

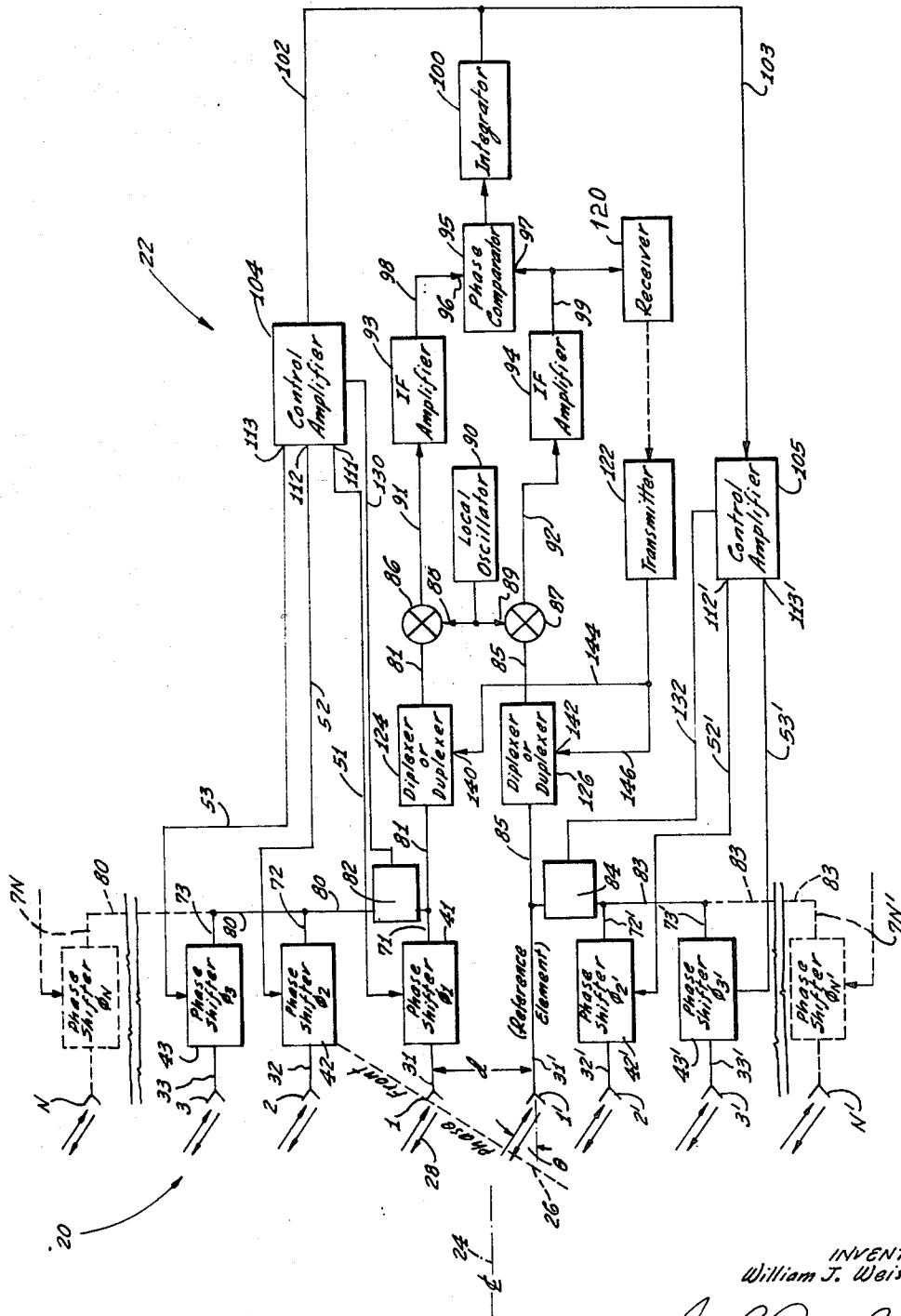
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RETRODIRECTIVE ANTENNA ARRAY

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1

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RETRODIRECTIVE ANTENNA ARRAY

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The present invention relates to directional antenna means for electromagnetic energy radiations and more particularly to antenna means for receiving electromagnetic radiations and automatically directing the sensitivity pattern thereof toward the source of said radiations whereby electromagnetic radiations may be transmitted back toward said source.

At the present time, it is frequently desirable to maintain communications between two remotely located stations by means of mobile installation where the amount of power available for operating radio receiving and/or transmitting equipment may be severely limited. Accordingly, it is very desirable to obtain an efficient transmission of the signals. One means of accomplishing this is to employ high gain antenna means having a sensitivity pattern which comprises a very narrow beam width. When the antenna pattern is very narrow, the antenna must be properly oriented with respect to the two stations. Unfortunately, when at least one of the stations is of a mobile nature, the bearing between the two stations may be constantly varying throughout a wide angle. As a result, it is necessary under such circumstances to employ some form of scanning of the antenna pattern. Although there are a large number of means for mechanically and electronically scanning an antenna array, it has been very difficult, if not impossible, to maintain the antenna pattern exactly oriented with respect to the two stations. As a result of these inaccuracies in the aligning of the various antenna patterns, it has been customary to employ antenna patterns having a beam width that is somewhat wider than necessary. As a result of the excessive beam width, a certain amount of misalignment of the beam may be permitted. However, because of the wide beam width, the antenna does not provide the maximum sensitivity which might otherwise be obtained. This in turn fails to optimize the efficiency of the transmissions and has necessitated excessive amounts of power and/or produced reception having low signal-to-noise ratios.

