April 1, 1947. A. G. KANDOIAN 2,418,124

DIRECTIVE ANTENNA ARRAY

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Fig. 1.

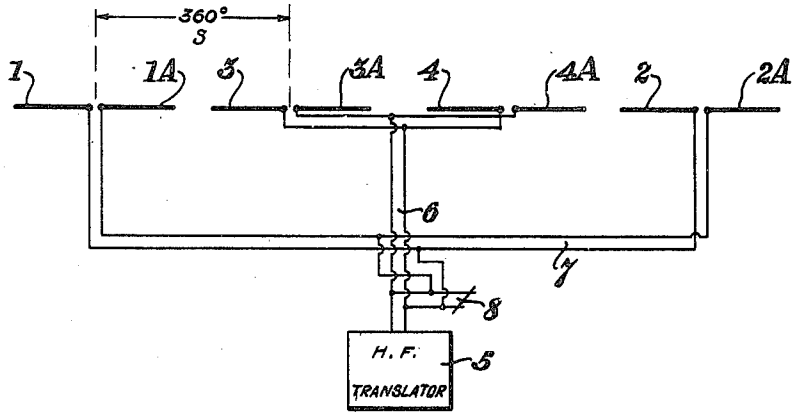


Fig. 2.

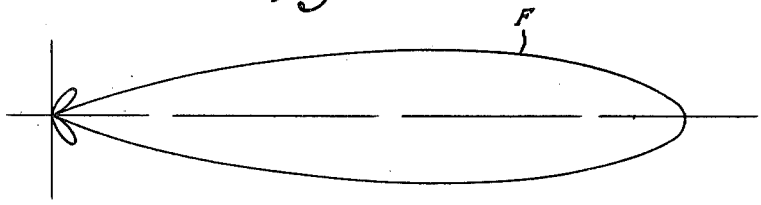
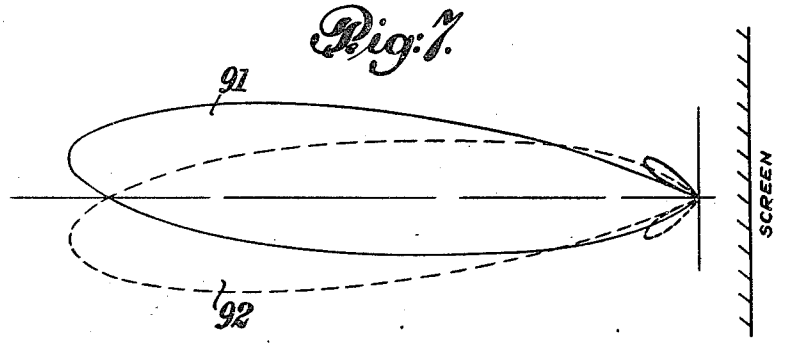


Fig. 7.



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Fig. 3.

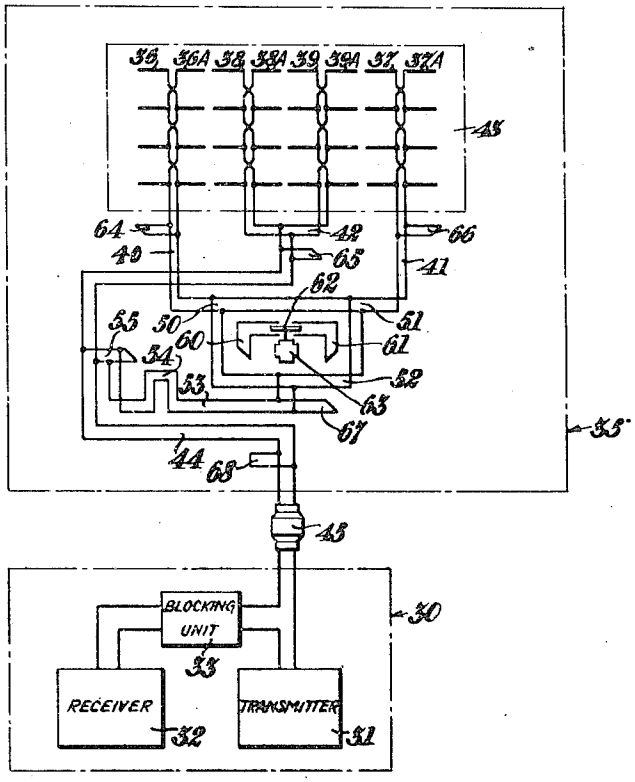
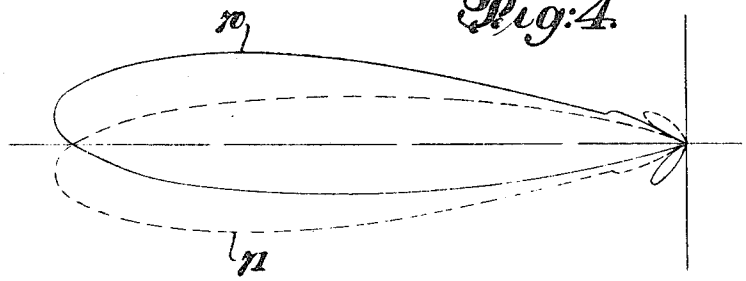


