system. Thus, in the case of a single linear array used for scanning in a single plane and comprising a plurality of antenna elements, minor lobe reduction may be accomplished by tapering the amplitudes of the antenna currents, as disclosed in Patent 2,419,205, granted on April 22, 1947, to C. B. H. Feldman. In the case of a single parabolic reflector, the desired minor lobe reduction may be secured by tapering the energization or illumination of the reflector, as described in Patent 2,422,184, granted on June 17, 1947, to C. C. Cutler. While these prior art methods have been successfully employed, they are not entirely suitable for reducing the minor lobes obtained in the double antenna or dual reflector system disclosed in the copending joint application of W. H. C. Higgins and applicant, Serial No. 453,390, filed on August 3, 1942, now Patent No. 2,424,982, dated August 5, 1947. The dual reflector system comprises two parallel horizontal arrays of colinear dipoles and a separate large cylindrical parabolic reflector associated with each array, and it is especially suitable for use in a dual plane lobe switching radar antenna system. Accordingly, it appears desirable to reduce the minor lobes, in the directive pattern of a dual reflector system, in a more satisfactory manner than heretofore effected.

It is one object of this invention to secure, in an antenna system, a highly satisfactory directive characteristic.

It is another object of this invention to reduce, in a directive antenna system, the minor lobes of the directive characteristic of the antenna.

It is another object of this invention to reduce, in a dual plane lobe switching antenna system, the first minor lobes of the directive patterns taken in the two perpendicularly related switching planes, without materially increasing the half power widths of the major lobes in said patterns.

It is a further object of this invention to eliminate, in a dual plane lobe switching antenna system, false cross-overs in each switching plane.

In accordance with one embodiment of the invention, an auxiliary antenna system is positioned adjacent to the dual reflector or main antenna system disclosed in the copending Higgins-Warren application and is utilized for securing the desired minor lobe reduction. For convenience, the single primary lobe of the main

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antenna pattern, the single primary lobe of the auxiliary antenna pattern and the single primary lobe of the resultant or combined pattern are termed herein the "major" lobe, the "maximum" lobe and the "principal" lobe, respectively; and the secondary lobes of the main, auxiliary and resultant patterns are termed herein the "minor," the "minimum" and the "subsidiary" lobes, respectively.

The auxiliary antenna system comprises a single cylindrical parabolic reflector and a pair of colinear dipoles aligned with the horizontal focal line of the small reflector. The auxiliary antenna system and the main antenna system are connected to the same radar transceiver. The vertical aperture dimension of the auxiliary reflector and the horizontal dimension of the auxiliary antenna system are relatively small compared to the corresponding dimensions of the main antenna system and are such that, in each switching plane, the width of the maximum lobe pattern of the auxiliary antenna system is at least as great as the total width of the major lobe, the nulls adjacent thereto and the first minor lobes. Amplitude control means are provided for regulating the currents supplied to or received from the two antenna systems, whereby the intensities of the maximum lobe of the auxiliary antenna and the aforementioned minor lobes may be equalized substantially. In each plane the two first minor lobes of the main antenna system are cophasal, and the major and first minor lobes of the main antenna system have opposite phases. During the dual plane lobe switching operation, the phase of the major lobe remains constant. A phase control means is inserted in the line to the auxiliary antenna system for securing an auxiliary antenna maximum lobe having a phase similar to that of the major lobe and opposite that of the first minor lobes.

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

Fig. 1 is a perspective front view of one embodiment of the invention;

Figs. 2 and 3 are, respectively, a front diagrammatic view and a side diagrammatic view of the embodiment of Fig. 1;

Figs. 4 and 5 are theoretical one-way directive patterns used for explaining the invention;

Figs. 6, 7, 8 and 9 are measured one-way directive patterns for the embodiment of the invention illustrated by Fig. 1; and

Figs. 10, 11, 12 and 13 are calculated two-way directive patterns for the embodiment illustrated by Fig. 1.

Referring to Figs. 1, 2 and 3, reference numeral 1 denotes a main antenna system comprising an upper cylindrical parabolic reflector or secondary antenna member 2 and a lower cylindrical parabolic reflector or secondary antenna member 3, each having a horizontal axis 4, a horizontal focal line 5, a common vertical latus rectum 6, an opening or aperture 7, and a focal distance d of a quarter wavelength. The apertures are relatively large and of equal size and, in the case of each reflector, the longitudinal dimension m is approximately equal to twice the transverse dimension n, so that the entire aperture of the main antenna comprising the two reflectors 2, 3 is substantially square. The axes 4, Fig. 3, are parallel to the "on-axis" or zero degree transceiving direction 8 which coincides with the equi-intensity direction for the dual plane lobe switching system or, stated differently, coincides with the axis of the scanning cone.

Reference numeral 9 denotes an auxiliary antenna system comprising a cylindrical reflector 10 positioned inside, and symmetrically in front of, the main reflectors 2, 3 and having a horizontal axis 4 aligned with the on-axis direction 8. The auxiliary reflector has a focal line 11, a vertical latus rectum 12, a substantially square opening 13 and a focal distance d of a quarter wavelength. The opening 13 is relatively small and is critically related to the dimensions of reflectors 2 and 3. As explained below, in one embodiment having a design or mean operating wavelength of about 30.5 centimeters the side dimension a of the square opening 13 is two wavelengths and the side dimension m, or $2n$, of the square opening for the two reflectors 2 and 3 is about six wavelengths. In other words, the dimension a is in the order of one-third of dimension m.

As shown in Fig. 1, the main antenna system 1 and the auxiliary antenna system 9 are supported by a yoke assembly comprising a rotatable vertical shaft and bearing 14, a horizontal turntable member 15 attached to shaft 14 and a pair of uprights or vertical arms 16. The two reflectors 2, 3 are secured to a framework comprising two side members 17 (only one shown in Fig. 1) which are mounted on a rotatable horizontal shaft 18. Shaft 18 is supported on bearings 19 in arms 16. As indicated by arrows 20, means (not shown) are provided for rotating the entire antenna system in the horizontal or azimuthal plane and for tilting it in the vertical or elevational plane. The auxiliary antenna system is supported by struts 21 extending through reflectors 2 and 3 and attached to the framework mentioned above.