It is now proposed to provide antenna means that will overcome the foregoing difficulties. More particularly, it is proposed to provide an antenna array and means for controlling the same that will automatically keep the pattern of the antenna centered on the axis of any signals being received so as to insure a maximum sensitivity of the receiving means. In addition, the antenna means may be reciprocal so that if it is desired, a return signal may be transmitted therethrough. Since the pattern of the antenna means will be automatically aligned with the direction of the received signal even though a very narrow beam width is employed for transmitting, it will always be properly oriented with respect to the other station.

More particularly, this is to be accomplished by providing antenna means and control means therefor which are adapted to receive electromagnetic radiations from any source located within a wide scan angle. The antenna means includes at least two elements that are spaced from each other and positioned to produce separate signals that are proportional to the electromagnetic energies incident thereon. Since these elements are spaced from each other by a predetermined distance, the signals therefrom will have a phase difference that is a function of the angle of incidence of the received wave front upon the antenna elements. Separate reciprocal phase shifters are provided for at least a portion of the antenna elements for shifting

2

the phase of any signals passing therethrough. Phase comparator means are interconnected with at least one of said elements and the output of one of said phase shifters so as to compare the phases of the two signals and provide a control signal that is proportional to the difference between the two phases. This control signal is fed to each of the phase shifters and will thereby be effective to control the amount of phase shifting occurring in each of the phase shifters. More particularly, the control signal may be effective to adjust the phase shifter to maintain the phase difference between the signals reduced to zero. With the phase shifters thus adjusted, the antenna pattern will be maintained normal to the wave front incident thereon. Thus, employing a suitable array of elements, the pattern of the array may be focused into as narrow a beam as desired and by providing separate phase shifters for the additional elements together with proportional control signals therefor, the antenna pattern will always be centered upon the direction from which the received signal is coming. If the antenna elements and the phase shifters therefor are all reciprocal, transmitting means may be provided for feeding electromagnetic energy through the phase shifters to the various elements so as to cause an electromagnetic signal to be radiated. Since the phase shifters will be effective to maintain the antenna pattern aligned with the received signal, the signals radiated from the individual elements will have the proper phase relations to combine into a beam having a narrow beam width which is centered on the same line from which the received energies are traveling.

It may thus be seen that the phase shifters and control means therefor will be effective to form a closed loop circuit which will automatically adjust the phase of the signals for each of the antenna elements to insure the receiving and transmitting antenna patterns being automatically centered on the axis of any signals incident thereon. As a result, the antenna may have a very narrow pattern whereby the energy in a signal may be concentrated in a beam aimed directly at a second station. Thus efficient communications will be insured between the two stations.

These and other features and advantages of the present invention will become more readily apparent from the following detailed description of the invention particularly when taken in connection with the accompanying drawing wherein like numerals designate like parts and wherein:

The drawing is a block diagram of an antenna array and control means therefor which embodies the present invention.

Referring to the drawing in more detail, the present invention is embodied in an antenna array 20 and the control system 22 therefor. The antenna array 20 includes a plurality of elements that may be arranged into any desired configuration of either two or three dimensions for use in any portion of the frequency spectrum such as the so-called microwave region. The number and configuration of the elements may be chosen to provide an antenna array 20 having a sensitivity pattern with the desired beam characteristics. The antenna elements may be any of the well known variety such as dipoles, resonant apertures, etc.

For purposes of illustration in the present instance, the array 20 is shown as a linear array 20 wherein elements are arranged in a straight line so as to form a first group of elements 1, 2, 3, . . . N and a second group of elements, 1', 2', 3', . . . N'. These groups and the elements therein are shown as being symmetrically disposed about a center line or axis 24 of the array 20 that extends between elements 1 and 1'. It should be understood that the elements may be symmetrical about a center line located anywhere within the array or may even be asymmetrical

if desired. In addition, the spacing between the elements may be uniform or irregular if desired.

If electromagnetic energy is radiated from a source such as a remotely located station, the radiations will form a wave front consisting of planes where the phase of the radiations are uniform. These planes of equal phase are illustrated in the drawings as lines 26 of equal phase that are substantially normal to the axis 28 of propagation.

When the antenna elements are arranged in a straight line, in the event the axis 28 of a wave front is oblique to the axis 24 of the array 20, the wave front will strike the element N nearest to the source first. It will then successively strike the succeeding elements N-1, . . . 3, 2, 1, 1', 2', 3', . . . N' after predetermined time delays. The duration of the time delays will be a function of the spacing between the antenna elements and if each of the spacings or distances between the adjacent elements are all equal, the time delays will all be equal. In addition, as may be seen from the drawing, the amount of time delay with which the phase fronts 26 strike the succeeding elements will also be dependent upon the angle θ formed between the axis 24 of the antenna array 20 and the axis 28 of propagation.

It may thus be seen that when a wave front 26 of electromagnetic radiation in the microwave region is incident upon each of the elements, each of the elements will provide a microwave signal that is characteristic of the electromagnetic radiations and will have a phase relation that is a function of the angle of incidence of the radiations.

