Sept. 5, 1967 H. W. SULLIVAN ET AL 3,340,530

DIRECTIONAL ANTENNA ARRAY

Filed Dec. 30, 1963 5 Sheets-Sheet 1

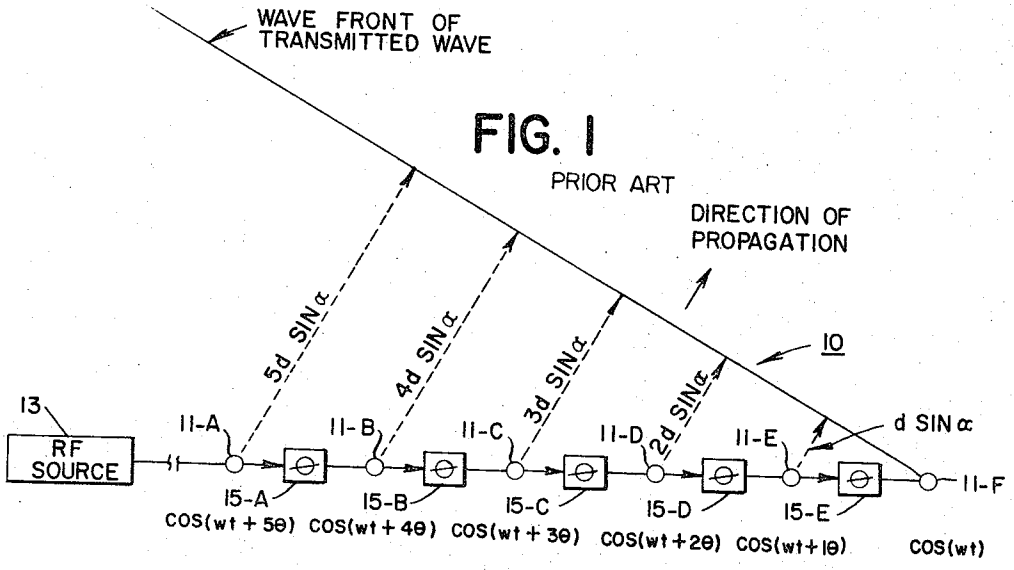


FIG. 1

PRIOR ART

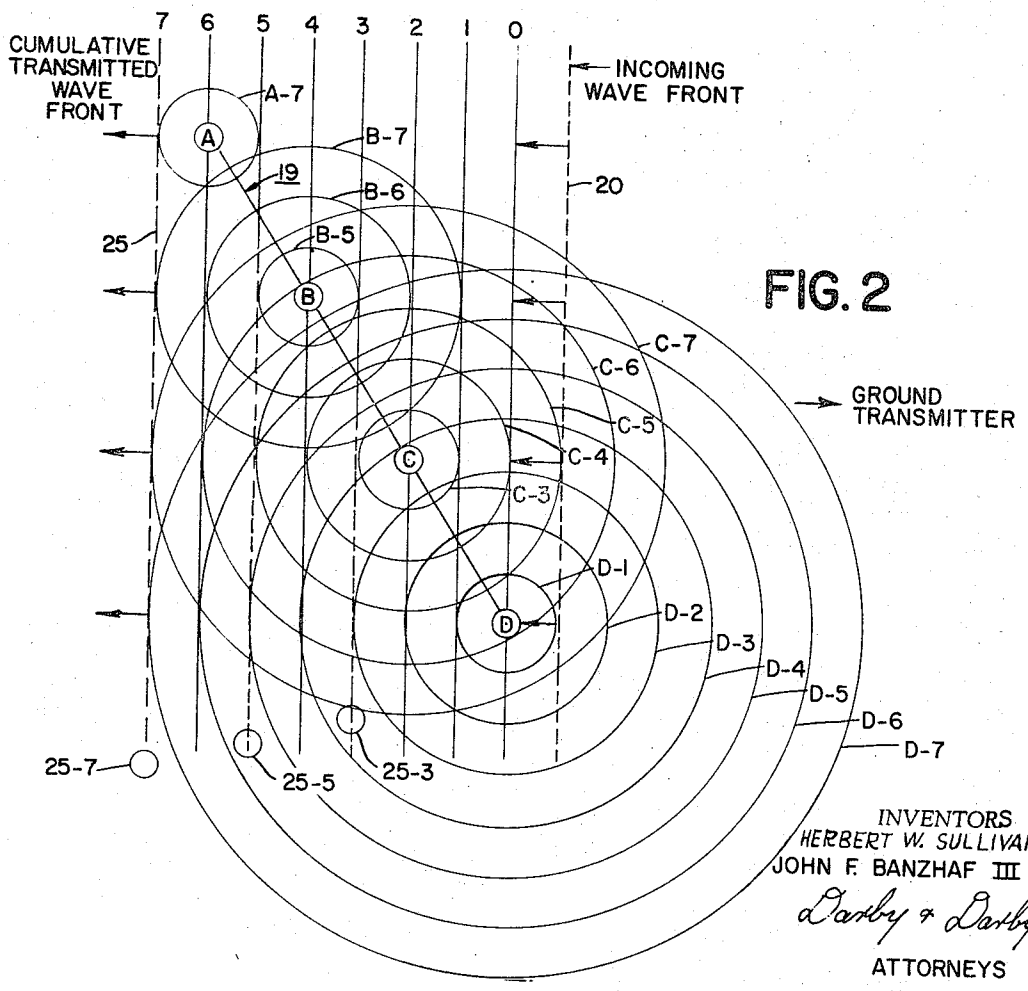


FIG. 2

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FIG. 3

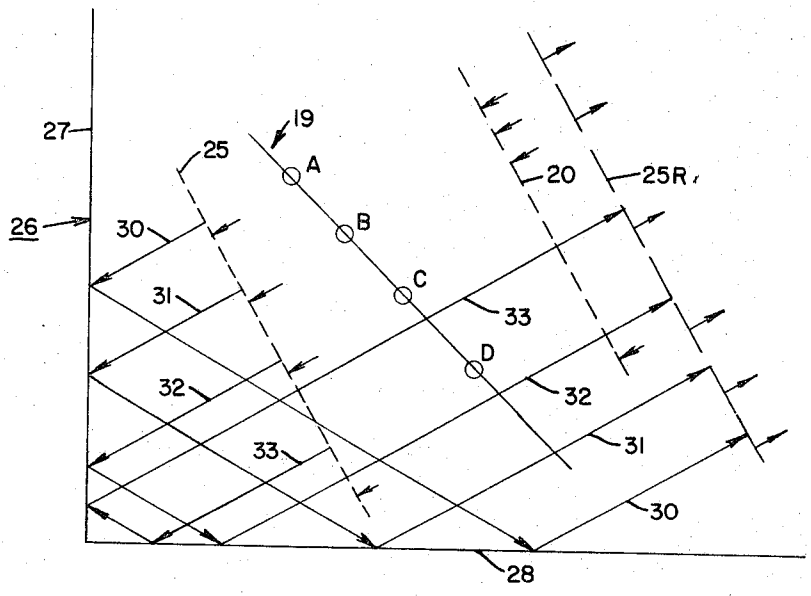