Referring to Fig. 2, reference numerals 22 and 23 denote the primary antennas associated with the upper and lower reflectors 2, 3, respectively, of the main antenna system. Each primary antenna comprises eight dipoles 24 arranged in a linear array and aligned with the reflector focal line 5 and each array 22, 23 comprises two subarrays of four colinear dipoles. For convenience, the left upper, right upper, left lower and right lower subarrays are denoted LU, RU, LD and RD, respectively. The four dipoles 24 in each of the four subarrays are connected by four individual coaxial dipole lines 25 and two coaxial branch lines 26 to a coaxial subarray line 27. Numeral 28 denotes a translation device, such as a radar transceiver, which is connected by the coaxial principal line 29 and the coaxial main line 30 to the junction 31 of two coaxial array lines 32, one of which is connected to the junction 33 of the two subarray lines 27 associated with subarrays LU and RU and the other of which is connected to the junction 34 of the two subarray lines 27 associated with subarrays LD and RD. Each of the above-mentioned coaxial lines comprises an inner conductor 35 and an outer conductor 36. As is apparent from the drawing, the sixteen dipole lines 25 have equal lengths, the eight branch lines 26 have equal lengths, the four subarray lines 27 have equal lengths and the two array lines 32 have equal lengths, so that the paths connecting device 28 to the sixteen dipoles have equal electrical lengths. Numeral 37 denotes an adjustable amplitude control means, such as an adjustable attenuator, included in the main line 30.

Reference numerals 38 denote four short-circuited quarter-wave coaxial lines each of which is bridged across a different subarray line 27 at a point a short distance from the junction 33 or 34, as explained in the copending Higgins-Warren application. Numeral 39 denotes a lobe switcher having a base member 40, four stator plates 41 and a rotor 42 designed for capacitive association with two stator plates. Each stator plate 41 is connected to the inner conductor 35 of a coaxial phasing line 43 through a different switch 44, and the outer conductors 36 of phasing lines 43 are connected to base member 40. The other ends of the four phasing lines 43 are each connected to the approximate midpoint of a different quarter-wave coaxial line 38 so that, as explained below, in the case of each of lines 38, the rotor 42 applies the correct capacity to the midpoint of the line. Preferably, the phasing lines 43 have negligible lengths, or lengths each equal to an odd multiple of a half wavelength. In one actual embodiment the phasing lines 43 are omitted and the capacity is successively applied directly by the rotor 42 to the midpoints of the four quarter-wave lines 38 which project into the lobe switcher 39. Numerals 45 and 46 denote a motor and shaft for driving the rotor 42. The main antenna system just described is basically the same as that disclosed in the Higgins-Warren application, the primary difference between the two systems being that the phasing lines 43 in the system of the aforementioned application are each connected to the subarray line 27 through a half-wave line instead of a portion of a short-circuited quarter-wave line 38.

Reference numeral 47 denotes the primary antenna associated with the reflector 10 of the auxiliary antenna system 9. The primary antenna 47 comprises two spaced dipoles 24 aligned with the focal line 11 of the auxiliary reflector 10. The two dipoles 24 are connected by the dipole lines 25, the coaxial auxiliary line 48 and the principal line 29 to the translation device 28. The auxiliary line 48 includes an adjustable attenuator 37 and an adjustable phase shifter 49.

In accordance with conventional practice, adjustable impedance transformers (not shown) are inserted at the line junctions and at the dipole junctions, for the purpose of matching the impedances throughout the system. A conventional short-circuited quarter-wave stub (not shown) is provided at the center of each dipole for rigidly connecting the inner coaxial line conductor 35 to the outer coaxial line conductor 36 through a high impedance. If desired, instead of employing the two special attenuators 37, the amplitude of the current delivered to the main antenna 1 may be controlled by the impedance transformer at the junction 50 of the principal line 29 and the main line 30, and the amplitude of the current supplied to the auxiliary antenna 9 may be controlled by the impedance transformer at the junction 50 of the principal line 29 and the auxiliary line 48.

In operation, assuming device 28 is a radar transceiver, pulsed energy is conveyed through the adjustable attenuator 37, and over lines 29, 30, 32, 27, 26 and 25, between the device 28 and the sixteen dipoles 24 of the main antenna system 1. At the same time, pulses are conveyed through the adjustable attenuator 37 and adjustable phase shifter 49, and over lines 29, 48 and 25, between device 28 and the two dipoles 24 of the auxiliary antenna system 9. As is now well understood, the high frequency pulses emitted by the combined antenna system 1, 9 are, after reflection at a target, returned thereto as echo pulses. Since only the transmitting operation of the antenna systems 1, 9 is described in detail herein, it should be pointed out here that the transmitting and receiving directive patterns are, by virtue of the reciprocity theorem, substantially the same.

