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3,151,326

COMMUNICATION STATION EMPLOYING STEERABLE ANTENNA ARRAY

Filed June 1, 1962

4 Sheets-Sheet 1

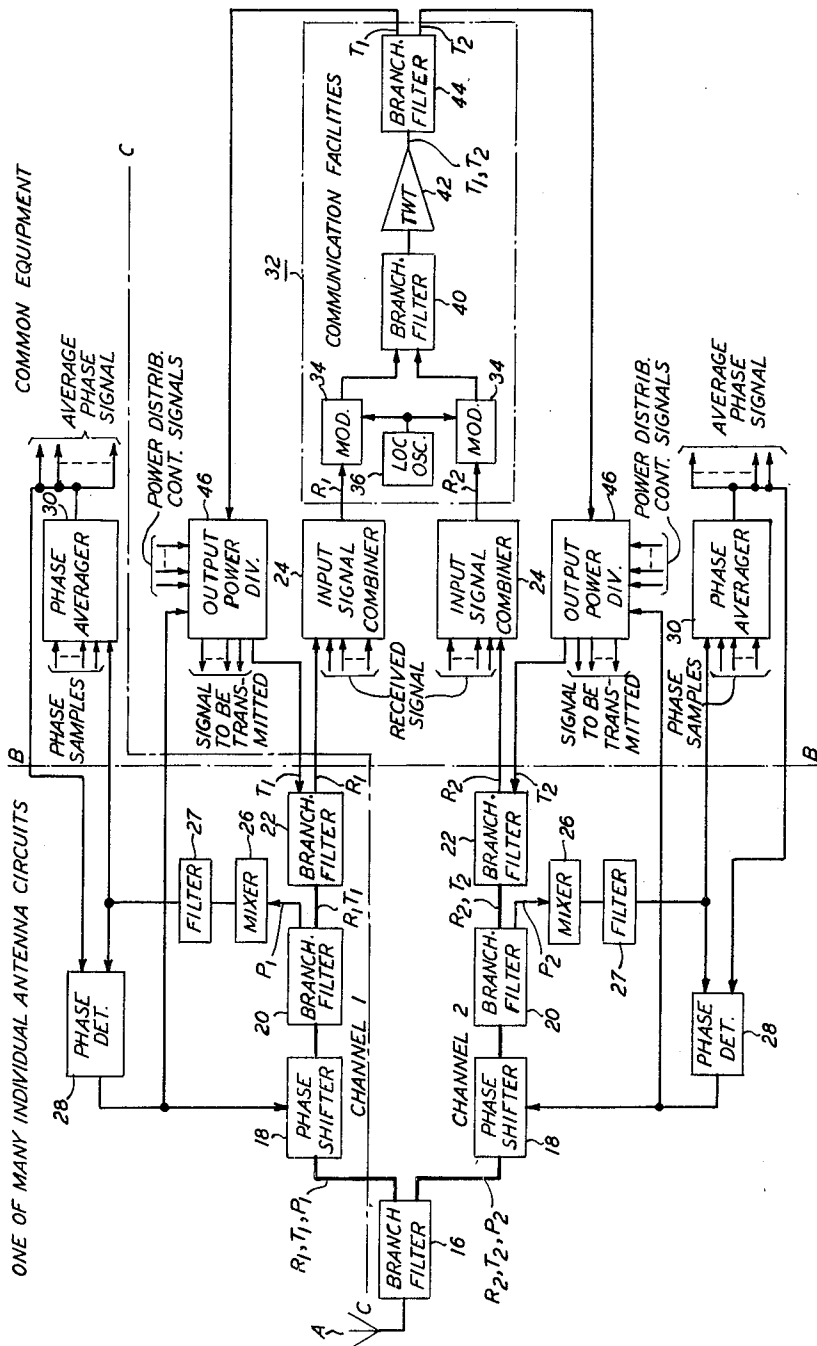


FIG. 1

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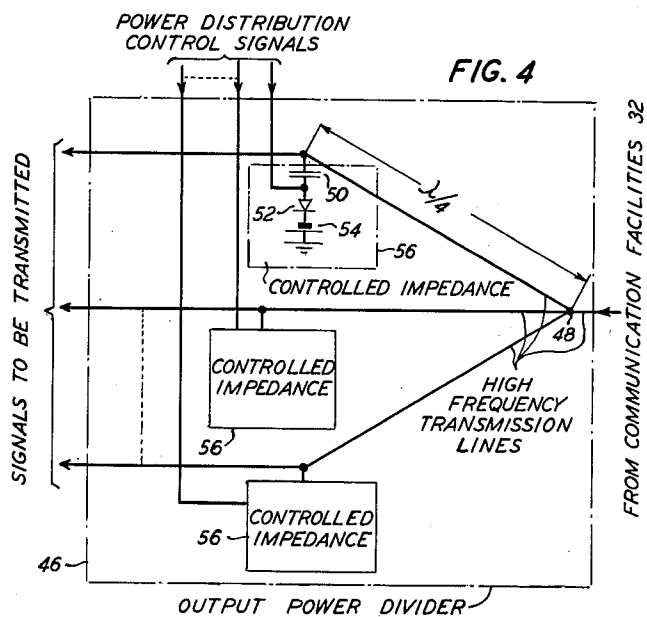
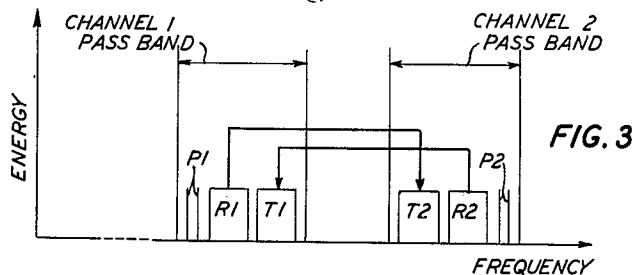
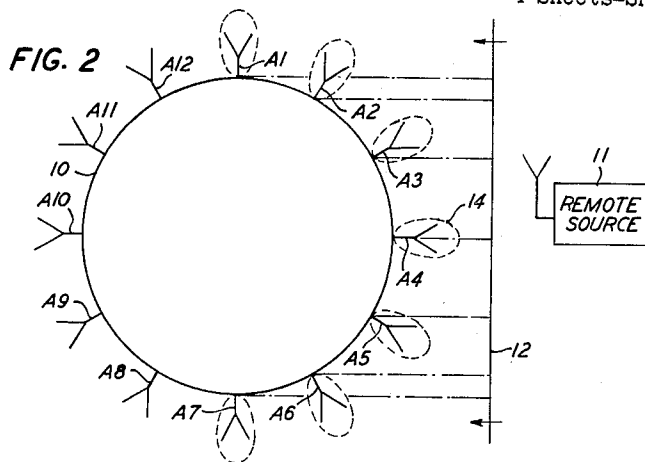
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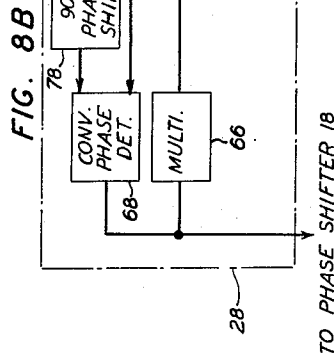