Fig. 4.



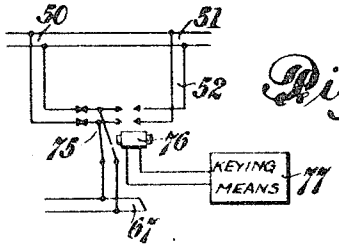


Fig. 5.

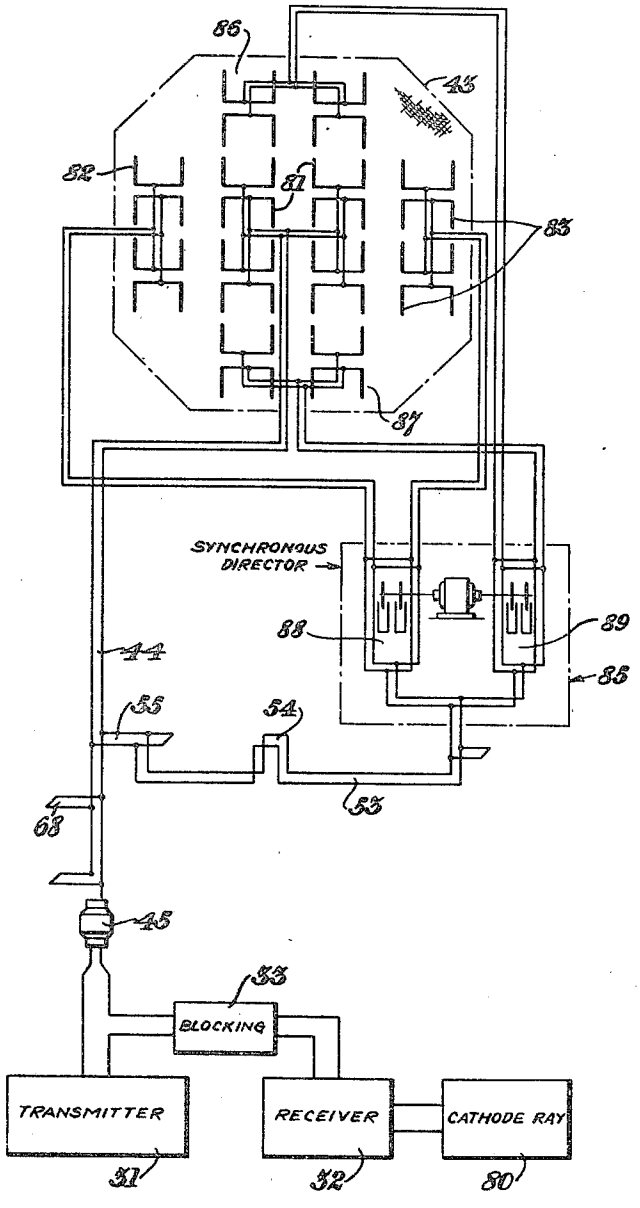
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Fig. 6.



