June 9, 1964 E. GOLDBOHM 3,136,993

ANTENNA ARRAY AND SIMULTANEOUS LOBING TRACKING SYSTEM

Filed Dec. 10, 1959 3 Sheets-Sheet 1

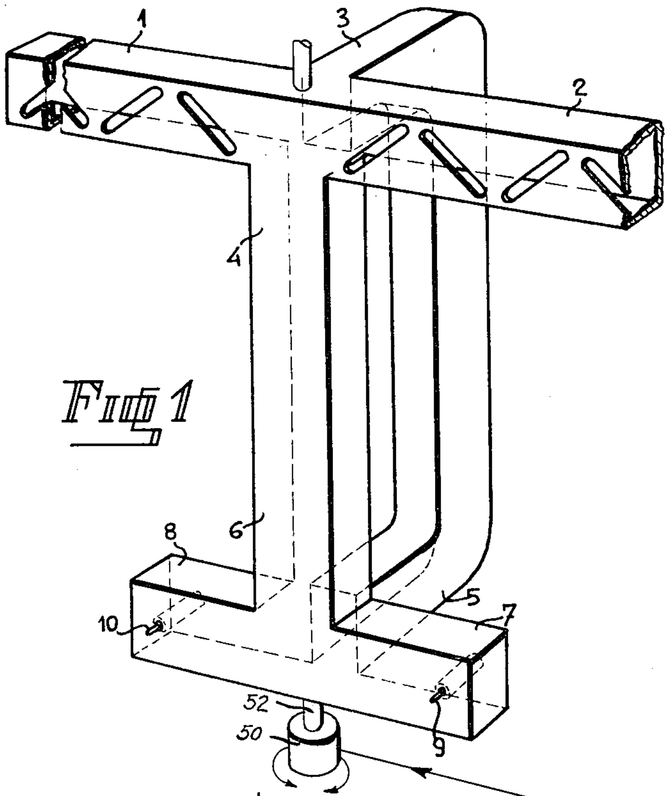


Fig 1

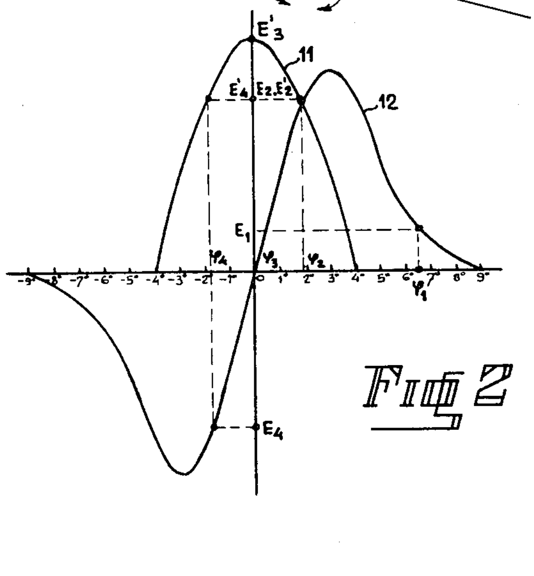


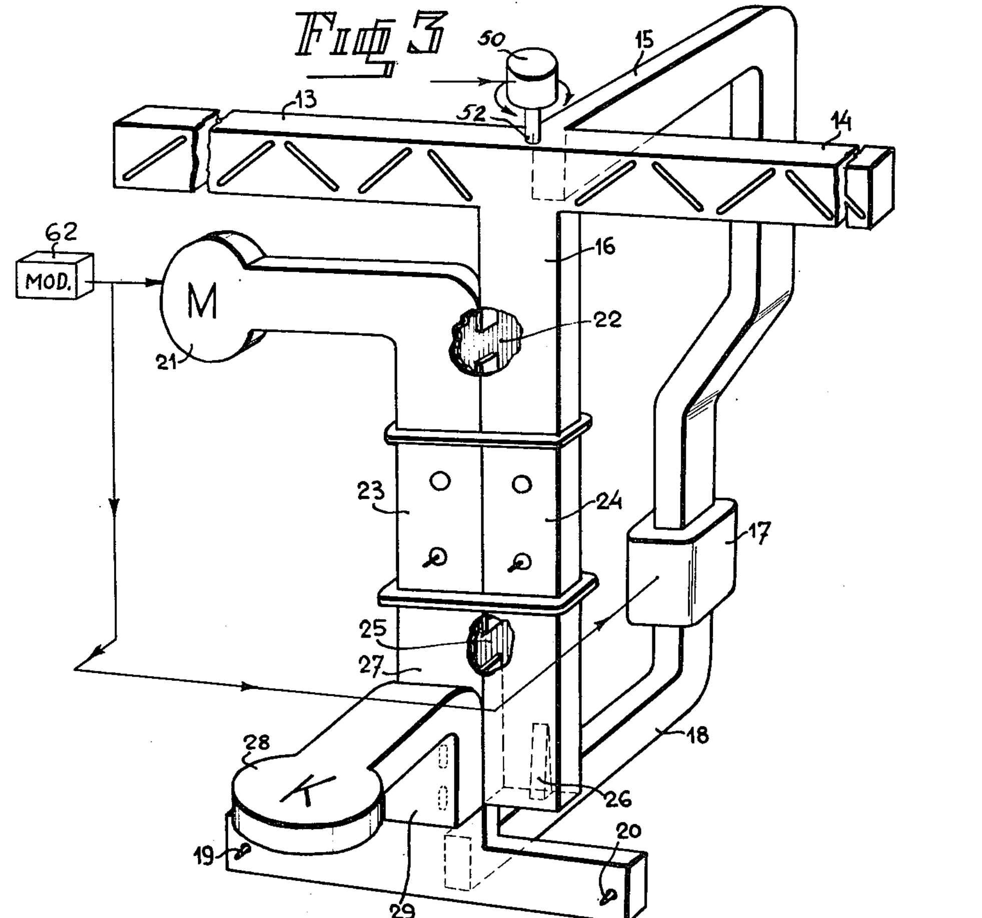
Fig 2

June 9, 1964 E. GOLDBOHM 3,136,993

ANTENNA ARRAY AND SIMULTANEOUS LOBING TRACKING SYSTEM

Filed Dec. 10, 1959 3 Sheets-Sheet 2

Fig. 3



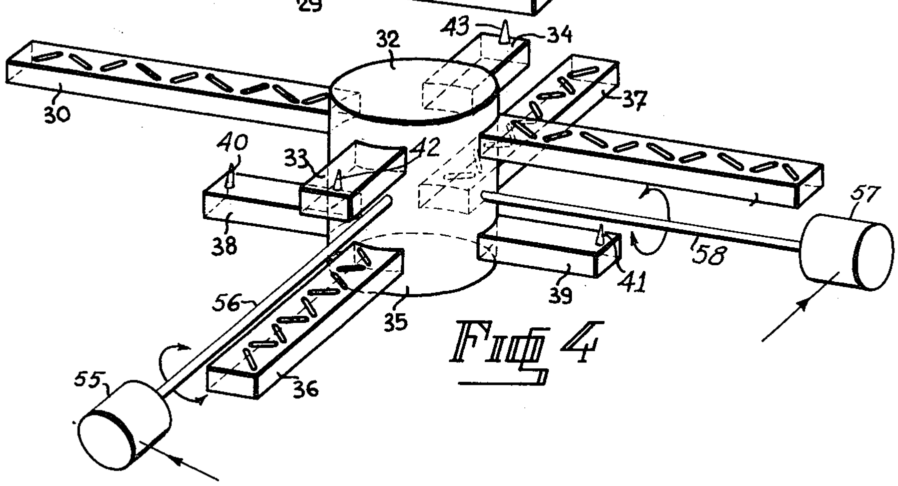


Fig. 4

June 9, 1964 E. GOLDBOHM 3,136,993

ANTENNA ARRAY AND SIMULTANEOUS LOBING TRACKING SYSTEM

Filed Dec. 10, 1959 3 Sheets-Sheet 3

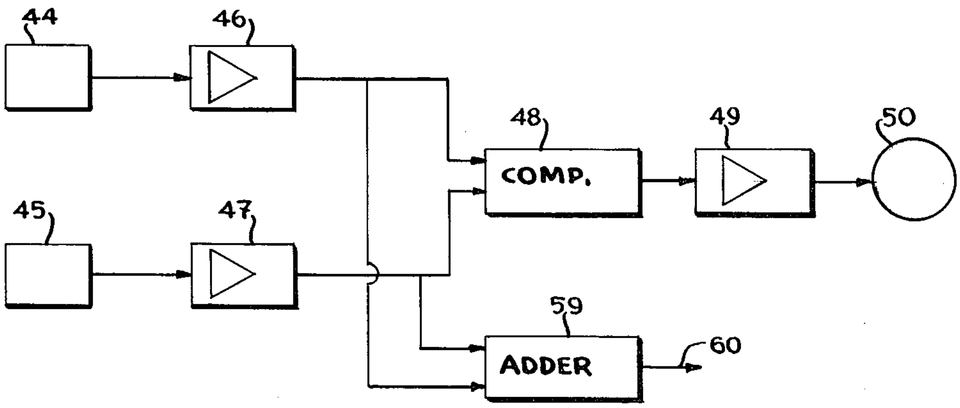


Fig 5

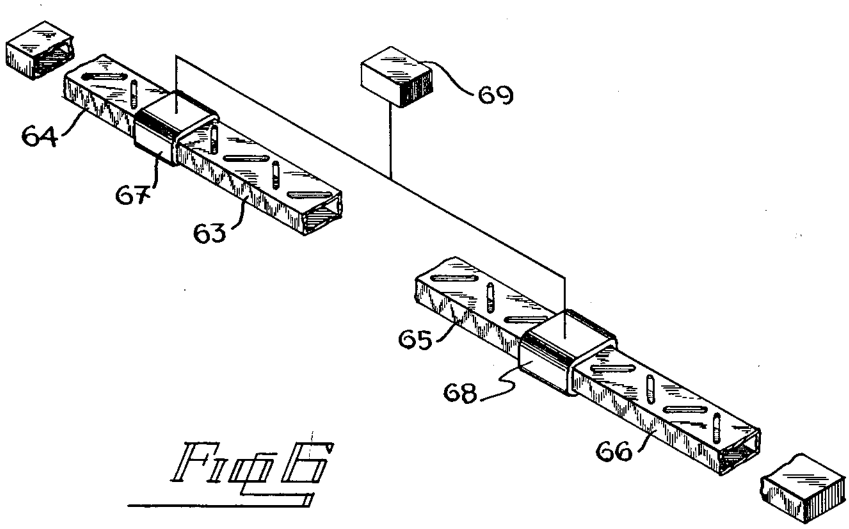


Fig 6

United States Patent Office

3,136,993
Patented June 9, 1964

3,136,993

ANTENNA ARRAY AND SIMULTANEOUS LOBING TRACKING SYSTEM

Erich Goldbohm, 57 Koningin Astrid Blvd., Noordwijk, Netherlands

Filed Dec. 10, 1959, Ser. No. 858,621
Claims priority, application Netherlands Dec. 11, 1958
25 Claims. (Cl. 343—7.4)

This invention relates to a directive antenna array.

It is well-known to those versed in the antenna art that by means of broadside arrays many radiation patterns can be generated dependent on the particular geometric and electric configuration of the individual radiating elements.

Below for reasons of clarity of expression the terms "to radiate" and "to feed" will be used for transmitting antennas as well as for receiving antennas. This is admissible because of the reciprocity law, without in any way deducting from the validity of the conclusions drawn.

Especially with centimetre waves so-called slotted wave guides offer many advantages, such slotted wave guides consisting of a wave guide with slots arranged in the walls thereof.

The phase and the amplitude of the wave radiated by these slots are dependent on the location and direction of the slots. With centerfed slotted wave guides two generic cases can be distinguished, i.e. the arrangement in which the radiating elements at both sides of the center are in phase and the arrangement in which the radiating elements at both sides of the center are of opposite phase. In the former case a so-called even radiation pattern is generated, which if the array is designed correctly, consists of a single main lobe without minor lobes, whilst in the latter case a so-called odd radiation pattern is generated, giving rise to two symmetrical main lobes, between which a sharp null in the direction at right angles to the array occurs. In the latter case the two main lobes are exactly 180 degrees out of phase with respect to each other. The sharp null makes an antenna which generates an odd radiation pattern very suitable for direction finding purposes. If a source of radiation is to be tracked by means of an automatic servo system the difficulty arises that if the antenna is exactly trained at the source no signal at all is received, whereby the information which is contained in the signal radiated by said source is not available.

It is an object of the invention to provide an antenna array which makes it possible to accurately track a source of radiation and which at the same time provides an output signal due to the radiation received.