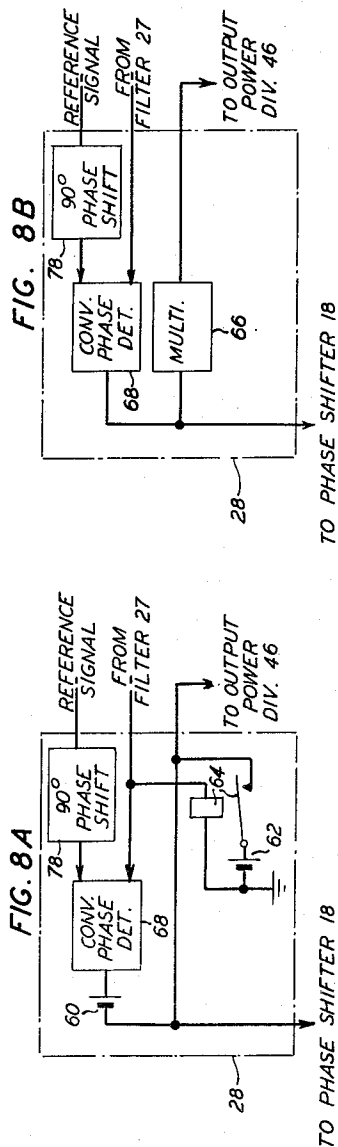
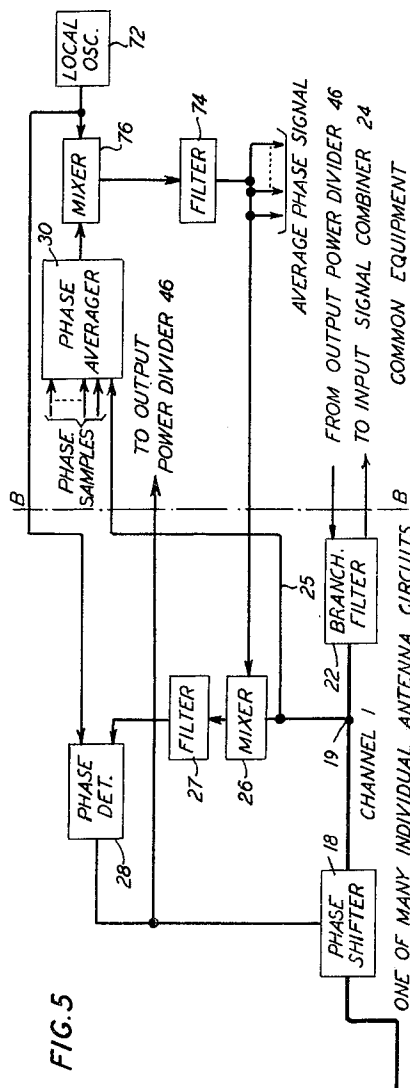
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COMMUNICATION STATION EMPLOYING STEERABLE ANTENNA ARRAY

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4 Sheets-Sheet 3



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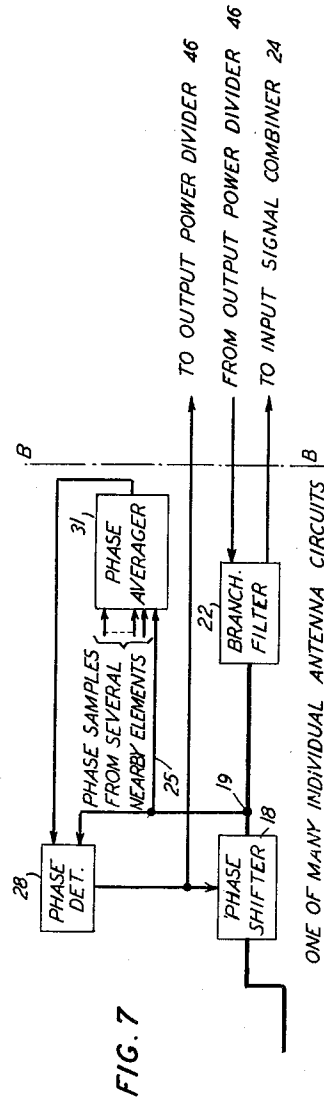
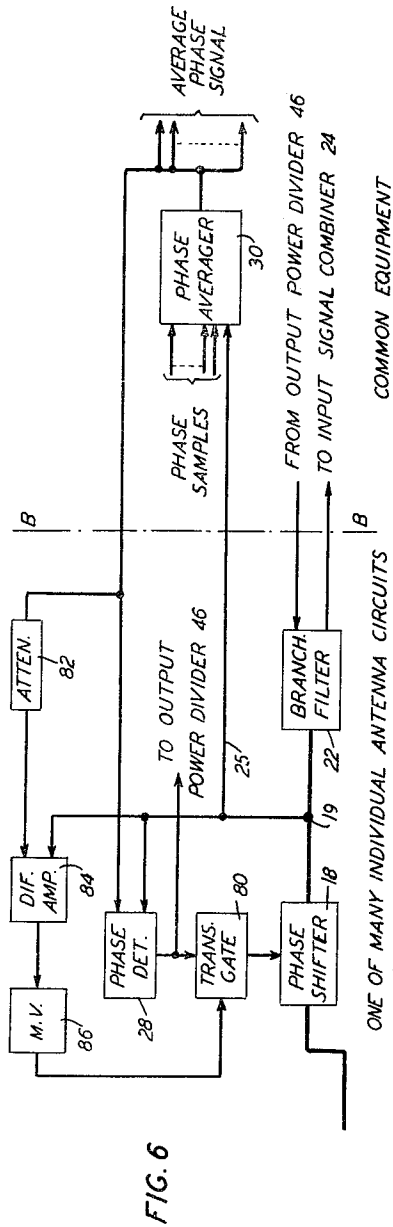
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COMMUNICATION STATION EMPLOYING STEERABLE ANTENNA ARRAY