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DIRECTIVE ANTENNA ARRAY

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Application September 7, 1942, Serial No. 457,543

14 Claims. (Cl. 250—11)

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This invention relates to antenna systems, and more particularly to antenna arrays which may be readily switched to change the directive radiation pattern in a desired manner.

It is often desired to produce a sharply directive radiation pattern the direction of which may be changed in an abrupt manner to produce the effect of crossed radiation patterns. Such patterns may be used for radio beacons, direction finder receivers or for transmitters and receivers for obstacle detection. In general, it is necessary to change the phase of energization or the antenna units in an array to shift the radiation pattern thereof. This phase shifting may entail the switching of relatively large energies particularly in the case of transmitters.

Moreover, it is desirable to have an array that will produce a sharply directive beam without the use of an excessive number of antenna units, and to use as few gradations of power feeding the respective units as possible in order to simplify the antenna feeding, and maintain the minor lobes at a desired minimum.

It is an object of my invention to provide a relatively simple, easily fed antenna array producing a sharply directive radiation pattern, with minor lobes at a desired minimum value.

It is a further object of my invention to provide a directionally shiftable antenna array which requires the switching of a relatively small percentage of the total power.

It is a further object of my invention to provide a relatively simple antenna array which may be shifted in two coordinates by switching a relatively small amount of power.

It is a still further object of my invention to provide a novel switching means for changing the phase of energy supplied to two points relatively to one another.

According to my invention I provide an antenna array in which the antenna units are energized in pairs the energization decreasing from the center antenna pairs outwardly preferably so that the currents are related in accordance with the coefficients of a binomial expansion. This array has been found to produce a sharper radiation pattern than the normal binomial array with considerable decreases in feeding complications.

Furthermore, I have found that the directive pattern may be shifted by shifting the phase of energization of the outer units only. Since these outer units carry considerably less energy than the center units, the desired directive shifts may be made by shifting a comparatively low power.

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This phase shifting may be accomplished abruptly in accordance with a further feature of my invention by a simple loop network, provided with means effectively to cut out or open circuit one side or the other of the loop.

Moroever, an array and relatively simple switching means may be provided for shifting the directive pattern in two coordinates so that it may be used in both the horizontal and vertical planes.

A better understanding of my invention and the objects and features thereof may be had by reference to the accompanying description of a few embodiments thereof made with reference to the accompanying drawings in which:

Fig. 1 is a diagram of a simple array in accordance with my invention;

Fig. 2 is a radiation diagram made with the array of Fig. 1;

Fig. 3 is a diagram of an antenna and switching system in accordance with my invention;

Fig. 4 is a radiation diagram in the horizontal plane of the system of Fig. 3;

Fig. 5 is a modified switching system which may be used in Fig. 3;

Fig. 6 is a system similar to Fig. 3 for use in two coordinates; and

Fig. 7 is a radiation diagram in the vertical plane of the system of Fig. 6.

It is known that if a plurality of antennae, for example, eight units, are arrayed in a broadside array, that is, the antenna units are spaced apart in a line and are fed in even phase with currents which are proportional to the coefficients of a binomial expansion a directive pattern can be obtained. When such units are spaced apart 180 electrical degrees no minor lobes will be present. Such an array, however, requires a considerable division of power since the current in the separate units will be divided in the following ratios: 1–7–21–35–35–21–7–1. It is thus seen that this system requires power to be divided in at least four different values for feeding the array.

In accordance with my invention, I provide an array of antenna units linearly arranged and excited to operate as a broadside array but instead of using individual antennae, the units are coupled together in pairs or other multiple units such as threes or fours, for example. Thus, as shown in Fig. 1, dipole antenna pairs 1—1A, 2—2A, 3—3A and 4—4A are provided. Pairs 3—3A and 4—4A are excited with energy supplied from high frequency translator 5 over a transmission line 6. The pairs 1—1A and 2—2A are excited with a lesser degree of power by