Considering in detail the operation of the main antenna system 1 taken alone, with the four switch members 44 open, and motor 45 inactive, the lobe switcher 39 is disconnected from the four quarter-wave lines 38 and the energies delivered to the sixteen dipoles 24 are cophasal. The quarter-wave lines 38 remain bridged across lines 27 but they do not affect the phases of the currents in the subarray lines 27, since they have a high impedance. With the switches 44 closed, and with motor 45 driving the rotor 42 clockwise, the rotor becomes capacitively associated with the upper pair, right pair, lower pair, and left pair of stator plates in succession, whereby two separate capacitive impedances, each comprising the rotor 42 and one of the stator plates 41, are simultaneously connected through two phasing lines 43 and associated quarter-wave lines 38 across two of the subarray lines 27, a capacitive impedance being connected successively across the four subarray lines 27. In other words, when a capacitive impedance is bridged across any of the four quarter-wave lines 38, the electrical length, and impedance, of the quarter-wave line is changed to a value which affects the phase of the current in the associated subarray line 27. Each capacitive impedance retards the phase of the current, say about sixty degrees, in the subarray line 27 to which it is momentarily connected. Hence, the lobe switcher functions to change the phase of one-half of the sixteen dipoles relative to the other half, the phases of the upper half, right half, lower half and left half being changed in succession. With the lobe switcher operating, the beam or direction of maximum action for the antenna system 1 is positioned "off-axis," that is, at an angle to the on-axis direction 8, and as rotor 42 rotates, lobe switching between the "up" and "down" beam positions and between the "left" and "right" beam positions is obtained, as explained in the Higgins-Warren application. The cone angle is dependent upon the value of the capacitive impedance mentioned above and in one system is about three degrees. The direction of maximum action for the system may be aligned with the on-axis direction 8 by opening the four switches 44.

Explanatory directive patterns

Referring to Fig. 4 and assuming switches 44 are open, curve 51 illustrates a theoretical on-axis directive pattern for the main antenna system 1 taken alone. The on-axis pattern 51 includes a major lobe 52, first nulls 53, first minor lobes 54, second nulls 55, second minor lobes 56, third minor lobes 57 and fourth minor lobes 58. In Fig. 5 curve 59 illustrates a theoretical off-axis directive pattern for the main antenna system 1 taken alone when the switches 44 are closed. The off-axis pattern 59 includes a major lobe 60, first nulls 61, first minor lobes 62, second nulls 63, second minor lobes 64, third minor lobes 65 and fourth minor lobes 66. Each of curves 51 and 59 represents either the electric or magnetic plane pattern, the electric or E-plane being horizontal and the magnetic or H-plane being vertical inasmuch as the dipoles 24 are horizontal.

In each of patterns 51 and 59, the first minor lobes are cophasal and have a phase opposite to that of the major lobe, as shown on the drawings by the plus and minus signs. Assuming the phase of the major lobe 52 of the on-axis pattern 51 is zero, the phase of the major lobe 60 of the off-axis pattern 59 is not zero but is −30 degrees, inasmuch as the lobe switcher introduces a lag of −60 degrees in one half the dipoles and does not affect the phase in the other half of the dipoles. It may be pointed out that if a lobe switcher were employed which introduces a phase change of +30 degrees in one half of the dipoles and a phase change of −30 degrees in the other half of the dipoles, the major lobes 52 and 60 of patterns 51 and 59 would have the same phase. The lobing or beam direction would be the same in both cases since, in so far as directivity is concerned, it is immaterial whether the 60 degree out-of-phase relation is secured by retarding the phase of one-half the system and leaving the phase of the other half the same, or by retarding the phase of one-half the system 30 degrees and advancing the phase of the other half of the system 30 degrees. In practice, it is more practical to use a simple lobe switcher, such as the switcher 39 which, as already stated, changes the phase of only one-half the dipoles.

It will be observed that the first minor lobes 54, Fig. 4, are symmetrical on each side of the major lobe 52 and that these minor lobes are of substantially the same amplitude. As shown in Fig. 5, when the major lobe 60 is shifted to one side of the on-axis direction 8 the intensity of the first minor lobe 62 on the opposite side of the on-axis direction 8 is increased considerably, and this first minor lobe 62 assumes a position closer to the on-axis direction 8. On the other hand, the intensity of the first minor lobe 62 on the same side of axis 8 as the shifted major lobe is decreased, and this first minor lobe assumes a position farther away from axis 8. The first minor lobes 54 and 62 of patterns 51 and 59 for the main antenna system 1, that is, for a prior art system such as that disclosed in the Higgins-Warren application, are highly detrimental and may, in radar operation, cause false crossovers and ambiguous indications. As will now be explained in connection with Figs. 4 and 5, the auxiliary antenna system 9 utilized in accordance with the invention, functions to eliminate or at least reduce substantially the first minor lobes 54 and 62 which are otherwise present when switches 44 are either open or closed.

Referring first to the on-axis explanatory directive patterns, Fig. 4, reference numeral 67 denotes an ideal or theoretical maximum lobe pattern, taken in either the E-plane or the H-plane, of the auxiliary antenna system 9. The maximum lobe has an angular width, taken at the 50 per cent or half-power point, which is primarily a function of the size of the auxiliary reflector opening 13, and an amplitude or height dependent upon the adjustment of the attenuator 49. By selecting an opening 13, Fig. 3, of proper size, as by adjusting the opening in a cut-and-try manner and by properly adjusting the attenuator 49, a maximum lobe may be obtained having a width and a height, that is, a shape, such as shown in Fig. 4. The maximum lobe 67, it will be observed, overlaps the major lobe 52 and the first minor lobes 54 and has, at its base, an angular width greater than that portion of the main antenna pattern 51 which includes the two first minor lobes 54, the first nulls 53 and the major lobe 52. The phase of the maximum lobe 67 is adjusted, by means of phase shifter 49, so that the major lobe 52 and the maximum lobe 67 are cophasal, and the cophasal first minor lobes 54 and the maximum lobe 67 are opposite in phase or antiphasal. Since the major lobe 52 has a constant zero phase when in the on-axis position shown in Fig. 4, the phase of the maximum lobe 67 for this condition is also zero.

The two fields from the main system 1 and the auxiliary system 9 add together in space to produce the resultant or combined pattern 68 having a principal lobe 69, first nulls 70, first subsidiary lobes 71, second subsidiary lobes 72, and third subsidiary lobes 73. More specifically, for the on-axis direction 8, the amplitude or field intensity E_m of the major lobe 52 and the amplitude E_a of the maximum lobe 67 combine to produce a maximum resultant intensity E_m+E_a, since in direction 8 the two lobes 52, 67 are cophasal. On the drawing, however, the unequal maximum amplitudes of the major lobe 52 and principal lobe 69 are, for the sake of simplicity, shown equal.