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4 Sheets-Sheet 4



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3,151,326 COMMUNICATION STATION EMPLOYING STEERABLE ANTENNA ARRAY

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Filed June 1, 1962, Ser. No. 199,318
17 Claims. (Cl. 343-100)

This invention relates to directional communication systems and, more particularly, to apparatus accomplishing directional transmission of electromagnetic waves from an antenna array in a steerable beam toward a source of electromagnetic waves impinging upon the array.

An antenna system that retransmits electromagnetic waves impinging upon it toward the source of impinging waves is disclosed in L. C. Van Atta Patent 2,908,002, issued October 6, 1959. This effect is achieved in the Van Atta patent by interconnecting pairs of antenna elements symmetrically arranged about a center axis in a planar array with transmission lines having equal electrical length. As a result, the pathlengths from a wavefront impinging upon the array from any direction within the radiation patterns of the individual antenna elements to each antenna element, through its transmission line, and from the associated antenna element to the initial wavefront are equal, and constructive interference of the wave radiated from the array occurs in the direction of the source of the impinging wavefront.

R. C. Hansen in an article in the Proceedings of IRE, June 6, 1961, page 1066 et seq., entitled "Communication Satellites Using Arrays," has proposed that amplifiers be placed in the transmission lines interconnecting the paired antenna elements to convert the Van Atta array into a active repeater which could be employed to advantage in space satellite communications. As pointed out by Hansen, since an antenna system having the characteristics described above is capable of transmitting radio signals with high gain in a direction which depends upon the location of the source of received radio signals, the requirements of attitude stabilization of the satellite for the purpose of carrying on directional radio transmission may be relaxed.

Hansen's article adapting the Van Atta array to satellite communication repeaters has initiated suggestions of other applications in which an antenna with such characteristics would prove valuable. Mobile radio systems, for example, might utilize the Van Atta array to permit directional transmission between relatively movable stations despite the fact that the location of these stations is not known in advance. Likewise such an antenna might be mounted on top of the high structures normally found in cross country line-of-sight radio relay systems. The amount of horizontal deflection or sway of the towers caused by environmental conditions, normally minimized to maintain alignment between the directional antennas of adjacent repeaters, would not be critical if the Van Atta array were used. Thus, the structural rigidity of the towers could be relaxed and a reduction in the cost of fabrication enjoyed. Many other uses for the Van Atta array in the field of communications and radar are also brought to mind from consideration of its characteristics.

The Van Atta array is severely restricted in its application, however, because it is not readily adaptable to nonplanar antenna arrays. Moreover, a nonplanar array accommodates waves impinging upon it from a wider range of angles than is possible with a planar array. In a patent application of C. C. Cutler-R. Kompfner-L. C. Tillotson, Serial No. 162,165, filed December 26, 1961, and assigned to the assignee of this application, electronic

apparatus is disclosed which produces with any configuration of antenna elements, planar or nonplanar, the same effect as the Van Atta array. The Cutler-Kompfner-Tillotson arrangement, when in the form of a spherical array, accommodates waves impinging from any direction, i.e., it provides isotropic antenna coverage. In this system, as in the Van Atta array proposed by Hansen, a power amplifier is provided for each antenna element to prepare the radio signals for transmission by the antenna array. Generally, the power contributed to the resultant antenna beam by the individual antenna elements of a nonplanar array varies as a function of the direction of transmission desired. No provision is made, however, in the Cutler-Kompfner-Tillotson system for allocating the power to be transmitted to the individual antenna elements according to need, and some of the radiated power is consequently wasted. Another source of power inefficiency in nonplanar arrays, particularly circular or spherical arrays, arises because not all the antenna elements are exposed to the incoming electromagnetic wave. The power amplifiers associated with the unexposed antenna elements remain idle but continue all the same to consume power in maintaining their operative state. Paradoxically, power efficiency of the apparatus is a prime consideration in many of the systems where such nonplanar arrays find their greatest potential, viz., land, mobile and space communications systems.

It is, therefore, the object of the present invention to enhance the power efficiency of communication stations employing a nonplanar antenna array that is steerable in a directional beam toward a source of electromagnetic waves impinging upon the array.

In accordance with the above object, plural antenna elements comprising a nonplanar array of any desired configuration are connected through individual transmission paths to a common communication facility at which amplification is provided for a signal to be transmitted by the antenna elements toward a source of electromagnetic waves impinging upon the array. The output of the communication facility is applied to a power divider that distributes power among the individual transmission paths leading back to the antenna elements in the same relative proportion in which the antenna elements intercept power from the impinging wave. Since a single power amplifier prepares for transmission the entire signal to be radiated from the array and power is allocated to the antenna elements only in the proportion needed to produce a radiated beam in the desired direction efficient use is made of the available power.

Phase shifters situated in the transmission paths are adjusted so that the received signals intercepted by all the antenna elements combine in phase for application to and utilization in the communication facility. The signal to be transmitted is applied from the communication facility to the antenna elements through the transmission paths which introduce phase shifts relative to each other causing constructive wave addition of the radiation from the several antenna elements of the array in the direction of the source of the impinging wave. A reference signal is derived representing the average phase of the received signals from all the antenna elements. This reference signal is compared in phase with the received signal on each transmission path to develop a control signal employed to adjust the phase shifter of that transmission path. The control signals, in many array configurations, are also indicative of the relative proportion of power to be allocated to the corresponding transmission lines for the most efficient transmission and are, in these situations, used to regulate the distribution of power by the power divider to the various antenna elements.