transmission line 7 bridged across a chosen point on building-out section 8. For example, the unit pairs are preferably fed with currents in accordance with the coefficients of a binomial expansion so that pairs 1—1A and 2—2A have one-third the current supplied to pairs 3—3A and 4—4A. With this arrangement I have found that the directive pattern is sharper than a corresponding eight element simple binomial array. The curve of the horizontal field pattern for an array such as shown in Fig. 1 is illustrated in polar coordinates in Fig. 2. This curve 1 made with a spacing S between pairs of 360° which corresponds to a 180° spacing of antenna units and with a reflector arranged at 60 electrical degrees behind the array. The equation for the field pattern F may be written:

$$F\theta = [\sin(60\cos\theta)]\left[\frac{\cos^2(90\sin\theta)}{\cos\theta}\right][\cos^3(180\sin\theta)] \quad (1)$$

where θ is the horizontal angle measured from the normal to the plane of the array.

This radiation pattern corresponds in sharpness approximately to the radiation pattern from a simple binomial array with a spacing of 240 electrical degrees between units. It can, therefore, be readily seen that an array in accordance with my invention produces an equal degree of sharpness with considerable saving in space for an eight element antenna array.

Furthermore, by adjusting the phase of the energy supplied to the outer units with respect to the central units a shifting in direction of the pattern may be accomplished. Thus, the pattern may be shifted to the right or left by supplying currents to the end units advanced and retarded in phase, respectively, with respect to the central units.

The fact that an antenna array, in accordance with my invention, produces a considerable saving of space, coupled with the further fact that the directional effect of the antenna array may be varied merely by changing the phasing of energy in the outer units which carry less power, lends itself to the construction of a portable system wherein it is desired to produce intersecting radiation diagrams for the purpose of beacon construction or for the purpose of direction finding.

In Fig. 3 is illustrated a portable unit designed for obstacle detection purposes. In this figure the obstacle detecting arrangement is shown generally at 30 and comprises a transmitter 31, a receiver 32 and a blocking unit 33. In the usual obstacle detecting arrangement the transmitter 31 transmits short pulses which are reflected from a reflecting object. The reflected pulses are then received on a receiver 32 and indications are made, preferably on a cathode ray screen, to show the position of the enemy craft. Blocking unit 33 is provided to block the receiver at all times while the transmitter is in operation. Examples of this type of obstacle detecting system may be had in more detail by reference to the copending application of Henri G. Busignies, Serial No. 381,640, filed March 4, 1941, entitled "Position finding system for gun fire control."

Associated with equipment 30 is provided the antenna system indicated generally at 35. This system comprises an eight element array of antenna units 36—36A, 37—37A, 38—38A and 39—39A arranged in pairs similar to those shown in Fig. 1. These dipole antennae are then fed by means of transmission lines 40, 41 and 42. In-

stead of a single antenna pair several antenna units arranged in a vertical array are provided to give a desired concentration in the vertical direction. The unit pairs 36—36A, 38—38A, etc., are spaced apart one wavelength and the antenna units in each vertical stack are spaced apart a half-wavelength. Behind the antenna units is provided a reflecting screen 43 which is preferably spaced a distance equal to a sixth of a wavelength behind the antenna array. Transmission line 42 connected to antenna units 38—38A and 39—39A is connected by means of a transmission line 44 through a rotary coupling unit 45 to the transmitter and receiver circuits of 30. Thus, a continuously fixed power is fed through these antennae from the transmitter.

Transmission lines 40 and 41 are interconnected and at spaced points 50 and 51 arranged apart a distance determined by the phase shift desired is connected a closed loop 52. This closed loop 52 is connected by means of a transmission line 53, phasing unit 54 and power dividing network 55 to transmission line 44 and hence over rotary coupling 45 to the circuit 30. By the use of power dividing network 55 the energy supplied to outer antenna units 36—36A and 37—37A is adjusted and preferably this adjustment is made such that the current fed to these units is one-third of that supplied to the central antenna pairs 38—38A and 39—39A. The phasing network 54 is provided to energize the outer units in phase displaced relation with respect to the center units of the array. In the construction shown, phase shifter 54 is designed to produce a 45° phase shift in the energy. The spacing between 51 and 52 is made twice this phase shift in electrical degrees or a quarter wavelength when 45° phase shift is provided. Thus, the outer antenna units 36—36A and 37—37A would normally be supplied with energy at 45° phase relationship with respect to the center units and at a current level one-third that supplied to the central units.