In order to obtain this and other desirable results which will be more fully discussed below it is a feature of the antenna array according to the invention when used for reception purposes that the array is designed so as to stimultaneously give rise to an odd pattern (for tracking purposes) as well as an even pattern (as a source of a reference signal and an information-carrying signal). For transmitting purposes the antenna array is so fed, that only an even pattern is generated, because the even pattern concentrates the radiated energy more narrowly.

For that purpose both halves of the slotted wave guide are connected to the equivalent branches of a first magic tee, the E- and H-branch respectively of which are connected to the E- and H-branch respectively of a second magic tee, in the equivalent branches of which the inputs of two identical amplifiers or detectors are arranged, the lengths of the wave guides interconnecting the E- and H-branches respectively being so chosen that the electrical distances from points in the E- and H-branches respectively of the first magic tee where an incoming planar wave front generates signals of equal phase to any of the inputs in the equivalent branches of the second magic tee differ by a straight multiple of $\lambda/2$, zero included.

Based on the same principle it also is possible to take bearings in spherical co-ordinates. To this end an antenna array which is rotatable about two axes at right angles to each other comprises two slotted wave guides having a fixed position with respect to each other, these slotted wave guides being so suspended that the first and second slotted wave guide respectively are always at right angles to the first and second rotation axis respectively, both halves of the first and second slotted wave guide respectively being connected to opposite branches of a first and second turnstile junction respectively, the central (round) branches of said turnstile junctions being connected to each other, a second and first pair of identical amplifiers or detectors respectively being connected to the remaining opposite branches of said first and second turnstile junction respectively.

These and other features and advantages of the antenna array according to the invention will be more apparent after a perusal of the following specification, taken in connection with the drawings, wherein

FIGURE 1 is an isometric view of an antenna according to the invention,

FIGURE 2 is a diagram of the radiation patterns appertaining to the antenna shown in FIGURE 1,

FIGURE 3 is an isometric view of a simplified embodiment of a radar set having an antenna according to FIGURE 1,

FIGURE 4 is an isometric view of an antenna for taking bearings in spherical co-ordinates.

FIGURE 5 is a block diagram of a servo system and information deriving means for use with the embodiments of FIGURES 1, 3 or 4, in which a separate amplifier is provided in each channel.

FIGURE 6 is a fragmentary diagram illustrating microwave switches included in the arms of the antenna to limit the electrical length of such arms.

Referring to FIGURE 1 the halves of a slotted wave guide are shown at **1** and **2**. These halves are connected to a magic tee having an E-branch **3** and a H-branch **4**. These branches are connected to the corresponding branches **5** and **6** respectively of a second magic tee, the equivalent arms **7** and **8** respectively of which contain probes or detector crystals **9** and **10** respectively.

The operation of a device as shown in FIGURE 1 is discussed with reference to the diagram of FIGURE 2, which shows both radiation patterns which can be obtained by means of the slotted radiator **1**, **2** of FIGURE 1. The field strength has been plotted along the vertical axis as a function of the angle included between the direction of radiation and a line which is at right angles to the array, said angle being plotted along the horizontal axis. If both halves of the slotted wave guide, which are assumed to be symmetric, are fed in phase, a correct design results in a single main lobe **11** without any side lobes.

This can be attained by means of resonant arrays in which standing waves are generated in the slotted wave guide as well as by means of non-resonant arrays, in which travelling waves are generated in the slotted wave guide.

If, however, both halves of the slotted wave guide are fed 180 degrees out of phase a double main lobe **12** results, having a sharp null in the direction at right angles to the slotted wave guide. At both sides of said null waves of opposite phase are radiated, which has been symbolized by drawing the left hand half of the odd pattern below the horizontal axis.

The former conditon will ensue if energy is fed to the slotted wave guide through the H-branch **4** and the latter condition will ensue if energy is fed to the slotted wave guide through the E-branch #3. If the slotted wave guide is correctly matched to the branches of the magic tee it is further to be observed that theoreticaly the H-branch is perfectly isolated from the E-branch. Several practical difficulties make it impossible to attain this ideal, but an isolation of 30 decibels is easily attainable and reproducible.

The possibility of locating and automatically tracking a radiating target by means of an antenna as shown in FIGURE 1 is discussed below with reference to a few examples. It is assumed that both probes or detectors **9** and **10** have substantially equal sensitivities.

If the target is located in a direction φ_1 no energy will be induced in the H-branch **4**, since the target is outside the even beam. In the E-branch **3** a voltage E_1 is generated, whereby the voltages at the detectors **9** and **10** respectively amount to

$$+\frac{E_1.\sqrt{2}}{2} \text{ and } -\frac{E_1.\sqrt{2}}{2}$$

respectively. After detection the sign of these voltages is no longer significant, so that the output signals of the detectors are equal. These output signals are supplied in a subtracting fashion to the input of a servo system which rotates the antenna around an axis which is at right angles to the slotted wave guide. In the above example the resulting input signal for the servo system is zero, so that the servo system is not energized.

However, if the target is located within the even lobe, as indicated at φ_2, energy will be induced in the H-branch as well as in the E-branch. The odd pattern generates a voltage E_2 in the E-branch and the even pattern generates a voltage E_2' in the H-branch. At the direction shown in the drawing these voltages are of equal magnitude, but this is not essential. Equal magnitudes have been chosen merely for ease of computation. The energy in the E-branch is again divided between the detectors **9** and **10**, giving rise to a voltage

$$+\frac{E_2.\sqrt{2}}{2}$$

at the detector **9** and a voltage

$$-\frac{E_2.\sqrt{2}}{2}$$

at the detector **10**.

The energy in the H-branch, which is caused by the even radiation pattern and which results in a voltage E_2' is also divided between the detectors **9** and **10**, however, without giving rise to a phase difference between the voltages generated at these detectors. Therefore the energy in the H-branch gives rise to voltage

$$+\frac{E_2'.\sqrt{2}}{2}$$

at the detector **9** and an identical voltage

$$+\frac{E_2'.\sqrt{2}}{2}$$

at the detector **10**. Therefore the total voltage at the detector **9** will be

$$\frac{\sqrt{2}}{2}(E_2+E_2')$$

whereas the total voltage at the detector **10** will amount to

$$\frac{\sqrt{2}}{2}(-E_2+E_2')$$

Since in the assumed conditions $E_2=E_2'$ the total voltage at the detector **9** is equal to $E_2.\sqrt{2}$, whereas the total voltage at the detector **10** is zero. Therefore the detector **9** will provide an output voltage, whereas the output voltage of the detector **10** will be zero, so that the resulting drive signal for the servo system will differ from zero.

If the servo system is connected in the appropriate sense it will rotate the antenna so as to decrease the angle φ_2.