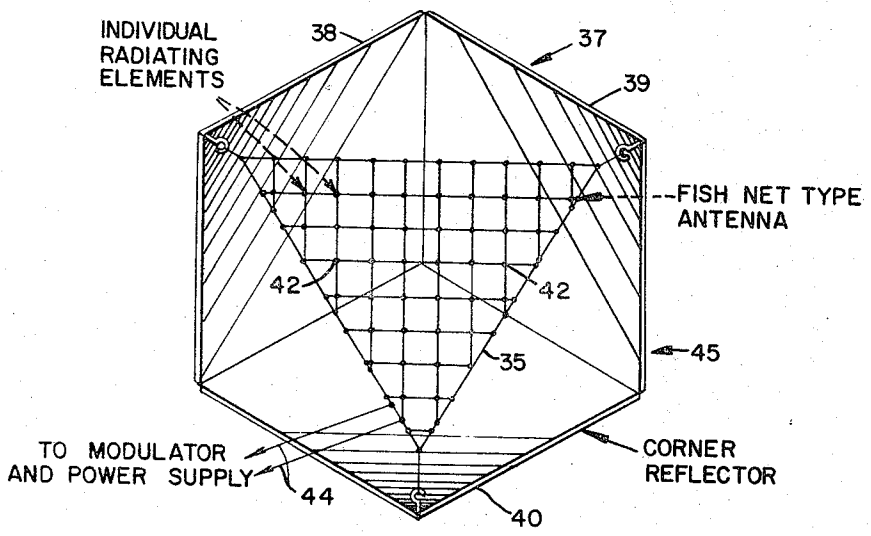


FIG. 4



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FIG. 5

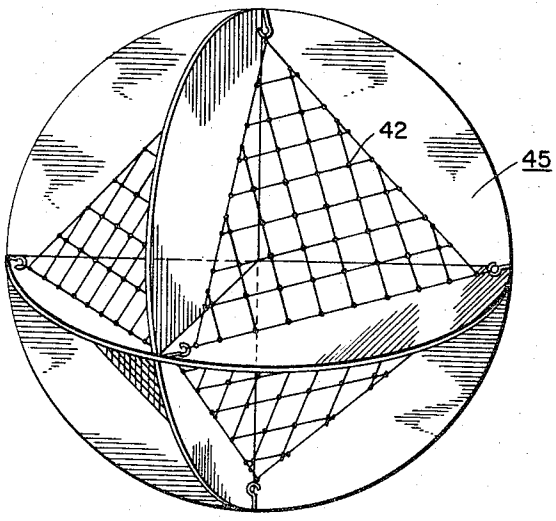
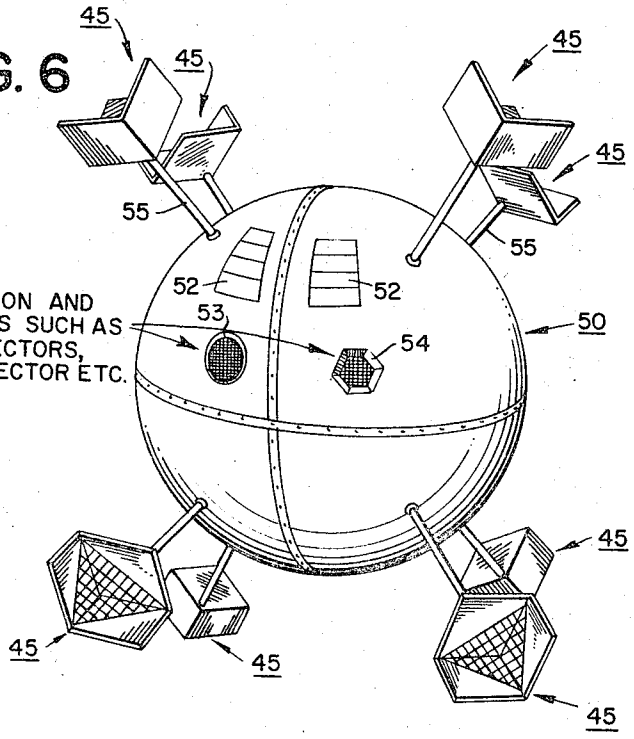


FIG. 6



INSTRUMENTATION AND SENSING DEVICES SUCH AS PARTICLE DETECTORS, RADIATION DETECTOR ETC.