In order to produce a shifting of the directive pattern switching means is provided for changing the phase of energy to the outer antenna units. This, as shown in Fig. 3, comprises a pair of coupled transmission line sections 60, 61 coupled to transmission loop 52 at points one-fourth of a wavelength from junction points 50 and 51, respectively. These coupled sections may be of the known type such as more fully described in the Andrew Alford Patent No. 2,259,510, entitled "Coupling arrangements for high frequency transmission systems," granted October 21, 1941. When these units are tuned to resonance they serve substantially as a cut-off filter, but, when detuned slightly from resonance they have substantially no effect on the transmission of energy through the lines. The midpoint of loop 52 to the end of sections 60 and 61 is made equal to a one-quarter of a wavelength at the operating frequency. A condenser 62 driven by motor 63 is provided to alternately tune sections 60 and 61 into resonance at the operating frequency. Thus, when section 61 is tuned to resonance the side of loop 52 toward junction point 51 will offer high impedance since it will operate as a short-circuited quarter wavelength transmission line building-out section. Accordingly, at this time, the energy will be fed to antenna units 36—36A and 37—37A from junction point 50, and that supplied antenna units 37—37A will lag that supplied to antenna units 36—36A 90° in phase because of the intermediate transmission line sec-

tion. Thus, the energy at 36—36A will lead that of the central units by 45° and that supplied at 37—37A will lag 45°. However, when coupled section 60 is tuned to resonance the feed will be made from point 51 and units 36—36A will lag in phase 90° behind units 37—37A reversing the phase conditions. Thus, as condenser 62 is rotated in phase relation of the antenna units will be alternately changed.

As a result a pair of patterns overlapping in space such as shown in Fig. 4 will be produced. These patterns 70 and 71 may be used for the transmission of the obstacle detecting pulses to a reflecting object. Similarly, the reflected pulses will be received on the antenna units of Fig. 3 and applied to the receiver. Because of the double pattern arrangement the antenna unit 35 may be adjusted in azimuth to align the array with the reflected object by observation of the equality of the received patterns. Thus, the azimuth of the reflecting object may be determined at the same time the distance determination is made at receiver 32. The field patterns shown in Fig. 4 may be determined by the following equation:

$$F(\theta) = [\sin (60 \cos \theta)] \left[\frac{\cos^2 (90 \sin \theta)}{\cos \theta}\right] [\cos (540 \sin \theta + 45) + 3 \cos (180 \sin \theta)] \quad (2)$$

in which θ has the same significance as in Equation 1.

Matching units may be provided in the system of Fig. 1 as shown at 64, 65, 66, 67 and 68.

While the system of Fig. 3 is shown applied to an obstacle detecting arrangement, it is clear that the antenna units may be used with a similar switching arrangement for defining a beacon course. Furthermore, the arrangement may be used, as a direction finder, if desired. The system is particularly useful in the transmitters since it necessitates the switching of only a small percentage of the total power. Thus, in the arrangement shown the current in the outer units is only one-third that in the inner units. The power is proportional to the square of the current so it can be readily seen that a shifting of the directive pattern is accomplished by switching only about one-tenth of the total power supplied to the antenna arrangement.

A greater directive shift may be accomplished by making the phase of the outer units normally greater than 45°. For example, if this phase shift is made equal to 60° a wider angle may be covered by the shifted lobes. In this case the outer units should be made to lag one another alternately by twice the normal phase shift or 120° to preserve the symmetry of the field pattern.

In Fig. 5 is shown an alternative connection which may be provided in place of the coupled section switching systems of Fig. 3. This arrangement is substantially similar to that shown in Fig. 3 except that loop 52 is made open-circuited at one end and a switching arrangement 75 is provided to alternately couple the transmitter or receiver to opposite sides of loop 52 for supplying energy at junction points 50 and 51, respectively. Switch 75 may be operated by a relay 76 controlled by keying means 77. Thus, instead of merely blocking the energy by means of the coupled section, actually opened circuits are alternately provided by switch 75. The relative phase shift in energy is produced in the transmission line section included by the junction points 50 and 51. Line 52 is preferably $\lambda/2$ or multiple of $\lambda/2$.