This will proceed until the radiating target is situated immediately in front of the antenna, which in the drawing has been shown as φ_3. A target in the direction φ_3 is situated exactly in the null of the odd radiation pattern and the maximum of the even radiation pattern. Therefore no energy is fed into the E-branch, whereas a voltage E_3' is set up in the H-branch.

The energy in the H-branch is divided between the detectors **9** and **10**, whereby a voltage

$$\frac{E_3'.\sqrt{2}}{2}$$

is set up at each detector. The output voltages of the detectors will therefore be equal, so that the resulting drive signal for the servo system is zero and the servo system does not rotate the antenna any more. From the above it appears that if a target is situated in a direction which is not at right angles to the antenna, but which lies within the even pattern, the target is caught, whereafter the antenna is automatically rotated so as to keep the target in the direction at right angles to the antenna. That this also applies for targets which are situated at the other side of the null appears from the situation indicated by φ_4. In this case also the received energy is divided between the H- and E-branches. φ_4 has again been chosen such that the voltages set up in the H- and E-branches have equal magnitudes. However, these voltages will include a phase angle of 180 degrees, so

$$E_4=-E_4'$$

The energy which results from the odd radiation pattern is equally divided between the detectors **9** and **10** respectively, voltages

$$+\frac{E_4.\sqrt{2}}{2} \text{ and } -\frac{E_4.\sqrt{2}}{2}$$

being set up at these detectors respectively. The energy in the H-branch, which results from the even radiation pattern, is also equally divided between the detectors **9** and **10** respectively, giving rise to a voltage

$$\frac{E_4'.\sqrt{2}}{2}$$

at each of these detectors.

Therefore the total voltage across the detector **9** will be

$$\frac{\sqrt{2}}{2}(E_4+E_4')$$

whereas the total voltage across the detector **10** will amount to

$$\frac{\sqrt{2}}{2}(-E_4+E_4')$$

Since $E_4=-E_4'$ the voltage across the detector **9** will be zero, whereas the voltage across the detector **10** will be $E_4'.\sqrt{2}$. Therefore the output voltage of the detector **9** will be zero, whereas the output voltage of the detector **10** will differ from zero. This again results in an input signal to the servo system which differs from zero, however, with opposite polarity as the signal generated at φ_2, so that in this case too the target is tracked automatically.

So far no particulars have been given about the type of the received signal. This can be either a continuous wave, a pulsed wave, a phase modulated wave, a frequency modulated wave or an amplitude modulated wave. Also the target to be tracked need not necessarily be an active target. It is possible to track passive targets, provided that these be illuminated by wave energy, the tracking being made possible by that part of the illuminating energy which is reflected by the target.

Therefore an antenna based on the principle described above makes it possible to track a moving or stationary target from a moving or stationary location. In contradistinction to known direction finder antennas, which reduce the received signal to zero in the bearing direction the possibility of communication is maintained by an antenna according to the invention, since in the exact direction of bearing the sensitivity of the even radiation pattern is maximum.

The same detectors 9 and 10 which serve for generating the input signal for the tracking servo system, which of course should be nearly zero while the antenna is tracking correctly, may also be employed for handling the information carrying signal, by adding their output voltages in a separate part of the receiver, thus deriving a signal which is a maximum if the antenna is tracking accurately. From this signal the information can be derived. If for instance the antenna is employed as a receiving antenna of a fire control radar (a transmitting antenna, which is mechanically coupled to the receiving antenna, radiating a beam of high frequency pulses in the direction at right angles to the receiving antenna) the range of the target can be derived from the time delay of the received pulses, the direction in which the target is located being indicated by the direction of the antenna.

By means of an antenna as described it is also possible to set up a point-to-point beam link between two vehicles or vessels, each of which may be moving, which especially in war time can be very important, since it is then often necessary to group vessels to convoys. The antenna described not only improves the safety as regards interception of the transmitted messages, since these can be intercepted only over a very restricted area, but moreover at each of the vehicles or vessels provided with antennas according to the invention continuous information about the location and course of the other vehicle or vessel is available.

If moreover the vehicles or vessels are provided with transponders it is also possible to obtain information about the distance between the vehicles or vessels, whereby both of the vessels are continuously informed about the position, course and speed of the other vessel. By suitably choosing the way of operation of these transponders, employing for instance a pulse code, an automatic identification is also possible. By means of a system as described it is therefore possible to automatically transmit or derive data on the identity, position, course and speed, whilst at the same time a beam communication between the vessels can be maintained. With pulsed signals it is possible to employ one single antenna for transmitting purposes as well as for receiving purposes. An embodiment of such a duplex-antenna is shown in FIGURE 3.

Referring to FIGURE 3, both halves of the slotted wave guide are connected to a magic tee having an E-branch 15 and an H-branch 16. The E-branch 15 via a microwave switch 17, the purpose of which will be explained below, is connected to the E-branch 18 of a second magic tee, the equivalent branches of which contain detectors or probes 19 and 20 respectively. The H-branch 16 of the first magic tee is connected to the H-branch of the second magic tee via means to be explained in detail below.

A magnetron 21 or another source of high frequency pulses is connected to one channel of a short slot hybrid 22, said channel being terminated by a TR cell 23 at its other extremity. As is well-known to those versed in the art a short slot hybrid comprises two parallel wave guide sections, the small walls of which are adjacent each other and are interrupted over a given distance. The second channel of the short slot hybrid 22 is connected to the H-branch 16 at one extremity and is connected to a TR cell 24 at its other extremity. If the magnetron 21 generates a pulse this pulse will reach the TR cell 23 and ignite it, whereby a total reflection occurs at the TR cell 23. The pulse will pass through the gap in the short slot hybrid 22 and reach the TR cell 24, which will be ignited too, whereby at that extremity as well a total reflection occurs. Therefore all energy leaves the short slot hybrid through the H-branch 16 and is equally divided between both halves 13 and 14 of the slotted wave guide. Since these are excited via the H-branch and consequently are in phase only the even pattern is generated. A small fraction of the energy (approximately —30 decibels) will pass into the E-branch 15, but this fraction is rendered harmless, as will be described below. During reception the energy received by the halves 13 and 14 of the slotted wave guide will be divided between the E-branch and the H-branch. The energy in the E-branch 15 is fed to the detectors 19 and 20 via the microwave switch 17. The energy in the H-branch 16 will divide in the short slot hybrid 22 and will reach the second short slot hybrid 25 via the TR cells 23 and 24, which do not ignite at this low energy level. The channel of the short slot hybrid 25 to which the TR cell 24 is connected is terminated at its other end by a matching impedance 26, which in the embodiment shown is a damping wedge. The channel of the short slot hybrid 25 which is connected to the TR cell 23 is connected to the H-branch of the second magic tee at its other extremity. It can be shown vectorially that all energy from the H-branch 16 ultimately reaches the H-branch 27 of the lower magic tee. Theoretically no received energy at all is absorbed by the magnetron 21 or the matching impedance 26. If the electric difference of path length between the E-branches and H-branches respectively, as measured from points in the E- and H-branches of the upper magic tee where an incoming planar wave front generates signals in phase is substantially equal to a whole multiple of $\lambda/2$, zero included, the same operation as in FIGURE 1 results.