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FIG. 7

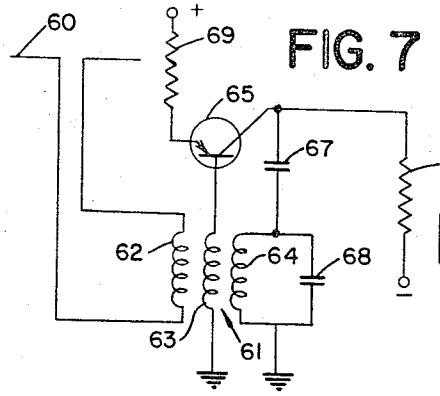


FIG. 8

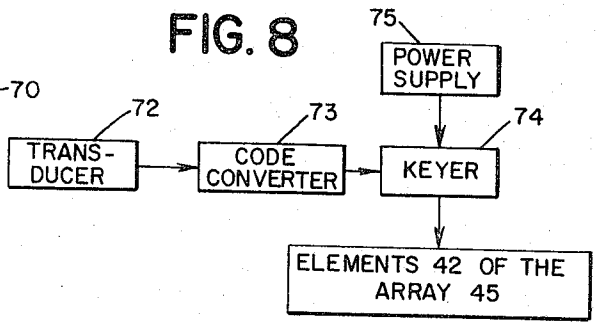
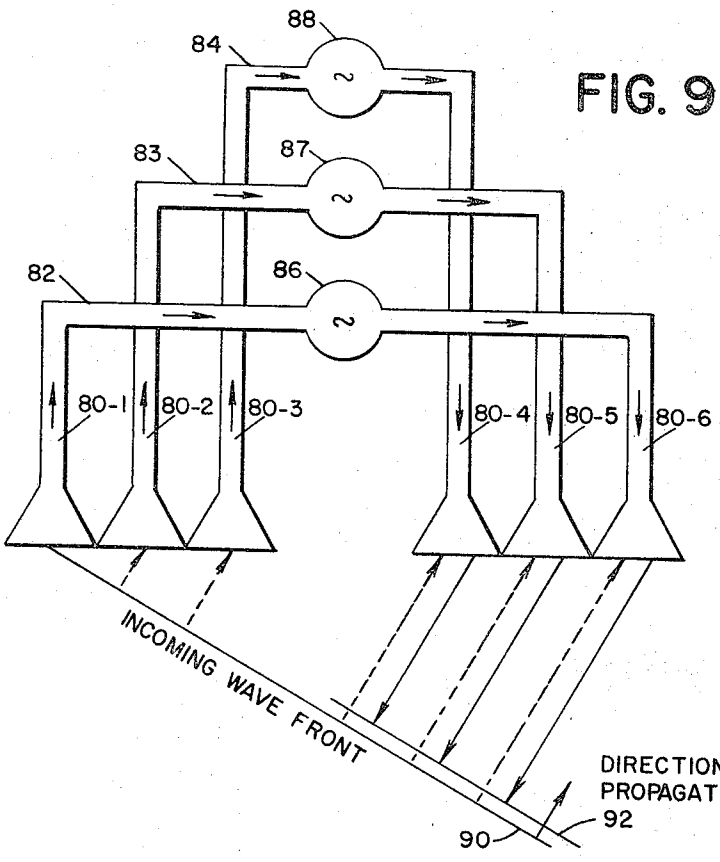


FIG. 9



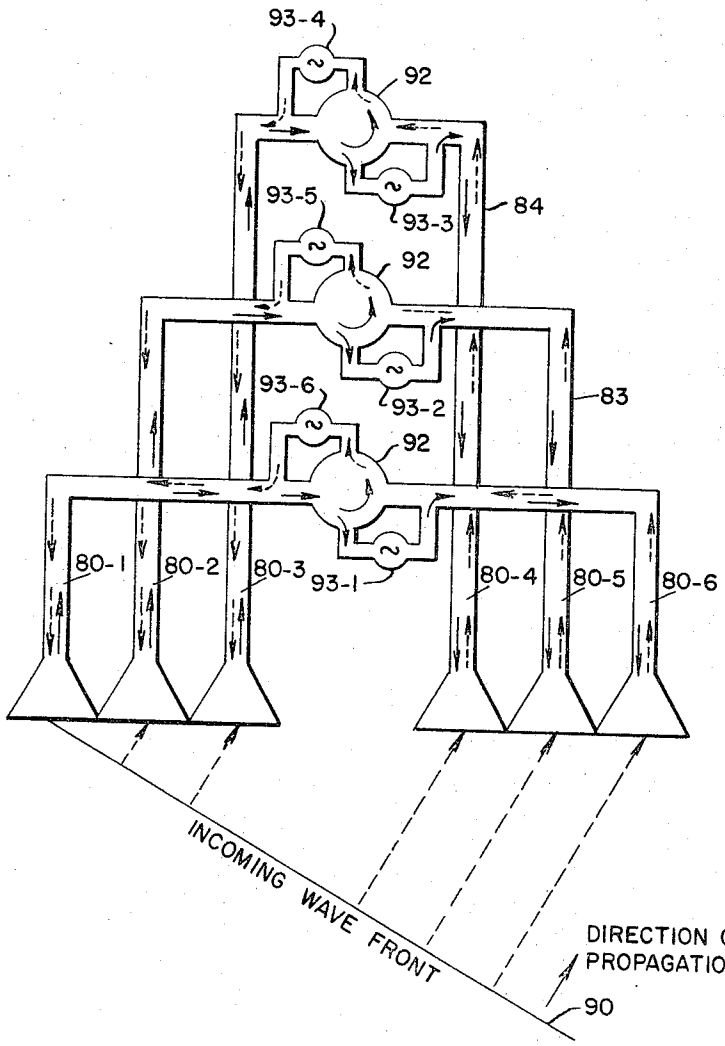
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FIG. 10



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3,340,530

DIRECTIONAL ANTENNA ARRAY

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Filed Dec. 30, 1963, Ser. No. 334,228
9 Claims. (Cl. 343—100)

This invention relates to directional antenna arrays and more particularly to an antenna array using a plurality of oscillators which are triggered by an incoming signal to produce a transmitted signal traveling in the same direction as that from which the incoming signal originated.

As is known, radio communications systems usually make use of some form of antenna at a first and second station between which radio communication is to be established. As a general matter, the different types of antenna systems can be grouped into three main categories, in accordance with the type of communications system being used. The first of these categories includes the so-called passive types of antenna systems. Here, in order to transmit information from a first station to a second station remote from the first, the first station beams energy toward the second. The second station is provided with a directional or non-directional passive antenna reflector system which receives the energy and reflects it back toward the first station. If desired, the second station can also modulate the received energy in some suitable manner to impress information upon it.

In the second category of antenna systems a nondirectional (or omnidirectional) active antenna is used at the station remote from the first station. In this case the remote station carries its own transmitter which transmits radio frequency energy modulated with information in a desired manner back to the first station. The third category of antennas are those of the active directional type, which may be used by a remote station which carries its own transmitter. Here the antenna at the remote station transmits a directional beam of energy back toward the first station.

While each of the three types of antenna systems described above has certain advantages for various applications, these same systems also have disadvantages which are inherent in their operation for any given application. In the passive or reflective type of antenna system, for example, no transmitter is needed at the remote station. Also, there is no problem of orienting the station when an omnidirectional passive reflector is used. However, when this type of passive antenna system is used the first station must transmit a large quantity of power in order for an adequate amount of energy to be received at the remote station and reflected back to the first station. This, of course, greatly increases the size and complexity of the transmitter at the first station. Similarly, while the second type of system, using a transmitter and omnidirectional antenna at the remote station, also has no problem of orienting the remote station's antenna, it imposes the requirement of a relatively large transmitter at the remote station when the first station is located a considerable distance away. Where the second station is unattended and/or inaccessible, any failure of its transmitter destroys communication between the two stations. While the third type of system using a transmitter and directional antenna at the remote station does not necessarily need the large transmitter required by the omnidirectional antenna, it should be understood that the remote station and/or its antenna must be stabilized and oriented in such a way so that the remote station's directional antenna points toward the first staion.