Each of the elements 1, 2, 3, . . . N and 1', 2', 3', . . . N' may be connected to a transmission line 31, 32, 33, . . . 3N or 31', 32', 33', . . . 3N' respectively. The transmission lines may be so called wave guide, co-axial line, strip line or any other form of transmission means suitable for use in the frequency range being employed. One of these elements 1' comprises a reference element, while the rest of the elements are secondary elements. The transmission lines 31 through 3N and 32' through 3N' from each of the secondary elements 1 through N and 2' through N' respectively may lead to an input of a variable phase shifter 41, 42, 43, . . . 4N and 42', 43', . . . 4N'. These phase shifters which are preferably all substantially identical to each other may be any of the well known varieties such as those employing a mechanically movable reactance member, a voltage responsive reactance member or a current responsive reactance member. For example, each of the phase shifters may have a ferrite element therein which may be energized by means of a current flowing through a solenoid wound around the ferrite element. Such a ferrite element may be a reciprocal reactance that will be effective to produce a phase shift that will be identical for energy flowing therethrough in either direction and will have a magnitude determined by the amount of current flowing through the solenoid. It may thus be seen that by employing a separate control conductor 51, 52, 53, . . . 5N and 51', 52', 53', . . . 5N' for each of the phase shifters 41, 42, 43, . . . 4N and 41', 42', 43', . . . 4N' and providing a suitable control signal thereto, each of the phase shifters will be effective to cause any microwave signals passing therethrough to have the phases thereof shifted. Each of the phase shifters 41, 42, 43, . . . 4N and 42', 43', . . . 4N' will cause the signals therein to be separately shifted by amounts that will be a function of the control signals applied thereto. Thus, by supplying separate control signals on each of the conductors 51, 52, 53, . . . 5N and 52', 53', . . . 5N' the amounts of phase shift $\phi_1, \phi_2, \phi_3, \dots \phi_N$ and $\phi_1', \phi_2', \phi_3', \dots \phi_N'$ respectively in each phase shifter may differ from the amount of shift in the other phase shifters.

It may thus be seen that each of the phase shifters 41, 42, 43, . . . 4N and 42', 43', . . . 4N' will shift the

microwave signals from the associated antenna elements by angles that are determined by the control signals on the conductors 51, 52, 53, . . . 5N or 52', 53', . . . 5N'.

A suitable transmission line 71, 72, 73, . . . 7N and 72', 73', . . . 7N' is connected to the outputs from each of the phase shifters whereby the signals from the antenna elements will be present in the transmission lines 71, 72, 73, . . . 7N and 72', 73', . . . 7N'.

The transmission lines 71, 72, 73, . . . 7N from the phase shifters 41, 42, 43, . . . 4N respectively may be joined to a common transmission line 80 that is connected to the transmission line 81 by a suitable isolating or switching means 82. This isolating means 82 may be effective to isolate the element 1 from the elements 2, 3, . . . N or to effectively interconnect all of the antenna elements together to form them into a first group. This isolator may be a suitable mechanical switch mechanism or any other suitable means such as a conventional gas-filled tube operated as a switch for interconnecting the phase shifters together in the manner to be explained subsequently. Thus, all of the elements 1, 2, 3, . . . N and the phase shifters 41, 42, 43, . . . 4N therefore may form a first group whereby the signals therefrom may all be present on the transmission line 81.

The transmission lines 72', 73', . . . 7N' from the phase shifters 42', 43', . . . 4N' may be joined to a common transmission line 83 that leads to a second isolating or switching means 84. This means 84 may be similar to the means 81 so as to effectively control the interconnection of the transmission lines 31' and 83. Although the operation of the means 84 will be explained subsequently, it may be seen that the elements 1', 2', 3', . . . N' and the phase shifters 42', 43', . . . 4N' therefore may form a second group whereby the signals therefrom may be combined with each other and present on the transmission line 85.

The first transmission line 81 may lead to the first input of a mixer 86 of any suitable variety while the transmission line 85 may lead to the first input of a second mixer 87 also of any suitable variety. In the event it is desired to transmit signals from the antenna array 20, suitable diplexers or duplexers 124 and 126 may be provided in the transmission lines 81 and 85 respectively for interconnecting the transmission lines 81 and 85 with a suitable source of microwave energy such as a transmitter 122. The operation of the transmitter 122 and diplexers or duplexers 124 and 126 will subsequently be explained in more detail. Each of the mixers 86 and 87 may also include second inputs 88 and 89 for receiving a second signal. These inputs 88 and 89 are connected to a common local oscillator 90 having a frequency that differs from the frequency of the radiations to be received by a predetermined amount. It may thus be seen that the signals in the transmission lines 81 and 85 will beat with the local oscillator signal to produce a beat frequency signal or an IF signal having a frequency equal to the intermediate frequency. The IF signals will be present in the outputs of the mixers 86 and 87. A separate transmission line 91 and 92 may be connected to the outputs from the mixers 86 and 87 so as to lead to the inputs of intermediate frequency amplifiers 93 and 94. These amplifiers 93 and 94 may have sufficiently narrow bandwidths to amplify only the IF signals to a more useful level.

A phase comparator 95 may be provided for comparing the phases of the signals in the outputs of the IF amplifiers 93 and 94 and providing a signal indicative of the difference between the phase angle thereof. The phase comparator includes two separate inputs 96 and 97. The first input 96 is connected to the output from the first intermediate frequency amplifier 93 by means of a transmission line 98 while the second input 97 is connected to the output from the second intermediate frequency amplifier 94 by means of a transmission line 99. The phase comparator 95 may be effective to compare the two amplified intermediate frequency signals and produce a dif-

ference signal that is indicative of the difference in the phase angles between the signals from the antenna elements 1 and 1' or the two signals from the groups depending upon the isolator means 82 and 84. Normally the energy that is incident upon the antenna elements will be in the form of relatively short duration pulses with intervals therebetween when no energy is received. As a result the inputs 96 and 97 will receive corresponding pulses for comparison. Normally if there is a phase differential between the two signals, the difference signal will have some measurable amplitude. However, if there is no phase difference between the two signals normally the output signal will have zero amplitude. Thus, in such a comparator a pair of signals in phase with each other and the no signal condition occurring between pulses will produce identical outputs at the output of the phase comparator 95.