So far the nature of the members 19 and 20 has not been described. In general these members can consist of probes, detectors or heterodyning crystals. Usually the input of a radar receiver consists of a heterodyning crystal. For that reasin the device as shown in FIGURE 3 comprises a klystron 28 (or a similar source of heterodyning oscillations), which is coupled to the H-branch of the lower magic tee through a directional coupler 29. The coupling direction of the directional coupler is so chosen that the energy from the klystron 28 is transmitted only in the direction of the heterodyning crystals 19, 20, in which consequently the received signals are subjected to heterodyning with the oscillation generated by the klystron.

Conventional intermediate frequency amplifiers can be connected to the outputs of the heterodyning crystals, but a reasonable phase stability of these amplifiers is desirable. It can be shown that all energy from the magnetron which might leak through the TR cells 23 and 24 is fed to the matching impedance 26, whereby the crystals 19, 20 are protected from overloading due to leakage energy. If energy which passes into the E-branch 15 due to insufficient isolation would be permitted to reach the E-branch 18 this energy could possibly damage the crystals 19 and 20 or at least overload them. This can be prevented by connecting an externally controlled microwave switch between the E-branches 15 and 18, such as the microwave switch 17. The microwave switch 17 can be controlled by a modulator circuit 62 which also controls the magnetron 21 in such a way that the microwave switch 17 is closed at least as long as the magnetron 21 is generating high frequency energy.

In the modulator circuit of the magnetron 21 from the triggering pulse a pulse can be derived which closes the microwave switch 17 during the period in which leakage energy could be transmitted through the E-branch 18 to the crystals 19 and 20.

As compared with those tracking radars employing a spinning dipole a radar apparatus according to FIGURE 3 has numerous advantages. First of all the available energy is put to greater use. If a spinning dipole antenna is correctly trained the tracked target is located on the axis of the cone generated by the radiated beam, so that the target is never situated in the direction of maximum transmitted energy. This is due to the fact that no pattern which could be compared to the even pattern according to the invention is employed.

Further the system according to the invention provides a continuous flow of information, in contradistinction to systems relying on spinning dipoles or other types of beam switching. Whereas beam switching systems rely on a comparison of two discrete intervals during which the radiated beam is pointed in two extreme directions, the radar apparatus according to FIGURE 3 enables a continuous comparison during the entire reception period. Therefore random fluctuations of the strength of the received signal, such as those caused by aspect variations of the tracked target, propellor fading and the like, interfere with the attainable tracking accuracy to a much smaller extent.

In systems employing beam switching it is usual to employ an amplifier which is switched over in the rhythm of the beam switching action. The system according to the invention enables a far higher switching rate to be employed with a single amplifier than would be possible with beam switching apparatus, the switching rate of the amplifier being limited to the beam switching rate in the latter case. In the system according to the invention switching over the amplifier at a rate which corresponds to the pulse repetition frequency is perfectly feasible, which implies an increase in switching rate by a factor of the order of 50. The more frequent sampling afforded thereby makes for a lower sensitivity to random fluctuations, which greatly enhances the tracking accuracy. It is also possible to employ two identical amplifier channels, in which case switching over of the amplifiers is superfluous. In the latter case random signal fluctuations have no influence whatsoever on the tracking accuracy.

Besides the slope of the radiation pattern of the odd beam near the null is substantially twice as steep as the slope of the characteristic of a single beam, as employed in beam switching apparatus, which also increases the tracking accuracy.

The acquisition sector of the antenna is limited to the width of the even pattern. If in special cases this acquisition sector is insufficient the even pattern can be broadened while searching for a target by providing microwave switches in each of the halves of the slotted wave guide. By switching off the outer parts of the slotted wave guide by means of these switches the beam pattern is broadened artificially, whereby the acquisition sector is broadened too. As soon as a target has been perceived the outer parts of the slotted wave guide are again connected, thus increasing the tracking accuracy.

The embodiments described above enable to take bearings in one co-ordinate direction only. For instance, if a horizontal slotted wave guide is employed azimuth bearings can be taken.

For tracking airborne targets bearings in spherical co-ordinates should be taken. This is possible if an antenna as shown in FIGURE 4 is employed. The antenna according to FIGURE 4 comprises two halves of a slotted wave guide **30**, **31** which are connected to opposite branches of a turnstile junction **32**.

The two remaining opposite branches **33** and **34** of this turnstile junction contain probes or detectors **42**, **43**. The central (round) branch of the turnstile junction **32** is connected to the central branch of a second turnstile junction **35**. The branches **36** and **37** of the turnstile junction **35** which are parallel to the detector branches **33** and **34** are connected to halves of another slotted wave guide, whereas the remaining branches **38** and **39** of the turnstile junction contain detectors **40**, **41**.

For ease of explanation it is assumed that the slotted wave guide **30**, **31** is arranged horizontally, whereas the slotted wave guide **36**, **37** is arranged in a vertical plane.

Signals which reach both branches **30** and **31** with equal phase and magnitude are fed to the branches **33** and **34** by the turnstile junction **32**, in which branches signals of equal phase and amplitude are set up. These signals can be considered as signals resulting from the even pattern of the slotted wave guide **30**, **31**. Similarly, the even pattern of the slotted wave guide **36**, **37** generates signals of equal phase and amplitude in the branches **38** and **39**. Signals due to the odd pattern of the slotted wave guide **30**, **31** are transmitted to the turnstile junction **35** and are there divided between the detector branches **38** and **39**, setting up signals of equal amplitude but opposite phase.

Consequently the branches **38** and **39** receive signals (of opposite phase) due to the odd pattern of the horizontal slotted wave guide **30**, **31** and signals (in phase) due to the even pattern of the vertical slotted wave guide **36**, **37**. Therefore just as in FIGURES 1 and 3 a servo system can be connected to the outputs of the detector branches **38** and **39**. If in the detector branches **38** and **39** signals due to the even pattern of the slotted wave guide **36**, **37** as well as signals due to the odd pattern of the slotted wave guide **30**, **31** are set up, the servo system will rotate the antenna in a horizontal plane until the signals due to the odd pattern of the horizontal slotted wave guide **30**, **31** are reduced to zero.