Considering, for purpose of explanation, one-half of the two patterns, for example, the pattern portions included in the angular sector at the left of axis 8, as the direction or angle increases from zero the amplitude of the major lobe 52 decreases, in accordance with the slope or shape of the lobe, to zero at the first null 53. In the angular sector or angle included between the on-axis direction 8 and the first null 53, the amplitude of the maximum lobe 67 is fairly constant and, since lobes 52 and 67 are cophasal, the portions of lobes 52 and 67 included in this small sector add to form one-half of the central portion of the principal lobe 69 of the resultant pattern 68. Considering the angular direction coincident with the the null direction 53, the intensity of the principal lobe 69 is equal to the intensity of maximum lobe 67. In the angular sector included between the null 53 and the axis 74, that is, the direction of maximum action, of the first minor lobe 54, the amplitude of the main antenna pattern 51 increases, in accordance with the shape of this minor lobe. Since the first minor lobe 54 and the maximum lobe 67 are antiphasal, as previously explained, the amplitude of the resultant pattern 68 in this angular section will be equal to the difference between the amplitudes of the maximum lobe 67 and the first minor lobe 54. At the off-axis direction at which the two amplitudes are equal, that is, at the point 75, at which the lobes or curves 54 and 67 intersect, the amplitude of the resultant pattern 68 is zero and the first null 70 of the resultant pattern is obtained. In the section between the first minor lobe axis 74 and the second null 55, the maximum lobe 67 and the first minor lobe 54 oppose each other and the small difference between their intensities forms a portion of the first subsidiary lobe 71 of the resultant pattern 68. It will be noted that the maximum lobe 67 slightly overlaps the second minor lobe 56. Preferably, the overlapping should be kept to a minimum, by proper adjustment of the shape of the maximum lobe 67, inasmuch as the maximum lobe 67 and the second minor lobes 56 are cophasal. Since both halves of pattern 51 and both halves of maximum lobe 67 are symmetrical about axis 8, the pattern portions at the right of axis 8 combine to produce the right half portion of pattern 68, in the manner explained above.

Referring now to the off-axis explanatory directive patterns, Fig. 5, reference numeral 76 designates the maximum lobe, taken in either the E-plane or the H-plane, of auxiliary antenna pattern. The lobe 76 is the same, except as to phase, as the lobe 67, Fig. 4. In this discussion it is assumed that the main antenna is lobe switched to the left and that, in the up-down or elevation plane, the major lobe 60 is aligned with the on-axis or horizontal direction 8, as in Fig. 4. The auxiliary antenna is not lobe switched but, as in Fig. 4, the axis or maximum direction of the maximum lobe 76 is fixed and aligned with the on-axis direction 8. As in Fig. 4, the maximum lobe 76 has, at its base, an angular width greater than that portion of the main antenna pattern 59, which includes the two first minor lobes 62, the first nulls 61 and the major lobe 60. As previously explained, the phase of the major lobe is −30 degrees and phase shifter 49, Fig. 2, is adjusted so that the maximum lobe 76 has a −30 degree phase, whereby the major lobe 60 and the maximum lobe 76 are cophasal, and the maximum lobe 76 and the cophasal first minor lobes 62 are antiphasal. In practice, if desired, after final adjustment of the phase shifter 49, the shifter may be replaced by a section of coaxial line having the proper length to effect the desired phase shift, that is, to secure cophasal maximum and major lobes. While the length of the coaxial line path connecting junction 50 to any main antenna dipole and the length of the coaxial line path connecting junction 50 to any auxiliary antenna dipole differ by an amount necessary to secure cophasal maximum and major lobes, these lengths should nevertheless be comparable in order that the cophasal relation of the maximum and major lobes may be maintained, substantially over the frequency range of the system.

The two fields from the main system 1 and the auxiliary system 9 add together in space to produce the resultant pattern 77 having a principal lobe 78, a broad or flat null 79 on the left or "shift" side of axis 8, a sharp null 80 and a first subsidiary lobe or pip 81 on the right side corresponding in position to the flat null 79, the second subsidiary lobes 82, third subsidiary lobes 83 and fourth subsidiary lobes 84. More particularly, the amplitude of the maximum lobe 76, when adjusted for optimum interaction with the pattern 51, Fig. 4, for the on-axis condition or position of the major lobe of system 1, as explained above, is also optimum for the cut-off axis condition represented in Fig. 5. The main antenna lobe 60 having a maximum amplitude E_m and the auxiliary antenna maximum lobe having a maximum amplitude E_a combine cophasally to produce the resultant principal lobe 78 having an amplitude E_m+E_a. As shown in Fig. 5, the particular first minor lobe 62 the amplitude of which is increased upon shift of major lobe 60, namely, the right-hand first minor lobe 62, assumes a position closer to the axis 8 of the maximum lobe 76 and therefore interacts, as is desired, with a portion of the maximum lobe 76 having a high amplitude. On the other hand, the left-hand minor lobe 62 having a decreased amplitude assumes a position farther away from axis 8 and therefore interacts, as is desired, with a portion of maximum lobe 76 having a low amplitude. In other words, when the beam is shifted, one of first minor lobes 62 increases in intensity and climbs up to a high amplitude portion of the maximum lobe 76 and the other first minor lobe 62 decreases in intensity and slides down to a low amplitude portion of the maximum lobe 76, whereby optimum mutual cancellation occurs and the first minor lobes 62 are eliminated or at least materially reduced. The right or high first minor lobe 62 extends above, and the left or low first minor lobe 62 just reaches, the maximum lobe 76. In practice, the attenuator 69 is adjusted to a value at which both first minor lobes 62 are reduced to a compromise value. As shown in Fig. 5 the left or low minor lobe 62, and the maximum lobe 76 in antiphase therewith, combine to produce the flat null 79 of the resultant pattern 77. The right or high first minor lobe 62, and the maximum lobe 76 in antiphase therewith, combine to produce the sharp null 80 and the pip or first subsidiary lobe 81 of the resultant pattern 77.