In Fig. 6 is illustrated a vertical dipole array similar to that shown in Fig. 3. However, in this figure means is provided for scanning the beam not only in the horizontal but also in the vertical direction. The observation units comprise a transmitter 31, a receiver 32 and a blocking circuit 33, as well as a rotary coupling device 45 similar to that shown in Fig. 3. In addition, a cathode ray indicator 80 is illustrated coupled to the output of receiver 32. Energy is transferred from transmitter 31 or to receiver 32 over line 44 from the central antenna units 81. Similarly, energy is transferred over power dividing network 55, phase shifter 54 and transmission line 53 and the synchronous director unit 85 to the horizontal array outer antenna units 82—83 and the vertical array outer units 86—87. The individual switching units for outer units 82—83 and 86—87 are each substantially similar in structure to the switching arrangement of Fig. 3. However, two such units are provided at 88 and 89 to alternately supply energy to antenna units 82—83, 86 and 87. The switching condensers for this system are preferably designed so that each blocking circuit is effective for three-quarters of its period to block transmission, permitting transmission only during the other one-quarter period.

The vertical radiation pattern for the system shown in Fig. 6 is illustrated by the curves 90 and 91 of Fig. 7. The equation for this is substantially the same in form as Equation 2 except that the vertical angle must be substituted for the horizontal angle of those equations.

It is clear that with the directive arrangement of Fig. 6 not only the azimuth angle but also the vertical angle of any reflecting object may be readily obtained. Furthermore, the system shown in Fig. 6 may be used as a simple direction finder or as a combined beacon as desired.

While I have described certain specific embodiments of my invention, it should be distinctly understood that these specific embodiments are given merely by way of example. It is clear that many changes may be made in the particular construction without departing from the spirit of my invention. For example, any type of switching system may be provided in place of the specific type illustrated. Furthermore, the principles for simplified feeding of an array may be extended simpler and more complex arrays than those illustrated. Likewise, any number of antenna units greater than one may be used as desired.

What is claimed is:

1. An antenna array comprising at least four antenna groups each of said groups containing at least two antenna elements arranged in a line, a translator apparatus, and means for transferring current between said apparatus and said groups said means serving to distribute the current with respect to said groups to diminish from the center group outwardly in accordance with the coefficients of the binomial expansion series.

2. An antenna array according to claim 1 further comprising means for adjusting the phase of current transferred between said translating apparatus and the outer of said groups so that the current in a group on one end of said array leads in phase and the current in a group on the other end lags in phase with respect to a central one of said groups.

3. An antenna array according to claim 1 further comprising means for adjusting the phase

of current transferred between said translating apparatus and the outer of said groups so that the current in a group on one end of said array leads in phase and the current in a group on the other end lags in phase with respect to a central one of said groups, and means for alternately reversing the phase relation of the currents in said outer pairs.

4. An antenna array comprising at least four groups of antenna units, said groups of units being arranged in a linear array, each group being spaced from the adjacent groups a distance equal between 270 and 480 electrical degrees at the operating frequency, a high frequency translating apparatus, means interconnecting said translating apparatus and the central groups of said antenna units to transfer a given amount of energy therebetween and means interconnecting said translating apparatus and said outer groups to transfer therebetween a different amount of energy than said given amount.

5. An antenna array according to claim 4 wherein means is provided to proportion said amounts of energy supplied to said groups to diminish from the center outwardly in accordance with the coefficients of a binomial expansion.

6. A radio system for scanning a radiation pattern over a predetermined angle comprising a plurality of antenna units arranged in a linear array, a high frequency translating device, means for interconnecting said translating device and centrally disposed antenna units of said array to transfer therebetween a predetermined amount of energy, means interconnecting said translating device and outer antenna units on opposite ends of said array to transfer therebetween an amount of energy less than said predetermined amount, and means in said last named interconnecting means for causing energy at said outer antenna units to lead and lag respectively in phase the energy at said centrally disposed antenna units.