To overcome the foregoing difficulty, the output of the phase comparator 95 may be connected to the input of an integrator 100 so that the output or difference signal will be supplied thereto. The integrator 100 will be effective to integrate pulses forming the difference signal and thereby provide a control signal. The integrator 100 may be of any well known variety. The time constant of the integrator 100 may be chosen so as to hold the pattern in position for any desired period. Thus, although the difference signal may fall to zero between pulses, the control signal from the integrator will remain substantially constant for extended periods and will only vary in amplitude at a rate corresponding to the rate at which the bearings between sending and receiving stations vary. A pair of conductors 102 and 103 may be connected with the output of the integrator 100 so as to feed the control signal to a pair of control amplifiers 104 and 105.

The first control amplifier 104 includes a single input but separate outputs 111, 112, 113, . . . 11N for each of the phase shifters 41, 42, 43, . . . 4N respectively in the first group. The conductors 51, 52, 53, . . . 5N are connected to these outputs so that a separate control signal will be applied to each of the phase shifters. Each of these separate control signals may be in some predetermined relation to the control signal from the integrator 100 and will thereby be effective to provide corresponding proportional phase shifts $\phi_1, \phi_2, \phi_3, \dots \phi_N$ of microwave signals passing through the phase shifters 41, 42, 43 . . . 4N.

Each of the control amplifiers 104 and 105 may be constructed in a conventional manner and may be provided with a plurality of output terminals or taps for providing the different outputs such as the outputs 111, 112 and 113. For example, the outputs 111, 112 and 113 may be different voltages from the amplifier 104, the values of these voltages depending upon the signal from the integrator 100. Since the outputs 111, 112 and 113 constitute different voltages, they are respectively instrumental in causing the phase shifters 41, 42 and 43 to produce different phase shifts.

The second control amplifier 105 is similar to the first amplifier 104 in that it also includes separate output 112', 113', . . . 11N' for each of the phase shifters 42', 43', . . . 4N' in the second group. These outputs are interconnected with the conductors 52', 53', . . . 5N' and also provide signals proportional to the output or control signal from the integrator 100. Thus, each of the phase shifters 42', 43', . . . 4N' will also provide proportional phase shifts $\phi_2', \phi_3', \dots \phi_N'$ for the microwave signals passing therethrough.

A receiver 120 may be provided that may be interconnected with an output of the phase comparator 95 or with the outputs of the IF amplifiers 93 and 94. The receiver 120 may be tuned to the intermediate frequency and includes suitable utilization means such as a remote control for actuating the transmitter 122.

In order to employ the present antenna array 20 and the control means 22 therefor, all of the various components are placed in an operative condition. The antenna array 20 is then physically oriented so that a remote sta-

tion with which it is desired to communicate has a bearing that is somewhere within the scan angle of the array 20. In the event the remote station is radiating microwave energy toward the antenna array 20, the wave front will strike the reference element 1' and the element 1 and will result in microwave signals being present in the transmission lines 31 and 31'. If the isolating means 82 and 84 are effective to prevent the signals in the lines 80 and 83 entering lines 81 and 85, only the signals from the elements 1 and 1' will be present on the lines 81 and 85. Since only the elements 1 and 1' are effective when operating in this mode, the array 20 will have a very wide pattern. As a result the presence of a signal from a source located anywhere within the scan angle of the array will be effective to actuate the control means 22.

It will be seen from the discussion in the previous paragraph that the isolating means 82 is effective in one state of operation to prevent signals from the line 80 from passing through the isolating means. In this state of operation of the isolating means 82, only the signals from the phase shifter 41 are present on the line 81 to control the introduction of signals from the control amplifier 104 to the phase shifters 42 and 43 to obtain phase shifts by the phase shifters. The isolating means 83 operates in a similar manner to prevent the signals from the phase shifters 42' and 43' from passing through the isolating means.

Energy incident upon the element 1 will travel along the transmission line 31, through the phase shifter 41 and into the transmission line 71. The signals will then pass through the isolator means 82 and onto the transmission line 81. The energy incident upon the element 1' will travel along transmission line 31' through the isolator means 84 and into the line 85. The signals in the lines 81 and 85 will thus have signals with a phase difference that will be a function of the angle of incidence θ and the phase shift angle ϕ_1 in the phase shifter 41. These two signals may then travel along the lines 81 and 85 through the diplexers or duplexers 124 and 126, if present, and into the mixers 86 and 87. Here the signals will beat with the total oscillator to produce IF signals in the transmission lines 91 and 92. These signals will then be fed to the IF amplifiers 93 and 94 where they will be amplified to a more useful level. The amplified IF signals may then be fed to the phase comparator 95. The phase comparator 95 will compare the phase of the two signals or transmission lines 98 and 99 and provide a difference signal. The amplitude of the signal will be a function of the difference between the phases of the two signals and the time duration thereof will be similar to the time duration of energy incident upon the antenna elements 1 and 1'. Since the received signals will normally be relatively short duration pulses, the difference signal will also be a short duration pulse. During the intervals between the pulses the difference signal will be zero.