For both the on-axis condition, Fig. 4, and the off-axis condition, Fig. 5, it will be observed that the second, third and fourth minor lobes of the main antenna pattern are considerably lower in intensity than the first minor lobe. In Fig. 4, the second, third and fourth minor lobes 56, 57 and 58 correspond respectively, to the first, second and third subsidiary lobes 71, 72 and 73 of the resultant pattern 68. Now, as stated before, the maximum amplitude of the major lobe 52 is E_m whereas the maximum amplitude of the principal lobe 69 is E_m+E_a so that, although minor lobes 56, 57 and 58 do not interact with the maximum lobe 67, the maximum amplitudes of the subsidiary lobes 71, 72 and 73 are each only a small percentage of the resultant principal lobe 69, whereas the maximum amplitude of the corresponding minor lobe is a somewhat larger percentage of the major lobe 52. Similarly, in Fig. 5, the maximum amplitudes of the subsidiary lobes 81, 82, 83 and 84 are each a relatively small percentage of principal lobe 78, whereas the maximum amplitudes of minor lobes 64, 65 and 66 are each a somewhat larger percentage of the major lobe 60. In short, as shown above, for both the on-axis condition, Fig. 4, and the off-axis condition, Fig. 5, the auxiliary antenna functions to reduce materially or obliterate the first minor lobes of the main antenna pattern or, in other words, to produce in cooperation with the main antenna system a resultant pattern having at the positions of the first minor lobes very insignificant subsidiary lobes, the maximum amplitudes of which are determined primarily by the ratio of the amplitudes of the higher order minor lobes and the maximum amplitude, not of the major lobe, but of the principal lobe. Also the auxiliary antenna produces a resultant principal lobe having a high gain as measured along the axis of the principal lobe.

For purpose of explanation, it has been assumed that the main antenna patterns for the E-plane and the H-plane are the same and accordingly that the ideal auxiliary patterns are the same for the two switching planes. In practice, the actual E-plane and H-plane main antenna patterns may be first determined, and the ideal or optimum auxiliary antenna patterns for the two planes may be separately determined. A limitation or requirement is that the on-axis or greatest amplitudes of the auxiliary antenna maximum lobe patterns must, of course, be the same for the two switching planes. It should be pointed out also that when the maximum lobe pattern is cophasal with the major lobe pattern in one plane, say the E-plane, it is also cophasal in the other plane, that is, the H-plane.

Measured one-way directive patterns

Figs. 6 and 7 illustrate the measured E or horizontal plane patterns and Figs. 8 and 9 illustrate the measured H or vertical plane patterns, obtained for a system comprising a main and an auxiliary antenna system and similar in construction to that illustrated by Figs. 1, 2 and 3. More particularly, Fig. 6 illustrates the E-plane resultant pattern when the beam is switched up (or down) or, stated differently, when the resultant principal lobe is on-axis in the E-plane and off-axis in the H-plane. Fig. 7 illustrates the E-plane resultant pattern when the beam is switched left (or right) or, stated differently, when the principal lobe is off-axis in the E-plane and on-axis in the H-plane. Fig. 8 illustrates the H-plane resultant pattern when the beam is lobed left (or right), that is, when the principal lobe is on-axis in the H-plane and off-axis in the E-plane. Fig. 9 illustrates the H-plane resultant pattern when the beam is lobed up (or down) that is, when the principal lobe is off-axis in the H-plane and on-axis in the E-plane. Roughly, but not exactly, Fig. 6 is comparable to Fig. 4 and Fig. 7 is comparable to Fig. 5.

The curves 85, 86, 87 and 88 shown in dash-dash lines in Figs. 6, 7, 8 and 9, respectively, represent the patterns for the main antenna system, as obtained with the auxiliary antenna system 9 completely removed from the structure. Hence, these curves illustrate the patterns obtained with a prior art system such as that disclosed in Higgins-Warren application. The dash-dot E-plane curves 89, Figs. 6 and 7, are identical and the dash-dot H-plane curves 90, Figs. 8 and 9, are identical; and these four curves illustrate the directive patterns for the auxiliary antenna system taken apart from the main antenna system 1. The full line curves 91, 92, 93 and 94 in Figs. 6, 7, 8 and 9 respectively, illustrate the resultant patterns obtained for the combined system comprising the main and auxiliary antennas 1, 9. Generally speaking, the main antenna patterns 85, 86, 87 and 89 each include a major lobe 95, first nulls or dips 96, first minor lobes 97 and higher order minor lobes 98. The auxiliary antenna patterns 89 and 90 each include a maximum lobe 99 and the minimum lobes 100. The resultant patterns 91, 92, 93 and 94 each include a principal lobe 101, first nulls 102, first subsidiary lobes 103 and higher order subsidiary lobes 104.

Considering the E-plane patterns 85 and 86, Figs. 6 and 7, for the main antenna system 1, taken alone, it will be noted that for the on-axis condition in the E-plane, Fig. 6, the maximum amplitudes of the first minor lobes 97 are about 23 per cent of the maximum amplitude of the major lobe 99. For the off-axis condition in the E-plane, Fig. 7, the left first minor lobe 97 which is on the opposite side of axis 8 from the beam shift, has a maximum amplitude of about 43.5 per cent and is closer to axis 8 than the left or corresponding first minor lobe of Fig. 6. On the other hand, the right first minor lobe 97, Fig. 7, which is on the same side of axis 8 as the beam shift, has a maximum amplitude of about 15 per cent and is farther away from axis 8 than the corresponding first minor lobe 97 of Fig. 6. The angle occupied by the major lobe 95, first nulls 96 and first minor lobes 97 of the main antenna patterns 85 in Figs. 6 and 7 is about ±20 degrees.