According to an additional feature of the invention, facilitating detection of the phase difference between the

signal received on each transmission path and the average phase signal, two pilot signals differing in frequency by a small amount are received by each antenna element. These pilot signals are mixed to produce a low frequency beat signal which is operated upon to produce the control signal.

Alternatively, phase detection may be facilitated by operating upon an information-bearing signal rather than a pilot signal. The average phase signal of the received signals is mixed with the output from a local oscillator and the resultant first order upper sideband is mixed with the received signal from each antenna element, producing a first order lower sideband at the frequency of the local oscillator. To derive the control signal the phase difference between the lower sideband of the second mixing process and the local oscillator output is then detected.

Another alternative facilitating phase detection is to insert a transmission gate in each of the phase control loops to permit operation thereof only when conditions are suitable for proper phase detection.

In still another alternative scheme for facilitating phase detection each antenna element is provided with individual means for deriving a reference signal representative of the average phase of only the signals received by the closely adjoining antenna elements.

The above and other features of the invention will be considered in detail in the following specification taken in conjunction with the drawings in which:

FIG. 1 is a schematic diagram in block form of apparatus for carrying out the invention;

FIG. 2 illustrates a possible arrangement of the antenna elements forming an array used in conjunction with the circuitry of FIG. 1;

FIG. 3 depicts a typical frequency assignment of the radio signals accommodated by the system of FIG. 1;

FIG. 4 is a schematic diagram showing in detail the circuitry of the output power dividers of FIG. 1;

FIGS. 5, 6, and 7 are schematic diagrams in block form of alternative arrangements of the control circuitry of FIG. 1; and

FIGS. 8A and 8B illustrate modifications to a conventional phase detector to provide compatibility with the output power divider of FIG. 4.

FIG. 2 illustrates an array of antenna elements, A_1 through A_{12} , distributed in a circular, stationary array on a body 10. To illustrate the concepts of the invention, it is now assumed that an electromagnetic wave the wavefront of which is represented by a line 12 emanates from a source 11, remotely located from the array, and impinges upon the array. As seen from FIG. 2, the path-lengths of wavefront 12 to the different antenna elements are not equal. For example, antenna element A_4 will intercept wavefront 12 before antenna elements A_3 and A_5 , and the signal intercepted thereby will lead in phase the signals intercepted by antenna elements A_3 and A_5 . In order to combine the signals intercepted by all the antenna elements constructively, their pathlengths to the combining point must be made equal, i.e., the intercepted signals must be brought into phase with each other. In reciprocal fashion, signals applied to the antenna elements of the array from a common source must be delayed by the same amount and sense relative to each other as the relative phase between the signals intercepted by the antenna elements from wavefront 12, in order to radiate an electromagnetic wave toward the source of wavefront 12.

FIG. 2 indicates that antenna elements A_8 through A_{12} are not exposed to wavefront 12 and therefore do not contribute any power to a beam directed toward the source of wavefront 12. Furthermore, if the individual antenna elements have typical antenna radiation patterns represented by dashed outlines 14, it can be seen that because of the different orientations of the antenna elements with respect to wavefront 12, they intercept different quantities of power. For example, the peak of the radia-

tion pattern of antenna element A_4 faces wavefront 12, while wavefront 12 cuts the radiation pattern of antenna elements A_3 and A_5 obliquely causing antenna elements A_3 and A_5 to intercept less power than antenna element A_4 . Due to reciprocity, the antenna elements contribute power to the radiation beam during transmission toward the source of wavefront 12 in the same proportion as the antenna elements intercept energy from wavefront 12. Power delivered to the antenna elements in excess of this proportionate amount is wasted, and thus should be avoided if efficient operation is to be practiced.

In FIG. 1 circuitry is illustrated which achieves the requirements for efficient transmission from and reception by the array of FIG. 2. Transmission paths connect each antenna element of the array to a single repeater, linking and exchanging information between two remote communication stations. The circuitry shown to the left of line B—B is repeated for each antenna element of FIG. 2, while all the antenna elements share in common the set of equipment shown to the right of line B—B.

FIG. 3 depicts the frequency assignments of the signals accommodated by the repeater. An information signal, designated R_1 , and a pair of pilot signals, designated P_1 and located at closely adjoining frequencies, are transmitted from a first remote station and intercepted by antenna element A of FIG. 1, which represents any element of an array. At the same time, an information signal, designated R_2 , and a pair of pilot signals, designated P_2 and situated at closely adjoining frequencies, are transmitted from a second remote station and also intercepted by antenna element A. In FIG. 1 a branching filter 16 separates the signals received by antenna element A from the first and the second station for application to bilateral transmission paths, shown as heavy lines, of a channel 1 and channel 2, respectively. A channel 1 and a channel 2 are associated with each antenna element. These channels are identical in all respects except the operating frequencies which they accommodate, channel 1 being arranged to operate with the first remote station signals and channel 2 with the signals from the second remote station.

In each channel the received signal passes through phase shifter 18 which is continually adjusted by an external control signal derived by means to be described below. Phase shifter 18 should introduce a time delay which is independent of the frequency of the applied signal. A ferrite device such as shown in the article entitled "A New Technique in Ferrite Phase Shifting for Deep Beam Scanning of Microwave Antennas" by F. Reggia and E. G. Spencer in the Proceedings of the IRE, November 1957, page 1510 et seq. could be used for this purpose. Phase shifter 18 brings the received signal into phase with the signals intercepted by the other antenna elements. Thereafter, a branching filter 20 abstracts the pair of pilot signals from the transmission path. A branching filter 22 interconnects the transmission path with an input signal combiner 24 in which the signals received by all the antenna elements from the same remote station are combined for application to communication facilities 32.