Thereby an azimuth bearing is taken. A special advantage is that the acquisition sector is broader than with the arrangement of FIGURES 1 and 3, because the even pattern, which is essential to the functioning of the servo system rotating the antenna in the horizontal plane is supplied by the vertical slotted wave guide **36**, **37**, which has a small directivity and consequently a large beam width in the horizontal plane.

Since signals due to the odd pattern of the slotted wave guide **36**, **37** generate signals (of opposite phase) in the branches **33**, **34** a servo system which rotates the antenna in a vertical plane can be connected to these branches. The operation of this servo system is analogous to the operation of the servo system already described and therefore need not be discussed in detail.

For illustrative purposes only a receiver for use with the embodiments of FIGURES 1, 3 or 4 is shown in FIGURE 5.

In FIGURE 5 the signal pick-off or detector means are shown at **44** and **45** respectively. These components correspond to the components **9** and **10** in FIGURE 1, the components **19** and **20** in FIGURE 3 and either **40** and **41** or **42** and **43** in FIGURE 4. As explained before these pick-off means can either be heterodyning crystals or any other convenient means, such as pick-up loops.

The signals generated by the pick-off means **44** and **45** respectively are supplied to separate amplifiers **46** and **47** respectively, which can be of any convenient construction and which may incorporate heterodyning stages, detectors and any other known devices. The amplification factors of the amplifiers **46** and **47** respectively should differ as little as is possible, for any gain differences occurring in the channels will be indistinguishable from signal differences at the pick-off means **44** and **45**.

The outputs of the amplifiers **46** and **47** are passed to a comparator circuit **48** which gives no output if the signals are equal, that is if the source of radiation is located right in front of the antenna array, but will give an output if the signals are unequal, that is if the radiation source is located in a different direction. In that case the polarity or the phase of the comparator output will depend on the direction of deviation of the radiation source. The output of the comparator is passed to a servo amplifier **49**, which delivers its output to a servomotor **50**, which rotates the antenna array until the radiation source is right in front of the array. As soon as that position is reached the comparator **48** no longer gives an output and the servo system is arrested. The servomotor **50**, as shown in FIGURES 1 and 3, rotates the antenna around the axis **52**.

If the pick-off means **44** and **45** correspond to the components **40** and **41** respectively in FIGURE 4, the servomotor **50** of FIGURE 5 corresponds to the servomotor **55** in FIGURE 4, which rotates the antenna array around the axis **56**. If, however, the pick-off means **44** and **45** correspond to the components **42** and **43** in FIGURE 4, the servomotor **50** of FIGURE 5 corresponds to the servomotor **57** of FIGURE 4, which rotates the antenna array around the axis **58**. It will thus be appreciated that an antenna array as shown in FIGURE 4 which can be rotated around two axes, requires two separate servo systems, each constructed as shown in FIGURE 5.

Since it is not easy to maintain the gains of the amplifiers **46** and **47** of FIGURE 5 exactly equal it may be preferable to employ instead a single amplifier that is rapidly switched from one to the other pick-off means.

If tracking the target is not sufficient, but the information contained in the radiataion from the target should also be made available, this can be effected as indicated in FIGURE 5, by adding the output signals of the amplifiers **46** and **47** respectively in an adding circuit **59**, which delivers the combined signal in a lead **60**. If two servo systems are employed, as in the embodiment of FIGURE 4, the adding circuit **59** should add the output signals of both pairs of amplifiers **46** and **47** of the servo systems.

The way in which the acquisition sector can be broadened while searching for a target is shown in FIGURE 6. In FIGURE 6 the slotted waveguides **63**, **64** and **65**, **66** correspond with the waveguide halves **1** and **2** of FIGURE 1 or the waveguide halves **13** and **14** of FIGURE 3. Microwave switches **67** and **68** respectively are connected between the waveguide sections **63**, **64** and **65**, **66** respectively. The switches **67** and **68** are simultaneously controlled by a switch unit **69**. As long as these microwave switches are in a condition in which they transmit wave energy the entire linear array, consisting of the waveguide sections **63**, **64**, **65** and **66** is operative and the directivity is maximum. If, however, the switch unit **69** renders the switches **67** and **68** in a condition in which they do not transmit wave energy, the outer waveguide sections **64** and **66** are isolated and the linear array, which then consists of only the sections **63** and **65**, exhibits a far smaller directivity. This may be a great asset in searching for a target, since the beam coverage is larger and a target is less easily overlooked. With the embodiment of FIGURE 4 there is no need for artificially broadening the beam while searching for a target, for the even pattern, the width of which is decisive for the possibility of picking up a target, is in this embodiment supplied by a slotted waveguide which has but little directivity in the plane in which the slotted waveguide supplying the odd pattern has its greatest directivity.

Although in the above description only slotted wave guides have been mentioned other types of linear arrays are suitable as well. Also modifications of the described hybrid types are feasible.

It is intended that all matter contained in the above description or shown in the accompanying drawings shall be interpreted as illustrative and not in a limiting sense.

What I claim is:

1. An antenna array, comprising a centerfed linear array, the halves of which are connected to the equivalent branches of a first magic tee, the E- and H-branch respectively of which are connected to the E- and H-branch respectively of a second magic tee, in the equivalent branches of which the inputs of two identical signal handling means are arranged, the lengths of the wave guides interconnecting the E- and H-branches respectively of the magic tees being so chosen that the electrical distances are such that signals from an external wave field, traveling along the waveguides interconnecting the E- and H-branches respectively on arrival at the signal handling means have a phase difference of a whole multiple of $\lambda/2$, zero included.

2. An antenna array, comprising a centerfed linear array, rotatable about an axis at right angles to the direction along which the linear array extends and the main radiating plane of said array, the halves of which are connected to the equivalent branches of a first magic tee, the E- and H-branch respectively of which are connected to the E- and H-branch respectively of a second magic tee, in the equivalent branches of which the inputs of two identical signal handling means are arranged, the lengths of the wave guides interconnecting the E- and H-branches respectively of the magic tee being so chosen that the electrical distances are such that signals from an external wave field, traveling along the waveguides interconnecting the E- and H-branches respectively, on arrival at the signal handling means have a phase difference of a whole multiple of $\lambda/2$, zero included, a comparator circuit to which the outputs of said signal handling means are connected, and a servo system that is connected to the comparator circuit and that is adapted for rotating the antenna around said axis.