In many cases, for example in a communications satellite, the problem of orienting the station and/or its antenna with respect to the first station is so great that the advantages obtained by using directional antennas are often outweighed by disadvantages introduced by the orientation equipment. It therefore becomes desirable to provide an antenna system which has the advantages of a directional antenna but does not introduce all of the problems and equipment associated with orientation. The latter means that the antenna should be capable of operating over a fairly large angular range. One antenna system which has been designed to accomplish this is the so-called electronically scanned antenna. In this type of system an antenna array is provided which has a number of elements and the phase of the energy supplied to the various elements is controlled in a manner to produce a beam of energy in a given direction within the limits imposed by the antenna construction. While the electronically scanned antenna is a partial solution to the problem of providing directivity of the energy beam and reducing the orientation problem to some extent, this type of system also has disadvantages in that it needs some type of programmer, usually a computer, to control the phase shift of the energy between the elements and it also needs the phase shifters. Hence, many of the advantages introduced by this type of antenna are often outweighed by its disadvantages in some applications.

The present invention is directed to an antenna array which combines various advantages of several of the foregoing systems. In accordance with the invention, a transmitting antenna array is provided which is directional, thereby reducing the transmitter power requirements at the remote station, and which is capable of operating over a rather large angular range, thereby reducing the orientation problem. The antenna array of the present invention is formed by a plurality of separate radiator elements, each of which has its own antenna and oscillator. The oscillators of the elements in the array are designed to oscillate at the same frequency and they are triggered or phase aligned by the incoming energy received by the individual element's antenna from another station. The signals produced by the various oscillators of the array are radiated by the antennas of the individual elements. While the signals are all of the same frequency, they are of different phases as determined by the incoming signal which triggers the oscillators. This arrangement produces a transmitted beam of energy whose phase front propagates in the same direction as the phase front of the incoming wave. By reversing the direction of the beam of energy produced by the oscillators, such as by a reflector or other suitable means, the beam can be transmitted back toward the direction from which the incoming wave originated. Thus, if the original wave is produced by a first station, a second station carrying the antenna array can communicate with the first station by any suitable techniques such as by modulating the energy produced by the element oscillators.

As can be seen, the antenna array of the present invention produces a directional beam of energy which is transmitted back to the station which produced the wave which triggered the element oscillators of the array. Thus, the antenna array has the advantages of a directional type of antenna. At the same time, the antenna array is capable of operating over a fairly wide angular range, which in some cases may be extended over a complete spherical configuration. This substantially eliminates the orientation problem. Also, the array of the present invention does not need or use the programmer and phase shifters normally associated with electronically scanned antennas even though it is capable of operating over a large angular range. This greatly reduces the complexity of the asso-

ciated equipment needed for providing communication between the two stations.

It is therefore an object of the present invention to provide an antenna array having a plurality of oscillators which are triggered by an incoming wave.

A further object of the invention is to provide an antenna array which responds to an incoming signal to produce a directional beam of energy.

Still a further object of the invention is to provide an antenna array in which a plurality of oscillators are triggered by an incoming wave to produce signals at the same frequency but of different phases, these signals being combined to produce a wave which is transmitted in the same direction as the incoming wave.

Yet another object of the invention is to provide a directional antenna array in which a plurality of oscillators respond to an incoming wave to produce a wave which travels in the same direction as the incoming wave and a reflector is also provided to reflect the wave produced by the oscillators back in the direction from which the incoming wave came.

Other objects and advantages of the present invention will become more apparent upon reference to the following specification and annexed drawings in which:

FIGURE 1 is a schematic drawing illustrating the operation of a conventional electronically scanned antenna;

FIGURE 2 is a drawing showing a linear antenna array made in accordance with the principles of the present invention and illustrating certain operating features thereof;

FIGURE 3 illustrates the operating principles of the array of FIGURE 2 when used with a reflector;

FIGURE 4 is a perspective view of an antenna made in accordance with the principles of the invention;

FIGURES 5 and 6 are perspective views showing various arrangements for mounting the antenna array of FIGURE 4;

FIGURE 7 is a schematic diagram of one type of circuits for use as the array element;

FIGURE 8 is a schematic diagram of one type of modulator system for use with the antenna of the present invention; and

FIGURES 9 and 10 show other types of antenna arrays using the plurality of oscillators.

To explain certain of the operating principles of the present invention reference is made to FIGURE 1 which shows a linear array of radiating elements **11**–A to **11**–F of a conventional electronically scanned antenna **10**. The elements **11** are separated from each other by a distance d and are fed from a source **13** of radio frequency energy through a number of phase shifters **15**A–**15**E. Each phase shifter **15** is interposed between two adjacent elements and illustratively introduces a phase shift θ in the energy to be transmitted. Thus, the energy radiated by element **11**D leads the energy radiated by element **11**E by this angle θ while the energy of the last element **11**F in the array lags the energy of element **11**A closest source **13** by an amount 5θ. The phase of the energy radiated by each element is shown adjacent to it.

The phase difference between two elements can be translated into a time difference between the times that two identical waves of the same phase leave adjacent elements, D and E for example, in the time for one complete cycle of the radiated energy wave the wave will travel a distance of c/f or

$$\frac{2\pi c}{\omega}$$

The distance that a wave will travel in time corresponding to the phase shift θ is then

$$\frac{\theta c}{2\pi f}$$

or

$$\frac{\theta c}{\omega}$$

The electronically scanned antenna array of FIGURE 1 can be considered as having a number of radiating elements which generate a number of identical signals of the same frequency and phase, each signal leaving θ before the one after it and traveling a distance

$$\frac{\theta c}{\omega}$$

before the wave from the next adjacent element leaves. Therefore, a constant phase front wave will be produced at an angle α with respect to the array which is given by

$$\alpha=\sin^{-1}\frac{\theta c}{d}$$

The distance that the wave produced by each element travels in reaching the phase front is shown adjacent each element. By varying the phase delay introduced by each of the phase shifters **15** the angle α can be varied and the phase front of the antenna beam produced by the elements will therefore scan electronically.

The type of electronically scanned antenna shown in FIGURE 1 is conventional in the art. The principles of the linear array shown have also been extended to planer arrays which can propagate a two-dimensional wave at any angle and in any direction from the surface of the planer array. In both the linear and planer array types of electronically scanned antennas the phase differences produced by the phase shifters are generally controlled by a computer or by varying the electrical path length between the source of radio frequency energy and the individual radiating elements in some other predetermined manner. While these antennas can be electronically scanned fairly rapidly, a considerable amount of complicated equipment is necessary to calculate, control and produce the phase shifts needed to do this. Thus, the antenna is usually extremely bulky and complicated. Also the directional properties of the electronically scanned antenna may be somewhat limited.

FIGURE 2 is a diagram which represents certain of the operating principles of the antenna array of the present invention. For the purpose of explanation, this array may also be considered to be electronically scanned like the antenna array of FIGURE 1. However, unlike a conventional electronically scanned antenna, the phase differences between different antenna elements are controlled by an incoming wave **20** from another station rather than from a computer or other similar device which controls physical phase shifters.