The difference signal, in its pulse form, is then fed to the integrator 100 which will provide a control signal indicative of the difference signal. The integrator 100 preferably has a relatively long time constant. As a result, the signal in the output of the integrator will be maintained at a substantially constant level for extended periods. If desired, the time constant of the integrator may be much longer than the intervals between the succeeding pulses being received by the array 20. This will result in a control signal that will remain substantially uniform between pulses although it may vary very slowly over extended periods. Although the bearing between two stations will remain relatively constant, the integrator must have a sufficient response to vary at a rate corresponding to the rate at which the bearings change.

The control signal from the integrator 100 will be fed over lines 102 and 103 to the control amplifiers 104 and 105. The output 111 will provide a control signal that will be fed over the conductor 51 to the phase shifter 41. The difference signal from the phase comparator 95 and the

resultant control signal from the integrator 100 will be proportional to the difference between the signals from the elements 1 and 1'. As a result, the control signal supplied to the phase shifter 41 will be effective to cause the phase shift ϕ_1 in the shifter 41 to be equal and opposite to the phase difference between the original signals. This in turn will cause the signals in transmission lines 81 and 85 to be in phase with each other.

As a result of the phase shift, the effective pattern of the antenna elements 1 and 1' will be centered upon a line extending toward the source. Although the relative broad pattern formed by only the two elements 1 and 1' is best suited for the initial acquisition of a signal, once the array 20 and the control means 22 therefor have located a source and has aimed the pattern thereon, it may be desirable to employ a narrower, higher gain pattern for further reception and/or tracking of the source. Accordingly, the isolation means 82 and 84 may be actuated by signals on the conductors 130 and 132 leading from the amplifiers 104 and 105. This will cause the isolator means 82 and 84 to interconnect the lines 80 and 81 together and 83 and 85 together. Thus, the signals from elements 2, 3, . . . N and 2', 3', . . . N' will be fed into the transmission lines 81 and 85 where they will combine with the signals from elements 1 and 1'. When operating in this mode, the array 20 will have a much narrower pattern that will insure a stronger received signal with less relative noise. Since the phase comparator 95 will provide a difference signal that now indicates the phase difference between the signals from the two groups of elements, the amplifiers 104 and 105 will be effective to maintain even the narrow beam centered on the axis 28.

It may thus be seen that the antenna array 20 may have a very broad pattern while operating in an acquisition mode for locating a signal source. However, once a signal source has been located and the antenna pattern has been aimed thereat, the isolator means 82 and 84 will cause all elements to become operative whereby the antenna pattern will become narrow so as to more accurately track the signal source.

As will be seen from the discussion above, the isolating means 82 operates in one state to prevent the signals on the line 82 from passing through the isolating means. This means that the phase comparator 95 is responsive only to the signals from the phase shifter 41 and not to the signals from the associated phase shifters such as the phase shifters 42 and 43. Accordingly, the output 130 from the control amplifier 104 is dependent only upon the signal from the phase shifter 41 and not from the associated phase shifters such as the phase shifters 42 and 43.

The signal produced by the phase comparator 104 is instrumental in controlling the phase shift provided by the phase shifters 41, 42 and 43 so that the output signals from these phase shifters approximate the same phases even though the antennas 31, 32 and 33 may be receiving signals of different phases. Furthermore, the signals from the phase shifter 41 may have approximately the same phase as the signals from the antenna 1'.

Since the phase shifter 42 and the antenna 1' provide signals of approximately the same phase, the phase comparator 95 provides a signal of relatively low amplitude. This causes the control amplifier 104 to provide outputs 111, 112, 113 and 130 of relatively low amplitude. As will be appreciated, the output 130 is similar to the outputs 111, 112 and 113 in that it constitutes a voltage which may be obtained from a tap, just as the outputs 111, 112 and 113 constitute voltages which may be obtained from taps.

When the output 130 falls below a particular value in amplitude, it causes the isolating means 82 to become operative in a second state. For example, the isolating means may be a conventional amplifier which is biased to a state of non-conductivity and which is triggered to a state of conductivity when the output 130 falls below

the particular level in amplitude. By way of further illustration, the conventional amplifier constituting the isolating means 82 may have a gas-filled tube as the switching element so that the amplifier remains in its second state of operation once the gas-filled tube has been triggered to the conductive state.

In its second state of operation, the isolating means 82 passes the signals on the line 80. Since the signals from the phase shifters 42 and 43 will generally have a greater error than the signals from the phase shifter 41, signals of increased error become introduced to the phase comparator 95 through the duplexer 124. At the same time, the isolating means 84 also becomes triggered to its second state since the isolating means 84 is constructed in a manner similar to the isolating means 82. This causes signals of increased error to pass through the duplexer 126 to the phase comparator 95 from the phase shifters 42' and 43'.

Since the phase comparator 95 receives signals of increased error, it produces an error signal of increased amplitude. This causes signals of increased amplitude to be produced by the amplifiers 104 and 105 so that further phase shifts are provided in the phase shifters 41, 42 and 43 and in the phase shifters 42' and 43'. In this way, the isolating means 82 and 84 are effective in one state to obtain a coarse control over the operation of the phase shifters and are effective in the second state to obtain a fine control over the operation of the phase shifters.