The pair of pilot signals abstracted by branching filter 20 is introduced into a mixer 26 and the first order lower sideband developed by beating the pair of pilots together is separated by a filter 27. This lower sideband retains the phase characteristics of the original pilot signals but is easier to work with. It is applied both to a phase detector 28 and as one input to a phase averager 30. Similar samples from the corresponding channel of the other antenna elements are also applied to phase averager 30. Since the signals applied to phase averager 30 are all oscillating at the same frequency and differ in phase, a signal having their average phase can be obtained by linear combination. Thus, phase averager 30 could be a simple resistor of small value with respect to the source impedance presented by filters 27. Input signal combiner 24

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could also be such a simple resistive network. The average phase signal produced by phase averager 30 is applied to each phase detector 28 of the appropriate channel (channel 1 or channel 2) as a reference to be compared with the phase of the lower sideband output of filter 27. Phase detector 28 produces a control signal for adjustment of phase shifter 18 which is proportional in magnitude to the phase difference between the two applied signals. The range of differences in phase of the signals recovered by the antenna elements is directly dependent upon the frequency of received signals and the displacement between antenna elements. The maximum phase difference occurring between the inputs to phase detector 28 is a function of the frequency increment between the pair of pilot signals, not of the absolute frequencies of the pilots. By properly choosing this frequency increment between the pilot signals, with regard to the space between antenna elements, the maximum phase difference occurring between the inputs to phase detector 28 can be kept smaller than 90 degrees so that conventional type phase detecting circuitry can be utilized. The described control circuitry thus adjusts phase shifters 18 in all the channels that are operating in order to synchronize in phase the signals received from a remote station by the antenna elements.

An alternative scheme for controlling phase shifter 18 without pilot signals is shown for a single channel in FIG. 5 and may be substituted for these elements shown above and to the left of line C—C in FIG. 1. Here only signal R_1 and/or R_2 is received by antenna A from a remote station. A portion of the signal appearing on the transmission path is abstracted at 19 and applied to mixer 26. A portion of the abstracted sample is also connected by a lead 25 to phase averager 30 where an average phase signal is derived from samples taken from all the antenna elements, as described in connection with FIG. 1. The average phase signal is beat in a mixer 76 with the output from a local oscillator 72. The first order upper sideband produced by mixer 76 is selected by a filter 74 and applied to each mixer 26 of the appropriate channel (channel 1 or channel 2). In each channel the first order, lower sideband of the signal produced by mixer 26 is selected by filter 27. This sideband is a signal the frequency of which is equal to the frequency of local oscillator 72 and the phase of which, with respect to the output from local oscillator 72, is equal to the difference in phase between the average phase signal and the signal extracted from the particular transmission path. When compared in phase detector 28 with the output of local oscillator 72, the output of filter 27 develops a control voltage to regulate phase shifter 18.

An alternative to FIG. 5 is shown in FIG. 6. Here a transmission gate 80, which blocks transmission unless an enabling signal is applied thereto, is interposed between the output of phase detector 28 and phase shifter 18. Most favorable operation of the phase control loops occurs when the phase difference between the inputs to each phase detector 28 is kept less than 90 degrees. In the present embodiment, unless the conditions are such, the phase control loops are not operative and phase detectors 28 are maintained in a "rest" state. When conditions become favorable for each phase control loop, an enabling signal is generated, transmission gate 80 passes the output from phase detector 28, and the phase control loop operates to adjust phase shifter 18. The condition in which the phase control loop should be closed is indicated by the amplitude ratio of the portion of the signal abstracted at point 19 to the average phase signal. For example, in the case of the array configuration of FIG. 2 above some fixed ratio, the value of which depends in part upon the antenna element spacing, the two inputs to phase detector 28 are always separated in phase by less than 90 degrees. To derive an enabling signal for transmission gate 80 during intervals when this condition persists, the signal abstracted at point 19 is applied

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directly to one input of a difference amplifier 84 to the other input of which the average phase signal is applied through an attenuator 82. Attenuator 82 diminishes the amplitude of the average phase signal in the same ratio as the fixed ratio of the signal abstracted at point 19 to the average phase signal. Thus, when the signal abstracted at point 19 rises above the other input to difference amplifier 84 the output from difference amplifier 84 changes polarity thus triggering a cathode-coupled multivibrator 86 (Schmitt trigger circuit). The output from multivibrator 86 remains in the same state, producing an enabling signal for transmission gate 80, as long as the amplitude ratio at the input to difference amplifier 84 is maintained above the minimum fixed ratio.

FIG. 7 discloses still another arrangement useful as an alternative to that of FIG. 5. In this case a phase averager 31 is provided for each antenna element and phase samples from only a few of the adjoining antenna elements are applied to each phase averager 31. This is to be distinguished from the arrangements of FIGS. 1, 5, and 6 in which a single phase averager 30 (for each channel) accepts phase samples from all the antenna elements. In the circuitry of FIG. 7 the desired conditions are maintained by choosing only phase samples for application to phase averager 31 from adjoining antenna elements sufficiently close to the antenna element the phase of which is being controlled to insure that the inputs to phase detector 28 are always less than 90 degrees apart in phase.

A second basis for deriving the control signals to adjust phase shifters 18, applicable with circular or spherical arrays, is the amplitudes of the signals recovered by the various antenna elements. As exhibited above in conjunction with FIG. 2, the amplitude of a signal recovered by an antenna element is related to its phase. For example, antenna element A_2 recovers a signal that has both a larger amplitude and leads in phase the signal intercepted by antenna element A_3 . Either an average amplitude signal can be developed and compared with the signal amplitude recovered by each antenna element to derive a control signal for adjusting phase shifter 18, or a control signal proportional to the amplitude of the signal recovered by each antenna element can be used directly to control phase shifter 18.

As shown in FIG. 1, and regardless of whether any of the modifications of FIGS. 5, 6, or 7 are used, input signal combiners 24 present the received information signals R_1 and R_2 to communication facilities 32, which in this case is a repeater for exchanging information between channels 1 and 2. Modulators 34, driven by a common local oscillator 36, convert the information signals R_1 and R_2 to new frequencies T_2 and T_1 , respectively, as illustrated in FIG. 3. The information signals are then combined in a branching filter 40 for simultaneous amplification by a traveling wave tube 42. The output from traveling wave tube 42 is applied to a branching filter 44 which separates the information signals to be transmitted, T_1 and T_2 , for application to channels 1 and 2, respectively. Each information signal to be transmitted is applied to an output power divider 46 which distributes the signal power to the bilateral transmission paths for radiation by the antenna elements in the same relative proportion in which the antenna elements intercept power from the remote station toward which they are to radiate. The distribution is accomplished under the control of the outputs of phase detectors 28, each of which is in fact indicative of the proportionate power recovered by its associated antenna element from the remote station. The power allocated to the individual antenna elements A for each remote station by power divider 46 is coupled to the corresponding antenna element A through branching filter 22, branching filter 20, phase shifter 18 and branching filter 16. Phase shifters 18, adjusted as described above to bring all the signals recovered by the antenna elements from a remote station into phase with one another, introduce time delays

into the signals to be transmitted that cause constructive wave interference, and thus directional radiation from the array toward the remote station.