In FIGURE 2 four radiating elements A, B, C and D out of the whole antenna are shown arranged in a linear array **19**. It should be understood that as many elements are provided as is needed. Each element, which is described in detail below, is provided with a substantially omnidirectional receiving and transmitting antenna, which may be the same antenna, and an oscillator. The oscillator at each element is provided with power from a source. In a preferred embodiment of the invention the source is turned on and off to effectuate transmission of information. This is described below. The parameters of the various components forming each oscillator are also selected to produce the same natural resonant frequency which is substantially the same and preferably equal to that of the incoming wave **20** from the other station. This other station may be on the ground or at any point in space.

In the array **19** of FIGURE 2 power is supplied to the oscillators of the elements A, B, C and D while a signal from the other station is being beamed towards it. The signal is received by the individual antennas of each of the elements and the received signal triggers the oscillator at the respective array element A, B, C or D into oscillation in phase with the signal as it is received by the respective antenna of that element. It should be clear that each element's oscillator will begin to oscillate at the same frequency but at a slightly different phase as determined

by the angle of incidence of the incoming wave with respect to the linear array **19**. Stated another way, this means that the phase between adjacent oscillators at elements A, B, C and D will be varied in accordance with the direction of the incoming wave. The signal produced by each oscillator during the reception of the incident wave is coupled to a radiator, preferably the same antenna used to receive the incoming energy, for transmission. Thus, each element radiates a wave of the same frequency, but of slightly different phase, which is in phase with the wave received by that element.

Since each of the oscillators at the respective elements A, B. C and D is producing a signal at the same frequency but of a slightly different phase, the radiated wave fronts of the signals produced by these oscillators will combine into a constant phase wave front at some point in space which is determined by the phase differences between the various oscillators. This is the same effect produced by the electronically scanned antenna of FIG. 1. However, the angle of the constant phase front wave with respect to the linear array is now determined only by the direction of the incoming wave rather than by physical phase shifters. As is described below, the resulting oscillations from each of the elements A, B, C and D in the array creates a composite wave front at least a portion of which propagates in the same direction as the direction of the original incoming wave **20**.

To explain in greater detail the creation of the phase front by the element oscillators which propagates in the same direction as the incoming phase front **20**, consider that each of the elements A, B, C and D of FIGURE 2 includes a sinusoidal oscillator and a small, individual receiving and radiating antenna such as a dipole. The power to each of the oscillators is off and there is no signal from ground. The ground or other first station now beams a signal of radio frequency energy towards the second station carrying the array. After a suitable time for transmission between the two stations, the array of FIGURE 2 is completely immersed within the signal from the first station, termed the ground transmitter in FIGURE 2. For clarity of understanding, the incoming wave front **20** coming from the ground transmitter is broken up so that each complete cycle of oscillation consists of 10 equal divisions of 36°. The first eight, portions 0 through 7, are indicated in FIGURE 2. Each of the oscillator elements A through D, begins oscillation in phase with the incoming wave at the same time but in different phase because the phase of the incoming wave is different at A, B, C and D. Thus in this simplified illustration, the wave from D is 72° behind the phase of the wave from C and the wave from C is 72° behind the wave from B.

It is possible, by using Huygens principle, to find the wave front resulting from the waves radiated by elements A through D. To do this, the wave fronts at the same phase must be added geometrically. The concentric circles surrounding each element indicate the waves which are radiating from each and the numbers associated with it indicate the phase with reference to some arbitrary datum. Thus C–**6** is the wave radiating from element C having a phase of 6×36° or 216°. In order to find the geometric sum of the radiating waves, they must be added so that the identical phase fronts are brought together. Thus, if the radiating wave fronts are added at the phase 7×36° or 252°, the resulting wave front is that labeled **25**–7 in FIGURE 2 which is obtained by adding A–7, B–7, C–7 and D–7, the contributions from each of the elements at the proper phase. The wave fronts indicated by **25**–**5** and **25**–**3** are the resultant wave fronts at phase 5×36° and 3×36° respectively. Since the resulting wave travels in the direction of increasing phase, it is easy to see that it will proceed from left to right in FIGURE 2.

In operation the oscillators of the four elements A–D of FIGURE 2 are all supplied with power at the same time and are triggered into operation by the wave **26** which is impressed upon each element's oscillator at the time power is applied. Each oscillator begins oscillation at a different phase but at the same frequency. The difference in phase is attributed to the angle between the incoming wave front **20** and the line of the array. When the resulting transmitted waves are added by Huygen's principle, the result is a transmitted wave **25** traveling in the direction of the original incoming wave. The transmitted wave front **25** is many times stronger than the incoming wave front **20** but travels in the same direction.

By placing a reflecting device, such as a 90° corner reflector adjacent the array **19**, the transmitted wave front **25** can be reflected by 180° and sent back toward the direction of the source from which the incident wave front **20** came. Thus the array of FIGURE 2, when provided with a reflector, can transmit a directional beam of energy in a direction exactly opposite to that of the incident beam which triggers the array. Thus, the array **19** when provided with a reflector can be considered as a scanning type of antenna which transmits a beam of energy back in the same direction from which the incident beam originated. The scanning angle of the array is only dependent upon the angle of incidence of the incoming wave and, as shown below, the angular scanning range is limited by the type of reflector used.

A conventional corner reflector **26** for the linear array **19** of FIGURE 2 is shown in FIGURE 3 and is formed by two sheets of electromagnetic energy reflective material **27** and **28** placed at right angles to each other. The array **19** of FIGURE 2 is shown having its elements A, B, C and D located within the aperture of the reflector. Incoming wave **20** impinges upon the elements of array **19** which produces the transmitted outgoing wave **25** in the same direction as the incoming wave in the manner described with respect to FIGURE 2. Several portions **30**–**33** of the outgoing wave front **25** are shown striking the reflectors **27** and **28**. These portions **30**–**33** undergo a 180° change of direction at the reflector walls and are reflected toward the direction of the incoming wave **20**. While only the portions **30**–**33** of the transmitted wave front **25** are shown it should be understood that the same reflection is produced for the complete wave front **25** so that all of it is reflected by 180° to produce the final wave front **25R**. Therefore, a directional beam **25R** is produced by the array **19** and reflector **26**, this beam being in the opposite direction to the incoming wave front **20**. This means that the beam **25R** will end up at the source which produced incoming wave **20**. The maximum aperture or effective scanning angle range of the antenna array of FIGURE 3 is approximately 90° as limited by the mouth of the reflector **26**. The scanning range can be varied by using other types of reflector arrangements.