In the event it is desired to maintain two way communication between a remote station and the present installation, a source of electromagnetic energy of suitable frequency may be provided. In the present instance, this source comprises a transmitter 122 capable of generating energy of suitable frequency and modulating the energy in the required manner. Although the transmitter 122 may be interconnected with the antenna elements 1, 2, 3, . . . N and 1', 2', 3', . . . N' by any suitable means, in the present instance isolating means are provided in the transmission lines 81 and 85. The isolating means may comprise duplexer or duplexer means 124 and 126. Each of these means which include an input 140 and 142 connected to the transmitter 122 by suitable transmission lines 144 and 146 may be of any suitable variety for effectively isolating the mixers 86 and 87, the IF amplifiers 93 and 94, the phase comparator 95 and receiver from the large amounts of power from the transmitter 122. For example, the means 124 and 126 may be a mechanical or electronic switching mechanism for alternately connecting the isolator means 82 and 84 to the transmitter 122 or for connecting the isolator means 82 and 84 to the mixers 86 and 87 may be employed. Alternatively, this means 124 and 126 may be a suitable directive coupling, filter means or other suitable means for permitting received energy to travel from the isolator means 82 and 84 directly through the transmission lines 81 and 85 to the mixers while permitting energy in the transmission lines 144 and 146 to be launched into the transmission lines 81 and 85 so as to propagate only in the direction of the isolator means 82 and 84.

It may thus be seen that when transmitting the energy from the transmitter 122 will propagate along the transmission lines 81 and 85 to the isolator means 82 and 84. The energy in the isolator means 82 will then enter line 71 and preferably line 80 whereby the energy will pass through the phase shifters 41, 42, 43, . . . 4N to the antenna elements 1, 2, 3, . . . N. The energy in the isolator means 84 will simultaneously enter the transmission line 31' and preferably also transmission line 83 and phase shifters 42', 43', . . . 4N' whereby the energy will excite the antenna elements 1', 2', 3', . . . N'. As a result, the energy from the transmitter will be radiated from the elements in the form of a beam having a pattern and direction that will be determined by the phase relations of the energies from the elements.

If a signal has been received by the array 20 and it is still within the time delay period of the integrator 100, the amplifiers 104 and 105 will be supplying control signals to all of the phase shifters. Since the phase shifters are all reciprocal, the transmitted energies passing there-
through will be shifted by the same number of degrees as the received energies. As a result, the transmitting ener-
gies arriving at the antenna elements will have the same phase relations as the energy that is being received. This in turn will cause the radiated energies to be formed into
a beam that will be directed along the axis 28.

In order to obtain increase in the efficiency of trans-
mission, it is desirable for the energy to be concentrated in as narrow a beam as possible. Thus, even though only
elements 1 and 1' are being used to receive, the isolating means 82 and 84 are preferably effective to cause all of
the antenna elements in the array 20 to be employed for transmitting. By employing all of the elements 1, 2,
3, . . . N and 1', 2', 3', . . . N', a very narrow beam may be radiated. Moreover, since the phase shifters 41,
42, 43, . . . 4N and 42', 43', . . . 4N' will all be controlled in response to a received signal, the radiated beam
will automatically be maintained properly centered on the axis of the received signal.

The isolator means 82 and 84 may be effective to pre-
vent the received energy in transmission lines 80 and 83 entering the transmission lines 81 and 85 while at the same
time permit the transmitted energy in transmission lines 81 and 85 to be coupled into the lines 80 and 83. Thus
the array 20 may receive with a very wide pattern while at the same time it may transmit with a very narrow pat-
tern that will be accurately aimed at the source from which energy is being received.

It may thus be seen that an antenna array and the con-
trol means therefor have been provided that will be effective to keep the pattern thereof accurately centered on the
axis of any signals received thereby so that the antenna will insure a maximum sensitivity when operating in both
the transmitting and receiving modes. Although only a single embodiment of the present invention has been dis-
closed, it will be readily apparent to those skilled in the art that numerous changes and modifications may be
made without departing from the spirit of the invention. For example, it may be desirable for the center line 24
of the array 20 to extend through the reference element 1' with the spacings between the elements 1 and 1' and
the elements 1' and 2' being equal. With a center line extending through the reference element 1' and the elements
being disposed symmetrically about that line, the phase shifts in the shifters 41 and 42' and the remaining sym-
metrically disposed pairs will be equal but of opposite sense. In addition, the same techniques may be employed
to extend the invention to include a two dimensional array. Accordingly, the foregoing description and drawing
are for illustrative purposes only and are not intended to limit the invention which is defined only by the claims
which follow.

What is claimed is:

1. Electromagnetic energy antenna means for receiv-
ing energy from an electromagnetic source comprising the
combination of
 - a plurality of antenna elements providing a narrow
beam width sensitivity pattern and arranged to re-
ceive energy from the electromagnetic source,
 - separate variable phase shifting means for a portion of
said antenna elements;
 - control means for generating a separate control signal
for each phase shifter, each of said control signals
being an analog signal that is continuously variable
throughout a predetermined range;
 - each of said phase shifting means being operatively
interconnected with a separate antenna element and
with said control means, said phase shifting means
being responsive to said control signals and effective