Similarly, referring to the H-plane patterns 87 and 88, Figs. 8 and 9, for the main antenna system, taken alone, it will be observed that for the on-axis position in the H-plane, Fig. 8, the maximum amplitudes of the first minor lobes 97 are about 28 per cent of the maximum amplitude of the major lobe 95 and therefore slightly greater than the maximum amplitudes of the first minor lobes 97 in the E-plane pattern 85, Fig. 6, for the on-axis condition in the E-plane. For the off-axis condition in the H-plane, Fig. 9, the left first minor lobe 97, which is on the side of axis 8 opposite from the beam shift, has a maximum amplitude of 45.7 per cent and is slightly closer to the axis 8 than the left first minor lobe 97 of Fig. 8. On the contrary, the right first minor lobe 97, Fig. 9, which is on the same side of axis 8 as the beam shift, has a maximum amplitude of about 23.7 per cent and is farther from axis 8 than the right first minor lobe 97 of Fig. 8. Note that in the E-plane and H-plane the two minor lobes 97 which increase in amplitude increase about the same amount, that is, 43.5 and 45.7 per cent.

Considering the auxiliary antenna patterns 89 and 90, Figs. 6, 7, 8 and 9, the minimum lobes 100 have, generally speaking, a maximum amplitude of about 21 per cent of the maximum amplitude of the maximum lobe 99 and about 6 per cent of the principal lobe 101 of the resultant pattern 91. Hence, as is desired, these minimum lobes 100 are almost negligible. If desired, the minimum lobes 100 may be further reduced by using more than two, for example four, properly spaced dipoles in the primary antenna 47 of the auxiliary antenna system 9 and by tapering the intensities of the dipole currents.

The mere presence of the auxiliary antenna system, particularly the auxiliary reflector 10, when disconnected from the translation device 28, causes a slight decrease in the width of the main antenna major lobe 95 and a slight increase in the intensities of the two first minor lobes 97. Accordingly, in practice, the amplitude control means 49, Fig. 2, associated with the auxiliary antenna system, is adjusted so that the maximum lobe and the enlarged first minor lobes mutually cancel. In the case of transmitting, in order to compensate for the change produced in the main antenna patterns 85, 86, 87 and 88, by the blocking effect of the auxiliary reflector, a slight increase in the power or energy supplied to the auxiliary antenna system is required. This increase in power will not increase the width of the resultant principal lobe 101, since the tendency of this lobe to increase is compensated by the decrease in width of the major lobe 95 produced by the passive action of the auxiliary reflector 10. In one tested embodiment, it was found that the desired minor lobe suppression was achieved when energies of equal intensities were supplied to, or received from, the antenna systems 1 and 9 by device 28. Also, the blocking action of the auxiliary antenna system 9 causes a slight increase in the higher order minor lobes 98 but, because of the intensity increase in the major lobe 99, that is, because of the large amplitude along axis 8 of the principal lobe 101, these higher order minor lobes 98 are in a sense restored to normal.

Considering in detail the E-plane resultant patterns 91 and 92, Figs. 6 and 7, note that the pattern 91, Fig. 6, includes a pair of deep nulls 102 at the angular directions corresponding to the first minor lobes 97 which, in the main antenna pattern 85, have amplitudes of 23.7 per cent. Hence, by reason of the action of the auxiliary antenna, the first minor lobes 97 are obliterated. The subsidiary lobes 103 and 104, Fig. 6, of the resultant pattern 91 are slightly greater than the higher order minor lobes 98 of the main antenna pattern 85, because of the blocking effect of the auxiliary reflector 10 and because of the fact that in the particular embodiment tested the auxiliary pattern 89 overlaps to some extent the higher order minor lobes 98. The subsidiary lobes 103 and 104 are about 10 per cent of the single trip or one-way resultant principal lobe 101 and about 1 per cent of the calculated round-trip or two-way principal lobe which is illustrated in Fig. 12. In Fig. 7, the left first minor lobe 97, which increased with beam shift, is in effect decreased from 43.5 per cent to 13.0 per cent in the resultant pattern, corresponding to the value of the left first subsidiary lobe 103, Fig. 7. The right first minor lobe 97 of 9 per cent is decreased almost to zero as shown by the value of the right first null 102 of pattern 92, Fig. 7. The right higher order minor lobe 98, Fig. 7, of 19.5 per cent is in effect reduced to 15.2 per cent which corresponds to the value of the right first subsidiary lobe 103, while the left higher order minor lobes 98 are increased somewhat, but confined to a maximum amplitude of 15 per cent.

Referring to the H-plane resultant patterns 93 and 94, Figs. 8 and 9, the left and right first minor lobes 97 of pattern 87, Fig. 8, which have amplitudes of 28.5 per cent, are in effect transformed into first subsidiary lobes 103 having amplitudes of about 12.8 per cent. In Fig. 9 the left first minor lobe 97, which increased to 45.8 per cent in amplitude with the lobing, is converted to the left first subsidiary lobe 103, the maximum amplitude of which is about 14.5 per cent; and the right first minor lobe 97, which decreased to 23.8 per cent in amplitude, is in effect changed to the right first subsidiary lobe 103 having a 10.3 per cent amplitude.

Actually, the first minor lobes 97 in the H-plane patterns, Figs. 8 and 9, are each a combination of the first and second minor lobes. While in the E-plane the first and second minor lobes have opposite phases, it has been found in testing one embodiment that in the H-plane the first and second minor lobes have quadrature phases and therefore merge to form the large secondary lobes 97 which are shown in Figs. 8 and 9, and have been designated as "first" minor lobes. Note that in Fig. 8 the secondary lobes 97 are, at the ±18 degree peak amplitude, reduced to zero or nulls 102 in the resultant pattern, but that fairly prominent first subsidiary lobes 103 are aligned with certain off-axis or off-peak directions included in the secondary lobes 97 and having minor amplitude values. The presence of the relatively prominent first subsidiary lobes 103, in each of Figs. 8 and 9, indicates that the maximum lobe 99 of the auxiliary antenna is merging with the second minor lobe 98 (not shown) which is in phase quadrature with the maximum lobe. As a result, while in the E-plane patterns, Figs. 6 and 7, substantially complete elimination of the first minor lobes 97 is effected, in the H-plane, the reduction is not entirely complete. If only the directive operation in the H-plane is of interest, a compromise phase adjustment of the auxiliary antenna system may be made for the purpose of further decreasing the H-plane secondary lobes 97.