The signal transmitted by the other station to trigger the various oscillators of the array **19** need not be exceptionally strong but only of sufficient strength to be greater than the noise normally present in the oscillator circuit at each element. The resultant transmitted wave front **25R** produced by the oscillators is far stronger than the received signal and completely engulfs it as both signals impinge upon the corner reflector and propagate back in the direction of the incoming signal.

FIGURE 4 shows the principles of the present invention, as described with respect to the linear arrays of FIGURES 2 and 3, extended to a planer array **35** of elements which can produce a radiated directional beam in two dimensions. Array **35** is arranged in front of a corner reflector **37** which is formed by three sheets of reflective material **38**, **39** and **40** placed at right angles with respect to each other. The corner reflector **37** is capable of reflecting by 180° any wave coming into its aperture. The reflector **37** has an angular range effective over a solid angle of 90°, i.e., it covers one octant of a sphere. The array **35** of elements is suspended in a plane within the aperture of the reflector **37** in a manner so that there is little as possible signal energy absorbed by each element and its supporting structure. One manner of doing this is shown

in FIGURE 4 in which a fishnet type of structure is suspended between the outer corners of the pieces **38**, **39** and **40** of the corner reflector. This fishnet is preferably formed by a number of strands of light, stringy material, such as nylon, which run in two directions in the plane of the array. Since the antenna array of the present invention is not adversely affected to any great degree by small translations or rotations of the elements **42** there is no need for real rigidity in the fishnet and the supporting wires and strings may be quite thin and light.

At each intersection or at selected intersections of two strands of the fishnet an element **42** is located. These elements **42** are the same as elements A, B, C and D described in the linear array of FIGURES 2 and 3 and are shown by the dots on FIGURE 4. The power for the oscillator of each of the elements **42** is provided by wires **44** which run along the strands of the fishnet. Alternatively, these wires could form the fishnet. It is also possible to make the array **35** rigid by mounting the elements **42** on a piece of radiant energy transparent material. This would be, for example, a printed circuit board on which the components of the oscillators and the antennas are printed or otherwise placed by using other suitable techniques such as microelectronic deposition for the oscillators and strip lines for the antennas. In all types of array structures, whether flexible or rigid, the elements **42** are preferably encapsulated or provided with some other type of environmental protection.

The planer array **35** of FIGURE 4 operates in accordance with the same principles as the linear arrays **19** of FIGURES 2 and 3. Depending upon the direction of the incident wave front the oscillator for each element **42** will be triggered into operation at slightly different places to produce a transmitted wave front traveling in the same direction as the incident wave front. This transmitted wave front is reflected 180° by the reflector **37** and sent back in a direction opposite that of the incoming wave. Because of the planer array **35** and the corner reflector a directional beam in two dimensions can be received and retransmitted.

It should be noted that the mounting angle of the array **35** with respect to the reflector **37** is not critical since any wave incident to the array will always produce the desired result of having the array produce a transmitted wave traveling in the same direction as the incident wave. For example, even if the incident wave phase front is parallel to the plane of the array, the resultant transmitted wave phase front will be in the same direction before it is reflected by 180°.

The effective angle of operation of the fishnet antenna of FIGURE 4 is 90 solid degrees, or a single octant in space. This antenna could be used on any type of vehicle in which the vehicle or antenna could be stabilized so that the antenna would be within a 90° range of the source transmitting the incoming wave front **20**. If this gross stabilization requirement is satisfied then the fishnet antenna will retransmit energy in a direction opposite to that of the incoming energy. This gross stabilization to within only 90° is a much simpler requirement to meet than the requirements imposed by the finer orientation and stabilization needed for a directional antenna of the narrow-beam type and it can be achieved relatively simply.

In order to further increase the angular range of the fishnet type of antenna, two or more could be mounted back to back thereby increasing the total angular range of the composite antenna by an octant of a sphere for each fishnet antenna that is added. Where eight of these antennas are combined as shown in FIGURE 5, the edges of the reflectors are trimmed to resemble a sphere and are effective to receive energy from any angle without any sort of orientational stability needed for the vehicle or the composite antenna.

Eight corner reflector fishnet antenna arrays **45** can also be extended, such as by rods **55** from different points of a vehicle as shown in FIGURE 6 to cover a complete sphere of operation for receiving and transmitting a directional beam. In this embodiment the antenna array **45** are mounted on a communication satellite **50**. The advantages of the embodiment illustrated in FIGURE 6 are that the surface area of the satellite may be used for mounting solar batteries **52**, test and sensing devices, such as the radiation and particle detectors **53** and **54**, and other instruments (not shown).

It should also be understood that the various embodiments of antennas shown in FIGURES 6 and 7 can be modified by removing one or more of the fishnet antennas **45**. This, of course, will reduce the overall angular range of the composite array. In the embodiment of FIGURE 7, removing one of the antennas **45** will make some sort of orientation arrangement necessary for the vehicle. However, the large angular range provided by the remaining antennas **45** still reduce the orientation problem to a degree where it can be handled fairly easily.

It should be understood that the fishnet antenna of FIGURE 4 has several constructional advantages which makes its use particularly adaptable for certain applications. For example, the antenna may be sent aloft as a package in which the three pieces **38**, **39** and **40** forming the corner reflector **37** are folded one on top of the other with the fishnet array **35** folded therebetween. In a preferred embodiment of this arrangement the three pieces of the reflector have springs interposed therebetween with the pieces being held together by suitable fasteners. At the proper point in space the fasteners are released so that the springs snap the reflector pieces to the open condition. The reflector is also provided with suitable catches for holding the pieces in this open condition. This provides a relatively simple and compact arrangement for unfolding the antenna in space.

FIGURE 7 shows a circuit for use as one of the elements **42** of the array **35**. Here an antenna **60** is provided which both receives the incoming wave and transmits the wave produced by the oscillator. While the antenna is illustratively shown as a dipole it should be understood that any other suitable type may be used, for example, a feed horn having a common feed element and open front and back horns pointing toward and away from the reflector, a monopole, slotted waveguide, slotted line, printed slot line antenna, etc. All of these antennas are well known in the art and the only requirement imposed upon them is that the antenna radiation pattern be capable of operating over an angular range at least equal to that of the corner reflector. Design of antennas for satisfying this requirement is conventional in the state of the art and no further description thereof is needed.

The signals received by the antenna **60** are coupled to one winding **62** of a transformer **61**. Winding **62** is inductively coupled to a second transformer winding **63** which is connected between the base electrode of a transistor **65** and a point of reference potential. A third transformer winding **64** which is shunted by a capacitor **68** is connected to the collector of the transistor by a capacitor **67**. Bias is supplied to the transistor from a suitable power supply (not shown) by the resistors **69** and **70** which are connected respectively to the emitter and collector electrodes.