3. An antenna array, comprising a centerfed linear array, the halves of which are connected to the equivalent branches of a first magic tee, the E- and H-branch respectively of which are connected to the E- and H-branch respectively of a second magic tee, in the equivalent branches of which the inputs of two identical signal handling means are arranged, the lengths of the wave guides interconnecting the E- and H-branches respectively of the magic tees being so chosen that the electrical distances are such that signals from an external wave field, traveling along the waveguides interconnecting the E- and H-branches respectively, on arrival at the signal handling means have a phase difference of a whole multiple of $\lambda/2$, zero included, the wave guide connected to the H-branch of the first magic tee comprising in the order cited: a first channel of a first short slot hybrid, a first TR cell, a first channel of a second short slot hybrid and a matched terminating impedance, the wave guide connected to the H-branch of the second magic tee comprising in the order cited: a second channel of said second short slot hybrid, a second TR cell, a second channel of said first short slot hybrid and a source of high frequency pulses.

4. An antenna array, comprising a centerfed linear array, rotatable about an axis at right angles to the direction along which the linear array extends and the main radiating plane of said array, the halves of which are connected to the equivalent branches of a first magic tee, the E- and H-branch respectively of which are connected to the E- and H- branch respectively of a second magic tee, in the equivalent branches of which the inputs of two identical signal handling means are arranged, the lengths of the wave guides interconnecting the E- and H-branches respectively of the magic tees being so chosen that the electrical distances are such that signals from an external wave field, traveling along the waveguides interconnecting the E- and H-branches respectively, on arrival at the signal handling means have a phase difference of a whole multiple of $\lambda/2$, zero included, a comparator circuit having inputs to which the outputs of said signal handling means are connected, a servo system that is controlled by the comparator circuit and that is adapted for rotating the antenna around said axis, the wave guide connected to the H-branch of the first magic tee comprising in the order cited: a first channel of a first short slot hybrid, a first TR cell, a first channel of a second short slot hybrid and a matched terminating impedance, the wave guide connected to the H-branch of the second magic tee comprising in the order cited: a second channel of said second short slot hybrid, a second TR cell, a second channel of said first short slot hybrid and a source of high frequency pulses.

5. An antenna array, comprising a centerfed linear array, the halves of which are connected to the equivalent branches of a first magic tee, the E- and H-branch respectively of which are connected to the E- and H-branch respectively of a second magic tee, in the equivalent branches of which the inputs of two identical signal handling means are arranged, the lengths of the wave guides interconnecting the E- and H-branches respectively of the magic tees being so chosen that the electrical distances are such that signals from an external wave field, traveling along the waveguides interconnecting the E- and H-branches respectively, on arrival at the signal handling means have a phase difference of a whole multiple of $\lambda/2$, zero included, the wave guide connected to the H-branch of the first magic tee comprising in the order cited: a first channel of a first short slot hybrid, a first TR cell, a first channel of a second short slot hybrid and a matched terminating impedance, the wave guide connected to the H-branch of the second magic tee comprising in the order cited: a second channel of said second short slot hybrid, a second TR cell, a second channel of said first short slot hybrid and a source of high frequency pulses, a heterodyning oscillator being coupled to one of the branches of the second magic tee through a directional coupler.

6. An antenna array, comprising a centerfed linear array, rotatable about an axis at right angles to the direction along which the linear array extends and the main radiating plane of said array, the halves of which are connected to the equivalent branches of a first magic tee, the E- and H-branch respectively of which are connected to the E- and H-branch respectively of a second magic tee, in the equivalent branches of which the inputs of two identical signal handling means are arranged, the lengths of the wave guides interconnecting the E- and H-branches of the magic tees respectively being so chosen that the electrical distances are such that signals from an external wave field, traveling along the waveguide interconnecting the E- and H-branches respectively, on arrival at the signal handling means have a phase difference of a whole multiple of $\lambda/2$, zero included, a comparator circuit having inputs to which the outputs of said signal handling means are connected, a servo system that is controlled by said circuit and that is adapted for rotating the antenna around said axis, the wave guide connected to the H-branch of the first magic tee comprising in the order cited: a first channel of a first short slot hybrid, a first TR cell, a first channel of a second short slot hybrid and a matched terminating impedance, the wave guide connected to the H-branch of the second magic tee comprising in the order cited: a second channel of said second short slot hybrid, a second TR cell, a second channel of said first short slot hybrid and a source of high frequency pulses, and a heterodyning oscillator that is coupled to one of the branches of the second magic tee through a directional coupler.

7. An antenna array, comprising a centerfed linear array, the halves of which are connected to the equivalent branches of a first magic tee, the E- and H-branch respectively of which are connected to the E- and H-branch respectively of a second magic tee, in the equivalent branches of which the inputs of two identical signal handling means are arranged, the lengths of the wave guides interconnecting the E- and H- branches respectively of the magic tees being so chosen that the electrical distances are such that signals from an external wave field, traveling along the waveguide interconnecting the E- and H-branches respectively, on arrival at the signal handling means have a phase difference of a whole multiple of $\lambda/2$, zero included, the wave guide connected to the H-branch of the first magic tee comprising in the order cited: a first channel of a first short slot hybrid, a first TR cell, a first channel of a second short slot hybrid and a matched terminating impedance, the wave guide connected to the H-branch of the second magic tee comprising in the order cited: a second channel of said second short slot hybrid, a second TR cell, a second channel of said first short slot hybrid and a source of high frequency pulses, a microwave switch being provided in the wave guide joining the E-branches of both magic tee's, and means synchronizing the closing rhythm of said microwave switch with the source of high frequency pulses such that said E-branches are isolated from each other as long as a high frequency pulse is present in the system.

8. An antenna array, comprising a centerfed linear array, rotatable about an axis at right angles to the direction along which the linear array extends and the main radiating plane of said array, the halves of which are connected to the equivalent branches of a first magic tee, the E- and H-branch respectively of which are connected to the E- and H-branch respectively of a second magic tee, in the equivalent branches of which the inputs of two identical signal handling means are arranged, the lengths of the wave guides interconnecting the E- and H- branches respectively of the magic tees being so chosen that the electrical distances are such that signals from an external wave field, traveling along the waveguides interconnecting the H- and E-branches respectively, on arrival at the signal handling means have a phase difference of a whole multiple of $\lambda/2$, zero included, a comparator circuit having inputs to which the outputs of said signal handling means are connected, a servo system that is controlled by the comparator circuit and that is adapted for rotating the antenna around said axis, the wave guide connected to the H-branch of the first magic tee comprising in the order cited: a first channel of a first short slot hybrid, a first TR cell, a first channel of a second short slot hybrid and a matched terminating impedance, the wave guide connected to the H-branch of the second magic tee comprising in the order cited: a second channel of said second short slot hybrid, a second TR cell, a second channel of said first short slot hybrid and a source of high frequency pulses, a microwave switch being provided in the wave guide joining the E-branches of both magic tee's, and means synchronizing the closing rhythm of said microwave switch with the source of high frequency pulses such that said E-branches are isolated from each other as long as a high frequency pulse is present in the system.