7. A radio system for scanning a radiation pattern over a predetermined angle comprising a plurality of antenna units arranged in a linear array, a high frequency translating device, means for interconnecting said translating device and centrally disposed antenna units of said array to transfer therebetween a predetermined amount of energy, means interconnecting said translating device and outer antenna units on opposite ends of said array to transfer therebetween an amount of energy less than said predetermined amount, means in said last named interconnecting means for causing energy at said outer antenna units to lead and lag respectively in phase the energy at said centrally disposed antenna units, and means for periodically reversing the phase relation in said outer units to shift the radiation pattern of said array through a predetermined angle.

8. A radio system according to claim 7 wherein said plurality of antenna units comprises four pairs of antennae the two centrally disposed pairs constituting said centrally disposed antenna units, and wherein the currents representing said amounts of energy are proportioned between said centrally disposed pairs and the outer pairs in accordance with the cofficients of a binomial expansion.

9. A radio system for scanning a radiation pattern over a predetermined angle comprising a plurality of antenna units arranged in a line, other antenna units at opposite ends of said line, a translator, means for interconnecting said translator and said centrally disposed antenna units to effect a transfer of energy at a predetermined current level therebetween, coupling means for coupling said other antenna units to said translator to effect a transfer of energy at a lower current level between said translator and said other units, means in said coupling means for effecting a phase displacement of energy in said other antenna units with respect to said plurality of units, and means for alternately changing the direction of said phase displacement.

10. A radio system according to claim 9 wherein said coupling means includes a first line interconnecting said other antenna units, a symmetrically disposed line coupled at spaced points to said first line to form therewith a closed loop, and a feed line connected to the midpoint of said symmetrically disposed line, and wherein said last named means comprises tunable blocking means coupled at equally spaced points to said symmetrically disposed line, and means for alternately tuning said blocking means to resonance, to alternately block opposite sides of said closed loop.

11. A radio system for scanning a radiation pattern over predetermined angles comprising a plurality of antenna units arranged in two angularly disposed linear arrays, a high frequency translating device, means for interconnecting said translating device and centrally disposed antenna units of said arrays to transfer therebetween a predetermined amount of energy, means interconnecting said translating device and outer antenna units on opposite ends of each said array to transfer therebetween an amount of energy less than said predetermined amount, means in said last named interconnecting means for causing energy at said outer antenna units to lead and lag respectively in phase the energy at said centrally disposed antenna units, and means for periodically reversing the phase relation in said outer units of each to shift the radiation pattern of said array through a predetermined angle.

12. A radio system according to claim 11 wherein each of said plurality of antenna units comprises four pairs of antennae the two centrally disposed pairs constituting said centrally disposed antenna units, and wherein the currents representing said amounts of energy are proportioned between said centrally disposed pairs and the outer pairs in accordance with the coefficients of a binomial expansion.

13. A radio system for scanning a radiation pattern over predetermined angles in two coordinate directions comprising a plurality of antenna units arranged in line in said two coordinate directions, other antenna units at opposite ends of each said line, a translator, means for interconnecting said translator and said centrally disposed antenna units to effect a transfer of energy at a predetermined current level therebetween, coupling means for coupling each of said other antenna units to said translator to effect a transfer of energy at a lower current level between said translator and said other units, means in said coupling means for effecting a phase displacement of energy in said other antenna units in each coordinate direction with respect to said plurality of units, and means for alternately changing the direction of said phase displacement in said other units in each coordinate direction.

14. A radio system according to claim 13 wherein said coupling means includes a first line inter-

connecting said other antenna units in one coordinate direction, a second line interconnecting said other antenna units in the other coordinate direction, symmetrically disposed lines coupled at spaced points to said first and second lines, respectively, to form therewith closed loops, and a feed line connected to the midpoints of said symmetrically disposed lines to supply energy in phase thereto, and wherein said last named means comprises tunable blocking means coupled at equally spaced points, respectively, to said symmetrically disposed lines, and means for alternately tuning each of said blocking means to resonance, to alternately block opposite sides of said closed loops.

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