Branching filters 16, 20, 22, 40 and 44 may be of the type disclosed in FIG. 9.2-24 at page 313 of Principles and Applications of Waveguide Transmission by G. C. Southworth, D. Van Nostrand Co., Inc., 1950, or the equivalent if other than waveguide transmission apparatus, e.g. stripline, is used.

Since the transmission paths of channels 1 and 2 accommodate both transmitted and received signals, their pass bands must be designed to be wide enough to handle both frequency bands. This is illustrated in FIG. 3. Separate transmission paths could, of course, be employed for transmission and reception to connect the antenna elements with communication facilities 32. In this case, both transmitting and receiving phase shifters of each channel would be regulated by the same control signal derived by phase detector 28.

In FIG. 4 one possible circuit arrangement of output power divider 46 is shown. The closer an antenna element of the array shown in FIG. 2 is to the impinging wavefront the more power of the impinging wave it intercepts relative to the other antenna elements. Thus, the relative power desired to be distributed to the antenna elements, since it is equal to the relative power interception of the impinging wave by the antenna elements, is dependent upon the phase of the signal received by each antenna element. The antenna element associated with the received signal, the phase of which leads the average phase of all the received signals by the largest amount, should be provided with the greatest proportion of the total power. Incrementally less power should be allocated to the antenna elements in decreasing order of phase lead, the element associated with the received signal that lags in phase the average phase of all the received signals by the greatest quantity receiving the least power for transmission. Of course, the antenna elements not exposed to the impinging wave are not allocated any power for transmission. The power allocation to the antenna elements for transmission may be accomplished in practice on one of two bases. First, power is distributed to each antenna element in the same proportion to the remaining antenna elements that the power received by that antenna element bears to the power received by the remaining antenna elements. Second, the antenna elements, the received signals of which lead in phase the average phase of the received signals, are all distributed power in equal quantities and the remaining elements receive no power. This provides a close approximation to the first bases of power distribution because there the antenna elements associated with the lagging received signals do not contribute much of the total power.

If the former result is desired, the output from phase detector 28 to be compatible with the circuit of FIG. 4 described below, is a unipolar signal becoming increasingly negative from the condition wherein the phase of the received signal lags the average phase of all the received signals to the condition wherein the phase of the received signal leads the average phase of all the received signals. Such an arrangement for phase detector 28 is shown in FIG. 8A. The two signals to be compared i.e., the particular received signal and the average phase signal, are applied to the input leads of a conventional push-pull phase detector 68 such as that disclosed at page 45 in FIG. 1 of S. Krishnan's article in the publication Electronic and Radio Engineer, February 1959, entitled "Diode Phase Detectors." One of the inputs is connected to phase detector 68 through a device 78 that introduces a 90 degree phase shift. The output of conventional phase detector 68 is then zero when the signal from filter 27 is in phase with the reference signal (average phase signal with control circuitry of FIGS. 1, 6, and 7 or local oscillator output with control circuitry of

FIG. 5), becomes negative when the signal from filter 27 leads the reference signal, and becomes positive when the signal from filter 27 lags the reference signal. Conventional phase detector 68 is calibrated by connecting in series with its output lead a battery 60 producing a terminal voltage that causes a zero voltage on the output lead when the signal from filter 27 lags the reference signal by 90 degrees.

As shown in FIG. 4, a single transmission line, comprising a waveguide or a coaxial cable, because radio frequency signals are being carried, connects communication facilities 32 with a junction point 48 out of which emanate similar transmission lines to branching filters 22 of the various antenna circuits. Displaced one quarter wavelength from junction point 48 on the transmission lines are situated controlled impedances 56, each of which comprises the series combination of a direct-current blocking capacitor 50, a diode 52 and a battery 54 shunted to ground. Control voltages are applied from phase detectors 28 to controlled impedances 56 of their respective transmission lines at the node joining capacitor 50 and diode 52. When no voltage is present on the output lead of detector 28 the corresponding diode 52 has a large forward bias that short circuits the transmission line at that point to ground and reflects an open circuit to junction point 48. In this state no power is distributed to the transmission line. Upon the application of a negative voltage from phase detector 28, the forward bias on diode 52 becomes smaller, thus increasing the impedance at that point on the transmission line. As a result, the impedance of the transmission line at junction point 48 decreases permitting a larger power transfer to it. If the antenna element receives none of the impinging wave, there is no signal from filter 27 at the input to phase detector 28. A relay 64 in phase detector 28 of FIG. 8A completes a path from a battery 62 to diode 52 in FIG. 4, thus imposing a very large forward bias on diode 52 and preventing power transfer to the transmission line in this situation. In the presence of a signal from filter 27, relay 64 is energized to prevent battery 62 from affecting the bias on diode 52.

If the alternative, simplified scheme is to be employed, it is desirable to maintain diode 52 in FIG. 4 either open circuited or short circuited with no intermediate condition of partial conduction. In this case, a cathode-coupled multivibrator 66 is placed between conventional phase detector 68 and power divider 36, as shown in FIG. 8B. When the phase of the signal from filter 27 lags the reference signal or when no signal appears at the output of filter 27, multivibrator 66 is in one state and presents a positive output voltage for application to power divider 36, maintaining a high forward bias on diode 52. When the phase of the signal from filter 27 leads the reference signal, the output of conventional phase detector 68 changes polarity triggering multivibrator 66 into a change of state. Multivibrator 66 then produces a negative output, that cuts off diode 52. This condition persists as long as the signal from filter 27 leads the reference signal.

Phase detectors 28, as described above, produce the desired signals to control output power divider 46 in the case of convexly curved array configurations generally, e.g. circular or elliptical arrays. But, there are some nonplanar array configurations in which the described phase detectors 28 do not control the power allocation by output power divider 46 satisfactorily. Regardless what array configuration is employed, however, the relative power distribution desired between the antenna elements is uniquely a function, depending upon the array configuration, of the relative phases between the signals received by the antenna elements. Thus with some complex array configurations nonlinear circuits or function generators might need to be interposed between phase detectors 28 and power divider 46 to bring about the desired power distribution. Alternatively, separate control

loops independent of the phase control loops could be provided for controlling the power distribution. A sample of the signal received by each element could be taken, and a control signal proportional to the amplitude of the received signal developed. This control signal would then be applied to controlled impedance 56 (FIG. 4) corresponding to the antenna element sampled to regulate that portion of the power to be transmitted that is applied to that antenna element.