The transistor **65** and its associated components form an oscillator circuit which produces a signal of a frequency which is determined by the parameters of the transformer **61** and the capacitor **68**. This frequency is selected to be substantially the same as the frequency of the incoming wave used to energize the oscillator. The various components of the transistor are adjusted, for example, by setting the bias voltages and/or by varying the coupling between the transistor windings **62**, **63** and **64** so that the transistor will not be self-oscillating. However, when an incoming wave is received by antenna **60** it is coupled to transformer winding **62** and then to the base winding **63** to provide a signal to start the transistor oscillating. Feedback is provided by the winding **64** and

a portion of the signal in this winding is coupled to winding **62** for radiation by antenna **60**. Thus, the incoming wave from the ground station triggers oscillator **65** into oscillation and sets an initial phase for the oscillator. This incoming wave is not necessarily needed for continued operation of the oscillator.

While a transistor oscillator circuit has been shown it should be understood that any other suitable type of circuit may be utilized. For example, a tunnel diode, or other suitable type of semiconductor device may be used. Also, the transistor or tunnel diode may be of the printed or microelectronic variety in order to conserve space. The components of the circuit may be protected, for example, by encapsulation or other suitable means. Also, strip line or printed circuit components may be used for transmission line parameters at high frequencies.

While the circuit shown in FIGURE 7 contemplates that the oscillator for each of the elements **42** is an integral part thereof and is suspended on the fishnet antenna, it should be understood that only the receiving and transmitting antenna portion **60** of each element need be mounted on the fishnet and that the oscillator can be mounted at some other place, for example, the vehicle or base station on which the structure is used. In this case, the fishnet would have wires connecting each of the element antennas to an individual oscillator which is located somewhere on the vehicle.

FIGURE 8 shows a circuit for modulating information onto the energy produced by the elements **42** of the array. Here a transducer **72** generates the information which is to be transmitted. The transducer **72** may be of any suitable type, such as a thermometer, radiation measuring device, etc. The output of the transduced is applied to a code converter **73** which preferably produces a pulse-type code in response to the transducer output. This code is applied to a keyer **74** which also has applied thereto the power supply voltage from a source **75** for all of the oscillators of the elements **42** in the array. The keyer is any suitable device, for example, a silicon controlled rectifier, which is rendered conductive during and in response to selected portions of the code, for example, positive or negative bits thereof. This permits the voltage from the supply **75** to be applied to the oscillators so that they will be energized by the incoming wave.

In operation, the other station which is trying to communicate with the station having the array **45** will send out a relatively long continuous wave and will receive back a message in the form of bits as determined by the code converter **73**. In a preferred embodiment of the invention the power supply is energized only during selected periods by a master switch such as a timer. This will conserve the power supply and thereby reduce the requirements for batteries if the array is to be used at a station in which the batteries cannot be replaced or recharged readily.

FIGURE 9 shows an embodiment in which the principles of the present invention have been extended to a so-called Van Atta type array. Here a linear array of antennas **80–1 . . . 80–6**, which are illustratively of the horn type, are arranged in two sets **80–1**, **80–2** and **80–3** and **80–4**, **80–5**, and **80–6** which are disposed about a geometric center. The horn antennas **80–1** and **80–6**, **80–2** and **80–5**, and **80–3** and **80–4** are connected by the respective transmission media **82**, **83** and **84** which have equal electrical lengths. The transmission media **82**, **83** and **84** may be of any suitable type such as coaxial lines, two-wire lines, wave guides, etc. An oscillator **86**, **87** and **88** is disposed in the path of each transmission medium **82**, **83** and **84**.

Considering an approaching wave front **90**, it can be seen that this wave front strikes elements **80–1**, **80–2** and **80–3** at different times depending upon the angle of incidence. The wave incident on these three horn antennas travels down the transmission media **82**, **83** and **84** and triggers the respective oscillators **86**, **87** and **88**. Each oscillator is energized in phase with the received incoming wave front **90** and produces a signal of the same frefrequency. Thus, the signal continuing down each transmission media towards the respective antennas **80–6**, **80–5** and **80–4** bears the same phase relationship to the incoming wave front at antennas **80–1**, **80–2** and **80–3**.

It can be seen that the electrical wave length or path for each of the signals striking the respective antennas **80–1**, **80–2** and **80–3** and exiting through the respective antennas **80–6**, **80–5** and **80–4** is the same since the transmission media **82**, **83** and **84** are of equal length. Consequently, the wave front exiting from the antennas **80–4**, **80–5** and **80–6** travel in the opposite direction as the incident wave front **90**. This means that the waves produced by the oscillators form a new wave front which travels back along the direction from which the received signal was transmitted. Thus, the array of FIGURE 9 produces a 180° reversal in direction between the received signal and the signals produced by the respective oscillators. The incident signals impinging upon antennas **80–4**, **80–5** and **80–6** will reach the oscillators connected to these antennas after they have been triggered by the waves which first impinge on antennas **80–1**, **80–2** and **80–3**. Hence, the oscillator will be triggered by the first wave received and the signals incident on antennas **80–4**, **80–5** and **80–6** will not otherwise affect the operation of the system. The reverse would be true if the incoming wave struck antennas **80–1**, **80–2** and **80–3** last.

The array shown in FIGURE 9 has been described in linear form for simplicity. It should be obvious that the principles of this array can also be extended to a planer array in the same manner as described with respect to FIGURE 4. Hence, a wave in two dimensions can be produced for re-transmission back to another base station. While the array of FIGURE 9 has also been shown as using horn type antennas it should be understood that any other suitable type can be used, for example, a dipole, folded dipole, slot line, etc.

In the array of FIGURE 9 half of the antenna area is used for receiving the signal from the other station and the other half is used for transmitting a signal back to this station. An array for decreasing the wasted antenna area is shown in FIGURE 10. Here, the same type of antenna element such as horn antennas **80–1 . . . 80–6** is used but now a circulator **92** is placed in each of the respective transmission lines **82**, **83** and **84**. These circulators **92**, which may be of the strip line type, for example, have two oscillators **93** associated therewith. Each circulator receives energy from both of the connected horn antennas and conveys it to one of the oscillators. Thus, considering, for example, circulator **92** connected in transmission medium **82**, the incoming energy picked up by antenna **80–1** is shifted counterclockwise by 90° through the circulator **92** and applied to the oscillator **93–1**. Oscillator **93–1** in transmisison medium **82** is triggered by this energy and the signal it produces is conveyed the remaining length of the transmission medium **82** to exit through antenna **80–6**. Similarly, the energy picked up by antenna **80–6** is shifted 90° clockwise by the circulator **92** and applied to the oscillator **93–6**. Oscillator **93–6** is energized and its energy is transmitted via antenna **80–1**. The other antenna pairs work in the same manner. Thus, in the array of FIGURE 10 each antenna **80** serves as both a receiving and a transmitting antenna by virtue of the circulator **92** which is interposed in each of the connected transmission medium. This means that all of the antenna area is utilized for both transmission and reception. The principles of the linear array of FIGURE 10 may also be extended to a planer array.