to continuously vary the phase of the signal passing
therethrough,

- said control means being responsive to the signal from
a pair of the plurality of said antenna elements to
provide control signals for continuously varying the
amounts of phase shifts in said phase shifters to center
the narrow beam width sensitivity pattern pro-
vided by the antenna elements in the direction of the
electromagnetic source.
2. Electromagnetic energy antenna means comprising
the combination of
 - a reference antenna element and a plurality of second-
ary antenna elements spaced from each other and
said reference element, each of said elements being
positioned to receive energy from an electromagnetic
source and produce a microwave signal in response
thereto,
 - a variable phase shifting means operatively intercon-
nected with each of said secondary elements, each of
said phase shifting means including a control input
and means for varying the phase of said microwave
signals passing through in proportion to the ampli-
tude of a control signal applied to said input,
 - phase comparing means operatively interconnected with
at least one of said phase shifting means and being
responsive to the signal from said reference element
and the signal from the secondary elements corre-
sponding to the last mentioned phase shifting means
to provide a control signal that is a function of the
difference between the phases of the microwave sig-
nals on said elements,
 - control means operatively interconnected with said
phase comparison means to provide separate control
signals for each phase shifting means that are func-
tions of said output signal, said control means being
interconnected with each of said phase shifting means
to supply said control signals to vary the amounts
of phase shift in each of said shifting means to main-
tain predetermined phase differences between the
microwave signals from said phase shifting means.
3. Electromagnetic energy antenna means comprising
the combination of
 - a first group of antenna elements disposed in a substan-
tially straight line,
 - separate phase shifters for at least a portion of the ele-
ments in said second group,
 - a second group of antenna elements disposed in said
straight line symmetrically with respect to said first
to form a linear array,
 - a separate phase shifter for at least a portion of the
elements in said second group,
 - first transmission line means operatively interconnected
with the phase shifters and said elements in said
first group,
 - a second transmission line means operatively intercon-
nected with the phase shifters and elements in said
second group,
 - switch means in said transmission line means opera-
tive between a first condition wherein all of the ele-
ments in said groups are operatively interconnected
with said transmission line and a second condition
wherein only one element in each group is opera-
tively interconnected with said transmission means,
and
 - phase comparator means interconnected with said first
and second transmission line means for sensing the
phase relations of the signals from said groups when
said switch means is in said second operative condi-
tion, operatively interconnected with said phase
shifters for varying the phase shifts therein until the
difference between the signals in said first and sec-
ond transmission line means is zero.
4. Electromagnetic energy antenna means comprising
the combination of

a plurality of antenna elements, said elements being disposed in a substantially straight line to form a linear array which includes a first group of said antenna elements and a second group of said antenna elements symmetrically disposed with respect to said first group, each of said elements being positioned to receive electromagnetic energy and to provide a microwave signal in response thereto,

first transmission line means interconnected with the elements in said first group, said transmission means including a separate variable phase shifter for at least a portion of the elements in said first group to thereby variably shift the relative phases of each of said microwave signals in said first group,

a second transmission line means interconnected with the elements in said second group, said second transmission line means including a separate variable phase shifter for at least a portion of the elements in said second group to thereby variably shift the relative phases of each of said microwave signals in said second group,

first switch means in said first transmission line means operative between a first condition wherein all of the elements in said first group are connected to said first transmission line means and a second condition wherein only one of the elements in said first group is operatively connected to said first transmission line means,

second switch means in said second transmission line means operative between a first condition wherein all of the elements in said second group are connected to said second transmission line means and a second condition wherein only one of the elements in said second group is operatively connected to said second transmission line means, and

phase comparator means having a first input interconnected with said first transmission line means, and a second input interconnected with said second transmission line means, said phase comparator means being effective when said switch means are in said second condition to provide a separate control signal for each of said phase shifters, said control signals being effective to provide a phase shift in each of said phase shifters that will cause the signals therefrom to all be in phase with each other.

5. Electromagnetic energy antenna means comprising the combination of

- at least two reciprocal antenna elements,
- a source of electromagnetic energy,
- a plurality of transmission line means interconnecting said electromagnetic source with each of said elements for supplying energy to said elements for radiating a beam of electromagnetic energy therefrom, and
- phase shifting means in at least one of said transmission means for varying the phases of the electromagnetic energy passing therethrough,
- control means responsive to the phase of energy incident upon said antenna elements to vary the amount of phase shift in said phase shifting means to maintain said radiated beam aligned with the source of said incident energy.

6. Electromagnetic energy antenna means for radiating a return beam of energy back along the path of energy incident upon said means, said antenna means comprising the combination of

- a plurality of antenna elements,
- a source of electromagnetic energy,
- a plurality of transmission line means interconnecting said source with each of said antenna elements,
- reciprocal phase shifting means in at least a portion of said transmission line means for varying the phases of the energies passing therethrough,
- control means operatively interconnected with said pair of elements and responsive to the difference in phase

between the electromagnetic energy incident on said pair of elements to provide an analog signal that is continuously variable throughout a predetermined range, and

means operatively interconnecting said control means with each of said phase shifting means for varying the amount of phase shift in each of said transmission means so that energy radiated from said radiators will form a wave front directed along said path.

7. Electromagnetic energy antenna means comprising the combination of

- a reference antenna element for receiving a beam of electromagnetic energy and providing microwave signals in response thereto,
- a plurality secondary antenna elements disposed adjacent said reference element to receive said electromagnetic energy to provide separate microwave signals in response thereto,
- a separate reciprocal transmission line interconnected within each of the transmission lines for said secondary antenna elements, said phase shifting means being reciprocal and effective to vary the phases of the microwave signals traveling in the transmission lines for said secondary elements,
- a source of electromagnetic energy,
- phase comparator means,
- switch means operable between a first condition wherein said reference element and one of said secondary elements are connected to said phase comparator, and a second condition wherein all said phase shifters are connected to said source for transferring energy from said source to said antenna elements for radiating energy therefrom as a beam,
- said phase comparator being effective when said switch is in said first condition to provide a control signal proportional to the phase relation between the signal from said reference element and the signal from said phase shifter, and
- control means operatively interconnected with said phase comparator and responsive to said control signal and interconnected with said phase shifters for shifting the phase of the energy fed to said elements whereby said elements will be excited to radiate a beam of the energy having an axis coincident with the direction of said first beam.