Communication facilities 32 (FIG. 1) are not limited to repeater applications. For example, communication facilities 32 could include terminal equipment in which input signal combiners 24 are connected to a receiver delivering the received signal to a utilization device and an independent source of signals to be transmitted is applied to a transmitter and then distributed through output power divider 46 to the various antenna elements. However, the system need not be concerned with intercepting an information signal from the remote station, but only with transmitting in the direction of the source of a pilot signal. In this case, no receiver apparatus would be necessary and phase shifters 18 would be adjusted solely for the purpose of insuring the direction of transmission and the proper allocation of power among the antenna elements.

Furthermore, the system disclosed may be expanded to accommodate any number of remote stations. If each station is to be assigned a different frequency band, a different channel, each as shown in FIG. 1, would be required for each remote communication station per antenna element. An individual input signal combiner 24 and output power divider 46 would also be required for each remote station.

What is claimed is:

1. A communication station comprising an array of antenna elements having radiation patterns such that said antenna elements recover different quantities of power from an electromagnetic wave impinging thereupon, means for combining in phase waves impinging upon said elements from a remote source, a source of signals to be transmitted, means for applying said signal to be transmitted to said antenna elements in a relative phase relationship causing radiation of said signal to be transmitted with constructive wave interference in the direction of said remote source, and means for distributing the power of said signal to be transmitted among said elements in the same relative proportion in which said elements intercept the power of said impinging signal.

2. In a communication system, an array of antenna elements oriented to intercept unequal quantities of power from incident electromagnetic waves, a source of electromagnetic waves remotely located from said station for irradiating said array, transmission paths interconnecting said antenna elements with a common point, a controllable delay device situated in each of said transmission paths, means for developing a reference phase signal, means individual to each of said transmission paths for comparing in phase said reference phase signal and a direction indicating signal of the frequency of said reference phase signal derived from the signal of said remote source carried on said transmission path to develop a control voltage for regulating said delay device, a source of signals to be transmitted to said remote source, means for connecting said source of signals to be transmitted to said transmission paths for passage through said delay devices to said antenna elements, and means for allocating the power from said source of signals to be transmitted only to said antenna elements capable of contributing to a beam of radiation directed at said remote source.

3. A communication station comprising a plurality of antenna elements arranged to form an array, each of said elements connected by a transmission path to a common point, a variable phase shifter situated in each of said transmission paths, means for deriving control signals

individual to each of said transmission paths for adjusting said phase shifters to bring the signals irradiating said array from a remote source into phase with the average phase of said signals from said remote source, a source of signals to be transmitted toward said remote source, means for interconnecting said source of signals to be transmitted with each of said transmission paths, and means responsive to the control signal of each transmission path for regulating the proportion of the total power from said source of signals to be transmitted allocated to its corresponding transmission path.

4. In a communication station, an array of antenna elements, transmission paths interconnecting each of said elements with a common point, a source of signals to be transmitted connected to said common point, phase shifters situated in each of said transmission paths, and means individual to each of said transmission paths for regulating said phase shifters to cause radiation of said signal to be transmitted from said antenna elements toward a remote source irradiating said array comprising means for producing a direction-indicating signal the phase of which is related to the phase of the signal received by the corresponding antenna element, a source of signals at the frequency of said direction-indicating signal used as a phase reference for all of said regulating means, means for deriving a control voltage indicative of the phase difference between said reference signal and said direction-indicating signal, and means for applying said control signal to adjust said phase shifter.

5. A communication station comprising a plurality of antenna elements arranged in an array, means for interconnecting said antenna elements to a common point, said interconnecting means each introducing a controlled delay, means for deriving independent control signals for adjusting the delay introduced by each of said interconnecting means to cause signals intercepted by said antenna elements from a remote source to be brought into phase with one another comprising means for deriving a first signal the phase of which represents the phase of the signal from said remote source on the corresponding interconnecting means, means for producing a reference signal of the frequency of said first signal the phase of which represents the average phase of the signals from said remote station on all said interconnecting means, phase comparing means, and means for applying said reference signal and said first signal to said phase comparing means which produces said control signal, a source of signals to be transmitted from said array in the direction of said remote source, and means for applying said signals to be transmitted to said common point to be delivered to said elements.

6. A communication system comprising a plurality of antenna elements forming an array, a remote source of electromagnetic waves for irradiating said array, said remote source radiating two pilot signals of different frequencies, a source of signals to be radiated toward said remote station, transmission paths interconnecting each of said antenna elements with a common point, each of said transmission paths having means for introducing a controllable time delay, means individual to each of said transmission paths for deriving a control signal to adjust said time delays to align in phase the portions of said pilot signals recovered by all said elements comprising means for abstracting a sample of said pilot signals from said transmission path, means for beating said pilot signals together and separating the resulting lower sideband, a source of average phase signals derived by combining linearly the lower sidebands of all said transmission paths, and means for deriving as said control signal a signal representative of the phase difference between said average phase signal and said lower sideband, and means for coupling said source of signals to be radiated to said common point.

7. A communication system comprising a plurality of antenna elements arranged in an array, a remote source

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of electromagnetic waves irradiating said array, transmission paths interconnecting said antenna elements with a common point, a source of signals to be transmitted toward said remote source coupled to said common point, said transmission paths each having controllable time delay means, and means individual to each of said transmission paths for developing control signals to adjust said time delay means to align in phase the signals on all said transmission paths received from said remote source, comprising means for abstracting from said transmission path a sample of the signal received by said element from said remote source, means for linearly adding a first portion of said sample to similar samples from the other of said transmission paths to produce an average phase signal, means for mixing said average phase signal with the output from a local oscillator and separating the upper sideband produced, means for mixing said upper sideband with a second portion of said sample and separating the lower sideband produced by said last-mentioned mixing operation, and means for developing as said control signal a signal indicative in magnitude of the phase difference between said lower sideband and said output from said local oscillator.