It should be understood that the arrays of FIGURES 9 and 10 have advantages over the fishnet antenna described in FIGURE 4, the main advantage being in the angular range of operation. Antennas such as the horns **80** shown in FIGURES 9 and 10 can have a relatively

large angular opening by making the horn apertures small with respect to the mouth of the horn. In many cases this angular range of operation can approach 180°. Thus, while the fishnet antenna of FIGURE 4 is limited in range to one octant by the corner reflector, a planer array of horn antennas would not be so limited.

It should be understood that each of the various embodiments of arrays shown can be used at either a fixed or a movable station of any type, the latter including aircraft, ships, satellites, etc. Also, while one type of oscillator circuit has been shown in FIGURE 7 it should be understood that any other type of oscillator circuit may be used including those of the crystal controlled type for increased oscillator frequency stability. Further, since the arrays use a plurality of oscillators, failure of any one or several of the oscillators will not seriously detract or destroy the overall performance of the array. This is a distinct advantage over those antenna arrays which use only a single oscillator whose failure will destroy the operation of the entire system.

While preferred embodiments of the invention have been described above, it will be understood that these are illustrative only, and the invention is limited solely by the appended claims.

What is claimed is:

1. An antenna array for transmitting electromagnetic energy in response to and toward the same direction as the incident electromagnetic energy from a source comprising:

a plurality of radiator elements, each of said elements including

(a) means for receiving the incident electromagnetic energy at a phase in accordance with its position with respect to the phase front of the incident electromagnetic energy,

(b) normally quiescent oscillator means coupled to said receiving means for producing a signal in response to the received incident energy and at a predetermined phase relationship therewith,

(c) and means coupling said oscillator means to said receiving means for radiating the signal produced thereby, the signals produced by said plurality of radiator elements transmitted as energy with a phase which travels in the same direction and has the same phase characteristics as the phase front of the incident energy,

reflector means comprising a corner reflector adjacent the receiving means of said radiator elements for reflecting the phase front of the transmitted energy by substantially 180°, and means for mounting at least the receiving means of each said radiator element in a predetermined spaced relationship to said reflector means.

2. An antenna array as set forth in claim 1 wherein said mounting means comprises a plurality of strands of flexible material.

3. An antenna array for transmitting electromagnetic energy in response to and toward the same direction as the incident electromagnetic energy from a source comprising:

a corner reflector of a material for reflecting electromagnetic energy,

a plurality of antenna radiator elements,

means for mounting at least a portion of each of said elements in a planer array in a predetermined spaced relationship with respect to said reflector at the aperture thereof,

each of said elements including

(a) antenna means for receiving incident electromagnetic energy at a phase in accordance with its position in the array with respect to the phase front of the incident energy,

(b) normally quiescent oscillator means coupled to said antenna means for producing a signal in response to the received incident energy and at a predetermined phase relationship therewith,

(c) and means for coupling the signal produced by said oscillator means to said antenna means for radiation thereby,

the signals radiated by the antenna means of each of said plurality of radiator elements forming a transmitted phase front of energy which travels in the same direction as the incident phase front and is reflected by said corner reflector for transmission back toward the direction from which the incident energy originated.

4. An antenna array as set forth in claim 3 wherein said mounting means includes a number of strands of flexible material.

5. An antenna array as set forth in claim 3 wherein each said oscillator includes means for producing a signal of substantially the same frequency as the frequency of the incoming signal.

6. An antenna array of the Van Atta type comprising:

a plurality of pairs of antenna elements in which each element of a pair is spaced about a geometric center point,

an electrical transmission medium of the same electrical length connecting the elements of each said pair,

circulator means connected to each said transmission medium,

a pair of oscillator means electrically connected to different points of each said circulator means,

one of said oscillator means receiving energy through the circulator means from one of the elements of the pair and being energized thereby to produce a signal which is transmitted by the other element of the pair, the other oscillator means receiving energy from the said other element of said pair through said circulator and being energized thereby to produce a signal which is transmitted by the said one element of the pair.

7. An antenna array for transmitting electromagnetic energy in response to and toward the same direction as the incident electromagnetic energy from a source comprising:

a plurality of radiator elements, each of said elements including

(a) means for receiving the incident electromagnetic energy at a phase in accordance with its position with respect to the phase front of the incident energy,

(b) normally quiescent oscillator means coupled to said receiving means for producing a signal in response to the received incident energy and at a predetermined phase relationship therewith,

(c) and means coupled to said oscillator means for radiating the signals produced thereby, the signals produced by said plurality of radiator elements being transmitted as energy with a phase front which travels in the same direction as the phase front of the incident energy,

means connected to each of said oscillator means for supplying electrical operating power thereto,

means connected to said electrical power supply means for controlling the application of said electrical power in a desired manner, to thereby modulate the on-off condition of the oscillators,

and reflector means adjacent said radiator elements for reflecting the transmitted energy by substantially 180°.

8. An antenna array operative over an angle of greater than 90° of a sphere for transmitting electromagnetic energy in response to and toward the same direction as the incident electromagnetic energy from a source comprising:

a member of radiator arrays, each of said radiator ar-

rays including a plurality of radiator elements, each of said radiator elements comprising:

(a) means for receiving the incident electromagnetic energy at a phase in accordance with its position with respect to the phase front of the incident energy,

(b) normally quiescent oscillator means coupled to said receiving means for producing a signal in response to the received incident energy and at a predetermined phase relationship therewith,

(c) and means coupled to said oscillator means for radiating the signals produced thereby, the signals produced by said plurality of radiator elements being transmitted as energy with a phase front which travels in the same direction as the phase front of the incident energy,

each of said radiator arrays also having a reflector means operative over an angle of 90°, or less, of a sphere for reflecting the transmitted energy by substantially 180°,

and means for mounting at least two of said radiator

arrays in position with respect to each other to provide an antenna array having an operative angle of greater than 90° of a sphere.

9. An antenna array as set forth in claim 8 wherein said reflector means are corner type reflectors and the corner reflectors of at least two radiator arrays are located adjacent one another.

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