It should be pointed out that, in accordance with the invention, the minor lobe reduction is obtained with only a small increase in the main beam width. As shown in Figs. 6 and 7, in the E-plane, at the half power or 50 per cent point of the principal and major lobes, the increase is from 12 to 13.5 degrees or about 12.5 per cent. In the H-plane, Figs. 8 and 9, the increase in main beam width at the half power point is from 13.9 to 15.6 degrees or 12.5 per cent. In each plane, this increase in width is relatively small as compared to the 30 to 40 per cent increase in main beam width produced by the prior art method of minor lobe reduction which involves tapering the illumination of a reflector. Such an increase in the beam width is not desired, particularly because the gain of the antenna, for a given aperture, is reduced.

In addition, it should be noted that by reducing the first minor lobes, in accordance with the invention, the region close to the main beam is almost free of radiation. Hence, when the main beam is switched, false "crossovers" cannot occur between the main beam and the first minor lobes; and, as is desired, the only crossover is on axis 8 and between the two main beam positions. The true or desired crossover is the point on axis 8 at which the resultant lobe, in its up position, intersects the resultant lobe, in its down position. To illustrate, when the prior art pattern 88, Fig. 8, is reversed, the true crossover occurs on axis 8. In addition a false crossover occurs only 11 degrees from and on each side of axis 8. The false crossover is between the major lobe and the first minor lobe and its amplitude is about 38.5 per cent one way. Another false crossover occurs at $\pm$ 26 degrees with an amplitude of 23 per cent one way. The false crossovers may produce, of course, false or ambiguous indications on the train (right-left) indicator or the elevation (up-down) indicator in the radar transceiving device 28. In the system of the invention, which has the resultant pattern 94, Fig. 9, there are no crossovers in the $\pm$ 21 degree region, and, outside of this region, the maximum false crossover amplitude is relatively low, namely, 8.2 per cent one way.

It may also be stated that the band width characteristic of the system of Figs. 1, 2 and 3 is highly satisfactory. A frequency test of the embodiment of Figs. 1, 2 and 3 mentioned above showed that, over the 920–970 megacycle band, the angular sensitivity of the system is, as is desired, substantially constant over the above band or range, and the patterns are also almost constant.

Calculated two-way patterns

The two-way patterns of Figs. 10, 11 and 12 were obtained by calculating the echo amplitude received after reflection by a distant target. Figs. 10 and 11 illustrate the E-plane and H-plane resultant patterns, respectively, when the beam is lobed to the right position; and Figs. 12 and 13 illustrate the E-plane and H-plane patterns, respectively, when the beam or resultant lobe is switched to the up position. When the beam is lobed to the left position, the E-plane and H-plane patterns of Figs. 10 and 11 are each reversed; and when the beam is lobed to the down position, the E-plane and H-plane patterns of Figs. 12 and 13 are each reversed. In these four figures the reference numeral 105 denotes the resultant pattern for the system of the invention comprising a main antenna system and an auxiliary antenna system 9 and numeral 106 denotes the patterns for the main antenna system 1 taken alone. Numerals 107 denote the principal lobe, numerals 108 the first nulls and numerals 109 the subsidiary lobes of the resultant patterns 105. Numerals 110 denote the major lobes and numerals 111 the first minor lobes of the main antenna patterns 106.

Considering the two E-plane patterns 106, Figs. 10 and 12, the maximum amplitude of the first minor lobes 111 for these two patterns is 19.2 per cent of the maximum amplitude of the major lobe 110. The auxiliary antenna system functions to reduce this 19.2 per cent first minor lobe intensity to about 2.35 per cent, or, in other words, to reduce the maximum first minor lobe amplitude from about 1/5 to 1/43 of the maximum intensity of the principal lobe 107. For the two H-plane patterns 106, Figs. 11 and 13, the maximum intensity of the first minor lobes 111 is about 20.8 per cent and the auxiliary antenna reduces this intensity to 2.1 per cent, that is, from about 1/5 to about 1/50 of the maximum intensity of the principal lobe 107. In general, in Figs. 10, 11, 12 and 13, the first minor lobes 111 are completely eliminated or substantially reduced.

It has thus been shown that in accordance with the invention, a satisfactory directive characteristic is secured which is of high utility, not only in the radar art but also in the radio, telephone and telegraph arts. If desired, in radar operation, the main antenna may be disconnected from device 28 by suitable switching and the auxiliary antenna may be utilized as a "search" antenna for roughly locating the target direction. After the search operation is completed, the two systems may then be utilized for accurate dual plane lobe switching.

Although the invention has been described in connection with a particular embodiment, it is not to be limited to this embodiment inasmuch as other apparatus may be successfully employed in practicing the invention.

What is claimed is:

1. A method of reducing or obliterating at least one minor lobe in an antenna directive characteristic, which comprises aligning a direction of action of a lobe of another directive characteristic with the direction of maximum action or axis of said minor lobe, substantially equalizing the two lobe intensities, and rendering said lobes antiphasal.

2. A method of materially reducing at least one minor lobe in the directive pattern of a main antenna system which comprises aligning a direction of action in the maximum lobe of an auxiliary antenna with the direction of maximum action of said minor lobe, substantially equalizing the intensities of said lobes in the aligned directions, and rendering said lobes antiphasal.