9. An antenna array, comprising a centerfed linear array, the halves of which are connected to the equivalent branches of a first magic tee, the E- and H-branch respectively of which are connected to the E- and H-branch respectively of a second magic tee, in the equivalent branches of which the inputs of two identical signal handling means are arranged, the lengths of the wave guides interconnecting the E-and H-branches respectively of the magic tees being so chosen that the electrical distances are such that the signal from an external wave field, traveling along the waveguides interconnecting the H- and E- branches respectively, on arrival at the signal handling means have a phase difference of a whole multiple of $\lambda/2$, zero included, the wave guide connected to the H-branch of the first magic tee comprising in the order cited: a first channel of a first short slot hybrid, a first TR cell, a first channel of a second short slot hybrid and a matched terminating impedance, the wave guide connected to the H-branch of the second magic tee comprising in the order cited: a second channel of said second short slot hybrid, a second TR cell, a second channel of said first short slot hybrid and a source of high frequency pulses, a heterodyning oscillator that is coupled to the one of the branches of the second magic tee through a directional coupler, a microwave switch being provided in the wave guide joining the E-branches of both magic tee's, and means synchronizing the closing rhythm of said microwave switch with the source of high frequency pulses such that E-branches are isolated from

each other as long as a high frequency pulse is present in the system.

10. An antenna array, comprising a centerfed linear array, rotatable about an axis at right angles to the direction along which the linear array extends and the main radiating plane of said array, the halves of which are connected to the equivalent branches of a first magic tee, the E- and H-branch respectively of which are connected to the E- and H-branch respectively of a second magic tee, in the equivalent branches of which the inputs of two identical signal handling means are arranged, the lengths of the wave guides interconnecting the E- and H-branches respectively of the magic tee being so chosen that the electrical distances are such that signals from an external wave field, traveling along the waveguides interconnecting the H- and E-branches respectively, on arrival at the signal handling means have a phase difference of a whole multiple of $\lambda/2$, zero included, a comparator circuit having inputs to which the outputs of said signal handling means are connected, a servo system that is connected to the comparator circuit and that is adapted for rotating the antenna around said axis, the wave guide connected to the H-branch of the first magic tee comprising in the order cited: a first channel of a first short slot hybrid, a first TR cell, a first channel of a second short slot hybrid and a matched terminating impedance, the wave guide connected to the H-branch of the second magic tee comprising in the order cited: a second channel of said second short slot hybrid, a second TR cell, a second channel of said first short slot hybrid and a source of high frequency pulses, a heterodyning oscillator that is coupled to the one of the branches of the second magic tee through a directional coupler, a microwave switch being provided in the wave guide joining the E-branches of both magic tee's, and means synchronizing the closing rhythm of said microwave switch with the source of high frequency pulses such that said E-branches are isolated from each other as long as a high frequency pulse is present in the system.

11. An antenna array which is rotatable about two axes at right angles to each other, comprising two centerfed linear arrays having a fixed position with respect to each other, these linear arrays being so suspended that the first and second linear array are always at right angles to the first and second rotation axis respectively, both halves of the first and second linear array respectively being connected to opposite branches of a first and second turnstile junction respectively, the central (round) branches of said turnstile junctions being connected to each other, a second and first pair of identical signal handling means respectively being connected to the remaining opposite branches of said first and second turnstile junction respectively.

12. An antenna array which is rotatable about two axes at right angles to each other, comprising two centerfed linear arrays having a fixed position with respect to each other, these linear arrays being so suspended that the first and second linear array are always at right angles to the first and second rotation axis respectively, both halves of the first and second linear array respectively being connected to opposite branches of a first and second turnstile junction respectively, the central (round) branches of said turnstile junctions being connected to each other, a second and first pair of identical signal handling means respectively being connected to the remaining opposite branches of said first and second turnstile junction respectively, a first comparator circuit being connected to the outputs of said first pair of signal handling means, the output of said first comparator circuit being connected to the control input of a servo system adapted for rotating the antenna array about said first axis, a second comparator circuit being connected to the outputs of said second pair of signal handling means, the output of said second comparator circuit being connected to the input of a servo system adapted for rotating the antenna array about said second axis.

13. An antenna array comprising at least one centerfed linear array, the halves of which are connected to a pair of signal handling means through two hybrid junctions, in such a way, that signals corresponding to the even pattern of the linear array reach the signal handling means in phase, while signals corresponding to the odd pattern of the linear array reach the signal handling means in counterphase.

14. An antenna array as claimed in claim 1 comprising microwave switches in intermediate parts of each half of the linear array.

15. An antenna array as claimed in claim 2 comprising microwave switches in intermediate parts of each half of the linear array.

16. An antenna array as claimed in claim 3 comprising microwave switches in intermediate parts of each half of the linear array.

17. An antenna array as claimed in claim 4 comprising microwave switches in intermediate parts of each half of the linear array.

18. An antenna array as claimed in claim 5 comprising microwave switches in intermediate parts of each half of the linear array.

19. An antenna array as claimed in claim 6 comprising microwave switches in intermediate parts of each half of the linear array.

20. An antenna array as claimed in claim 7 comprising microwave switches in intermediate parts of each half of the linear array.

21. An antenna array as claimed in claim 8 comprising microwave switches in intermediate parts of each half of the linear array.

22. An antenna array as claimed in claim 9 comprising microwave switches in intermediate parts of each half of the linear array.

23. An antenna array as claimed in claim 10 comprising microwave switches in intermediate parts of each half of the linear array.

24. An antenna array as claimed in claim 11 comprising microwave switches in intermediate parts of each half of at least one of the linear arrays.

25. An antenna array as claimed in claim 12 comprising microwave switches in intermediate parts of each half of at least one of the linear arrays.

References Cited in the file of this patent

UNITED STATES PATENTS

2,825,057	Worthington	Feb. 25, 1958
2,981,948	Kurtz	Apr. 25, 1961