8. In a communication system, a plurality of antenna elements oriented to form an array, the elements of which intercept unequal quantities of power from incident electromagnetic waves, a source of signals to be transmitted, transmission paths interconnecting said source with said antenna elements, means for irradiating said array with an electromagnetic wave, means for introducing phase shifts into said transmission lines causing the signals from said source radiated by said elements to combine constructively toward the source of said irradiating wave, and means for distributing the power from said source of signals to be transmitted among said antenna elements in the same relative proportion as said antenna elements recover power from said irradiating wave.

9. In a communication system, a plurality of antenna elements forming an array, means for interconnecting said antenna elements with a common source of signals to be transmitted, a remotely located source of electromagnetic waves for irradiating said array, means for adjusting the delay introduced by said interconnecting means to effect coherent radiation from said elements in a direction related to the angle at which said irradiating wave impinges upon said array, and means for allocating the power from said source of signals to be transmitted to each of said antenna elements as a function of the phase of said irradiating wave intercepted by said antenna element with respect to the phase of the wave intercepted by the other antenna elements.

10. A communication system comprising a nonplanar array of stationary antenna elements, the radiation patterns of which are directed in a convex curve, a source of signals to be transmitted, individual transmission paths interconnecting said source to said antenna elements, means for irradiating said array with an electromagnetic wave, means for delaying the signals to be transmitted in said transmission paths to cause constructive wave interference from said array in the direction of the source of said irradiating wave, and means for distributing the power from said source of signals to be transmitted among said antenna elements in the proportion effecting optimum antenna gain toward said source of said irradiating wave.

11. A communication system comprising an array of antenna elements, transmission paths interconnecting said antenna elements with a source of signals to be transmitted, a remotely located source of electromagnetic waves for irradiating said array, means for delaying the signals to be transmitted in said transmission path to permit constructive wave addition of the signals radiated from said array toward said remote source, and means for individually controlling the impedance that each transmission path presents to said source so that each antenna element radiates the same proportion of the

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total power of said signal to be transmitted as the proportion of the total intercepted power of said irradiating wave said antenna element intercepts.

12. A communication system comprising an array of antenna elements arranged such that only some of said elements are exposed to any incident electromagnetic wave, a source of signals to be transmitted, individual transmission paths interconnecting said source to said antenna elements, means for irradiating said array with an electromagnetic wave, means for delaying the signals to be transmitted in said transmission paths to cause constructive wave interference from said array in the direction of the source of said irradiating wave, and means for distributing power from said source of signals to be transmitted only to said antenna elements that are exposed to said irradiating wave.

13. In a communication system, an array of antenna elements, the composite radiation pattern of which is convexly curved, means for interconnecting said antenna elements with a common source of signals to be transmitted, a remotely located source of electromagnetic waves for irradiating said array, means for adjusting the delay introduced by said interconnecting means to effect coherent radiation from said elements in a direction related to the angle at which said irradiating wave impinges upon said array, and means for allocating the power from said source of signals to be transmitted equally to each of said antenna elements that recovers a portion of said irradiating wave the phase of which leads the average phase of the portions of said wave intercepted by all said antenna elements.

14. In a communication station, a plurality of antenna elements forming an array, the elemental radiation patterns of which are such that said antenna elements recover different quantities of power from electromagnetic waves impinging thereupon, a source of signals to be transmitted, transmission paths interconnecting said source with each of said antenna elements, means for irradiating said array with an electromagnetic wave, means for introducing phase shifts into said transmission lines causing the signals from said source radiated by said elements to combine constructively toward the source of said irradiating wave, and means for distributing the power from said source of signals to be transmitted equally only to said antenna elements that receive said wave with a minimum predetermined phase characteristic.

15. A communication repeater station for linking together a plurality of remote communication stations comprising a nonplanar array of antenna elements some of which are exposed to electromagnetic waves from each of said remote stations, transmission paths interconnecting said antenna elements with signal combiner circuits corresponding to each remote station, each antenna element having a transmission path corresponding to each remote station, the transmission paths from said elements being connected to their corresponding combiner circuits, said transmission paths each having means for introducing a controlled time delay, means for adjusting said time delay to bring the signals intercepted by said antenna elements from each of said stations into phase with one another, means for applying the combined signals to repeater apparatus for amplifying and shifting the frequency assignment of said combined signals, a power divider corresponding to each remote station, said transmission lines interconnecting said power dividers with said antenna elements, means for channeling said combined signals from said repeater apparatus to the power dividers corresponding to each remote station to which said combined signals are to be transmitted, and means for controlling said power dividers to allocate the power of each of said combined signals only to said antenna elements capable of contributing to a beam of radiation directed at the corresponding remote station.

16. A communication station comprising a plurality of antenna elements arranged in an array, means for connect-

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ing said elements to a common point, a phase control loop individual to each of said elements for causing signals intercepted by said antenna elements from a remote source to be brought into phase with one another comprising means for deriving a first signal, the phase of which represents the phase of the signal from said remote source on the corresponding interconnecting means, a source of reference signals oscillating at the frequency of said first signal, a phase detector, means for comparing said first signal and said reference signal in said phase detector, means responsive to said phase detector output for adjusting the phase of the signal carried on said interconnecting means, and means for rendering said phase control loop operative only during intervals in which a predetermined characteristic between said reference signal and said first signal exists, a source of signals to be transmitted from said array in the direction of said remote source, and means for applying said signals to be transmitted to said common point to be delivered to said elements.

17. In a communication system, a plurality of antenna elements forming an array, a remote source of electro-

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magnetic waves for irradiating said array, transmission paths interconnecting each of said antenna elements with a common point, each of said transmission paths having means for introducing a controllable time delay, means individual to each of said transmission paths for deriving a control signal to adjust said time delays to align in phase the portions of said electromagnetic waves recovered by all said elements comprising means for abstracting a sample of said portion from said transmission path, a signal combiner circuit, means for applying similar portions abstracted from the transmission paths associated with near-by antenna elements to said combiner circuit, a phase detector, means for comparing the output from said combining circuit with said sample in said phase detector, and means for abstracting as said control signal the output from said phase detector, and means for coupling a source of signals to be radiated to said common point.

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