3. A method of reducing the two cophasal first minor lobes flanking the major lobe in the direc-

tive characteristic of a main antenna system, utilizing an auxiliary antenna having a maximum lobe the angular width of which is at least as great as the combined angular width of the three first-mentioned lobes, which comprises aligning the direction of greatest action of said maximum lobe with a direction included in said major lobe, substantially equalizing the intensities of said maximum lobe and said minor lobes, and rendering said maximum lobe and said minor lobes antiphasal.

4. A method of substantially reducing at least one of the first minor lobes adjoining the major lobe in the directive pattern of a unidirective main antenna system connected to a translation device, utilizing a unidirective auxiliary antenna system having a maximum lobe the angular width of which is as great as the angular portion of the pattern including said first-mentioned lobes and the null positioned therebetween, said auxiliary antenna being connected to said device through an adjustable attenuator for regulating the intensity of said maximum lobe and through an adjustable phase shifter for controlling the phase of said maximum lobe, which comprises aligning the axis of said maximum lobe with a direction of action included in said major lobe, adjusting said attenuator so as to equalize the intensities of said maximum lobe and said minor lobe, and adjusting said phase shifter so as to secure a maximum lobe having a phase opposite to that of said minor lobe.

5. In combination, a pair of antenna systems connected through separate lines to the same translation device, one of said antenna systems having a minor directive lobe and the other antenna system having a maximum directive lobe, a direction of action in said maximum lobe being aligned with the axis or direction of greatest action in said minor lobe, a phase shifter included in one of said lines for rendering said lobes antiphasal and an attenuator included in one of said lines for substantially equalizing the intensities of said lobes in the direction of said axis.

6. In combination, a pair of antenna systems connected through separate lines to the same translation device, one of said antenna systems having a major directive lobe interposed between a pair of cophasal directive minor lobes and having a phase opposite that of said minor lobes, the other antenna system having a maximum directive lobe aligned with said major lobe, the width of said maximum lobe being substantially equal to the combined widths of said major lobe and said minor lobes, and means comprising a phase shifter and an attentuator included in one of said lines for rendering said maximum lobe and said minor lobes antiphasal and for equalizing substantially said maximum lobe and said minor lobes.

7. In combination, a translation device, a main antenna system comprising a pair of parabolic reflectors, separate primary antennas at the foci of said reflectors, a first line connecting said primary antennas to said device, an auxiliary antenna system comprising a parabolic reflector, a separate primary antenna at its focus, a second line connecting said last-mentioned primary antenna to said device, said three reflectors facing the same direction and having parallel axes included in the same plane, the aperture dimension in said plane of each of the main antenna reflectors being greater than the aperture dimension in said plane of the auxiliary antenna reflectors, the directive pattern of the main antenna in a plane of radio action perpendicular to the first-mentioned plane including a narrow major lobe interposed between a pair of cophasal minor lobes having a phase opposite to that of the major lobe, and the directive pattern of the auxiliary antenna in said plane of action being aligned substantially with the first-mentioned directive pattern and including a maximum lobe having a width substantially equal to the combined widths of said major lobe and said minor lobes.

8. A combination in accordance with claim 7, an adjustable amplitude control means inserted in one of said lines for rendering the intensities of the two maximum lobe portions aligned with the two minor lobes substantially equal to the intensities of said minor lobes.

9. A combination in accordance with claim 7, an adjustable phase control means inserted in one of said lines for rendering the phase of the maximum lobe equal to that of the major lobe and different from that of the cophasal minor lobes.

10. A combination in accordance with claim 7, an adjustable amplitude control means inserted in one of said lines and an adjustable phase control means inserted in one of said lines, whereby said minor lobes may be greatly reduced and the minor lobes of the combined directive pattern of the two antenna systems may be rendered negligible.

11. In combination, a translation device, a main antenna system comprising a pair of parallel linear arrays each comprising a plurality of spaced antenna elements, a first line connecting all of said elements to said device, an auxiliary antenna system comprising a linear array of elements, a second line connecting the last-mentioned elements to said device, the plurality of elements in each of the two first-mentioned arrays being greater than the plurality of elements in the last-mentioned array, said main antenna having in one plane of radio action a directive pattern including a narrow major lobe interposed between two cophasal minor lobes, the phase of the minor lobes being different from that of the major lobes, and the directive pattern of said auxiliary antenna in said plane of action being aligned substantially with the first-mentioned directive pattern and including a maximum lobe having a width substantially equal to the combined widths of said major lobe and said minor lobes.

12. A combination in accordance with claim 11, an adjustable amplitude means inserted in one of said lines.

13. A combination in accordance with claim 11, an adjustable phase control means inserted in one of said lines.

14. A combination in accordance with claim 11, an adjustable amplitude control means inserted in one of said lines and an adjustable phase control means inserted in one of said lines.

15. In combination, a main antenna system and an auxiliary antenna each comprising a cylindrical parabolic reflector, said reflectors facing in the same direction and having parallel axes, the width and length dimensions of the main reflector being greater than the corresponding dimensions of the auxiliary reflector, separate primary antennas for said reflectors each comprising a linear array of antenna elements aligned with the reflector focal line, the plurality of elements in the primary antenna of the main system being greater than the plurality of ele-

ments in the primary antenna of the auxiliary system, and means for simultaneously connecting all of said elements to a translation device.

16. In a dual plane lobe switching system, a main directive antenna system comprising a large upper cylindrical parabolic reflector and a large lower cylindrical parabolic reflector, a pair of linear subarrays aligned with the focal line of each reflector and each comprising a plurality of dipoles, a translation device, separate lines connecting the four subarrays to said device, means connected to said lines for shifting the phase of the currents in two of said lines simultaneously and in all of said lines successively, an auxiliary directive antenna system positioned adjacent to said main system and comprising a small cylindrical parabolic reflector, a linear array aligned with the focal line of said small reflector and comprising a plurality of dipoles, an adjustable

attenuator, an adjustable phase changer, said auxiliary antenna system being connected to said device through said attenuator and phase changer.

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