8. Electromagnetic energy antenna means comprising the combination of

- a reference antenna element and a plurality of secondary antenna elements spaced from each other and said reference element, each of said elements being reciprocal and positioned to receive a beam of energy from a remote electromagnetic source and to produce microwave signals in response thereto and to receive microwave signals from a transmitter and radiate a beam of electromagnetic energy toward said remote source,
- a variable phase shifting means operatively interconnected with each of said secondary elements, each of said phase shifting means being reciprocal and effective to separately vary the phases of said signals traveling to and from said secondary elements,
- a transmitter for generating microwave signals,
- phase comparator means for being operatively interconnected with one of said phase shifting means and said reference element, said phase comparator means being responsive to the pair of microwave signals therefrom to provide a control signal that is a function of the difference between the phases of said pair of signals,
- switch means having a first operative condition effective to connect all of said phase shifters to said transmitter and a second operative condition effective to connect said reference element and one of said secondary elements to said phase comparator,

said phase comparator during said second condition being effective to supply said control signal to said phase shifter means to vary the amount of phase shifts therein so that said transmitter will excite said elements to radiate a beam of energy coincident with said first beam.

9. Electromagnetic energy antenna means for radiating a beam of energy back along the path of energy incident upon said means, said antenna means comprising the combination of

- a plurality of antenna elements arranged to form an array having a reference element and a plurality of secondary elements,
- a source of electromagnetic energy,
- transmission means interconnecting said source with each of said antenna elements,
- separate phase shifting means in each of the transmission means connected to said secondary elements, said phase shifting means being effective to change the phase of the energy passing therethrough, and
- means responsive to the difference in phase between the electromagnetic energy incident on said reference element and at least one of said secondary elements, said last mentioned means being operatively interconnected with each of said phase shifting means for varying the amount of phase shifting therein so that energy from said source radiated from said antenna elements will form a wave front directed along said path.

10. Electromagnetic energy antenna means for receiving a series of pulses of electromagnetic energy and radiating a beam of energy back along the path of said pulses, said antenna means comprising the combination of

- a plurality of antenna elements arranged to form an array having a reference element and a plurality of secondary elements, each of said elements being effective to receive a series of signals and to provide a series of microwave signals,
- a source of electromagnetic energy,
- transmission means interconnecting said source with each of said antenna elements,
- a separate phase shifting means in each of the transmission means connected to said secondary elements, said phase shifting means being responsive to a control signal and effective to change the phase of the energy passing therethrough as a function of said control signal,
- phase comparing means operatively interconnected with said reference element and the output of one of said phase shifters, said phase comparing means being responsive to the difference in phase of the series of microwave signals from said reference element and one of said phase shifting means so as to produce a control signal,
- integrating means operatively interconnected with said phase comparing means and responsive to said control signal, said integrating means having time constant that is long compared to the time between the signal's said series,
- control means operatively interconnected with the output of said integrating means to provide a separate control signal for each phase shifter that are functions of said first control signal, said control means being operatively interconnected with each of said phase shifting means for feeding the control signals thereto for varying the amount of phase shifting therein so that a beam of the energy from said source will be radiated from said elements.

11. Electromagnetic energy antenna means for radiating a beam of energy back along the path of energy incident upon said means, said antenna means comprising the combination of

- a first group of antenna elements disposed in a straight line,
- a second group of antenna elements disposed in said straight line symmetrically with respect to said first group to form a linear array,
- separate phase shifters for at least a portion of the elements in said first group,
- separate phase shifters for at least a portion of the elements in said second group,
- each of said phase shifting means being reciprocal and effective to change the phase of energy passing there-through in response to a control signal,
- a source of electromagnetic energy,
- first transmission line means,
- switch means in said transmission line means having a first operative condition effective to interconnect said source with each of said antenna elements in said first group and a second operative condition effective to interconnect said source with only one of the elements in said second group,
- second transmission line means,
- second switch means in said second transmission line means having a first operative condition interconnecting said source with each of the antenna elements in said second group and a second operative condition interconnecting said source with only one of the elements in said second group,
- phase comparator means operatively interconnected with each of said transmission line means and effective when said switch means are in said second condition to provide a difference signal that is a function of the phase difference between the signals from said groups,
- control means operatively interconnected with said phase comparator and responsive to said difference signal to provide a separate control signal for each of said phase shifters, said control means being operatively interconnected with said phase shifters for feeding said control signals to said phase shifter and effective to vary the phases of energies fed from said source to said elements when said switch means are in said first condition so that said energy radiated from said elements will form a wave front symmetrically disposed about said path.

References Cited

UNITED STATES PATENTS

2,173,858	9/1939	Pierce et al.	343—854 X
3,036,210	5/1962	Lehan et al.	343—854 X
3,056,961	10/1962	Mitchell	343—854
2,975,275	3/1961	Adams	343—117
2,042,831	6/1936	Crosby.	
3,138,800	6/1964	Speller	343—117

OTHER REFERENCES

Journal of the Patent Office Society, vol. 31, No. 8, pp. 634—635, August 1949.

Sommer, I.R.E. Transactions on Aeronautical and Navigational Electronics, vol. ANE-3, No. 2, June 1956, pp. 67—70.

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