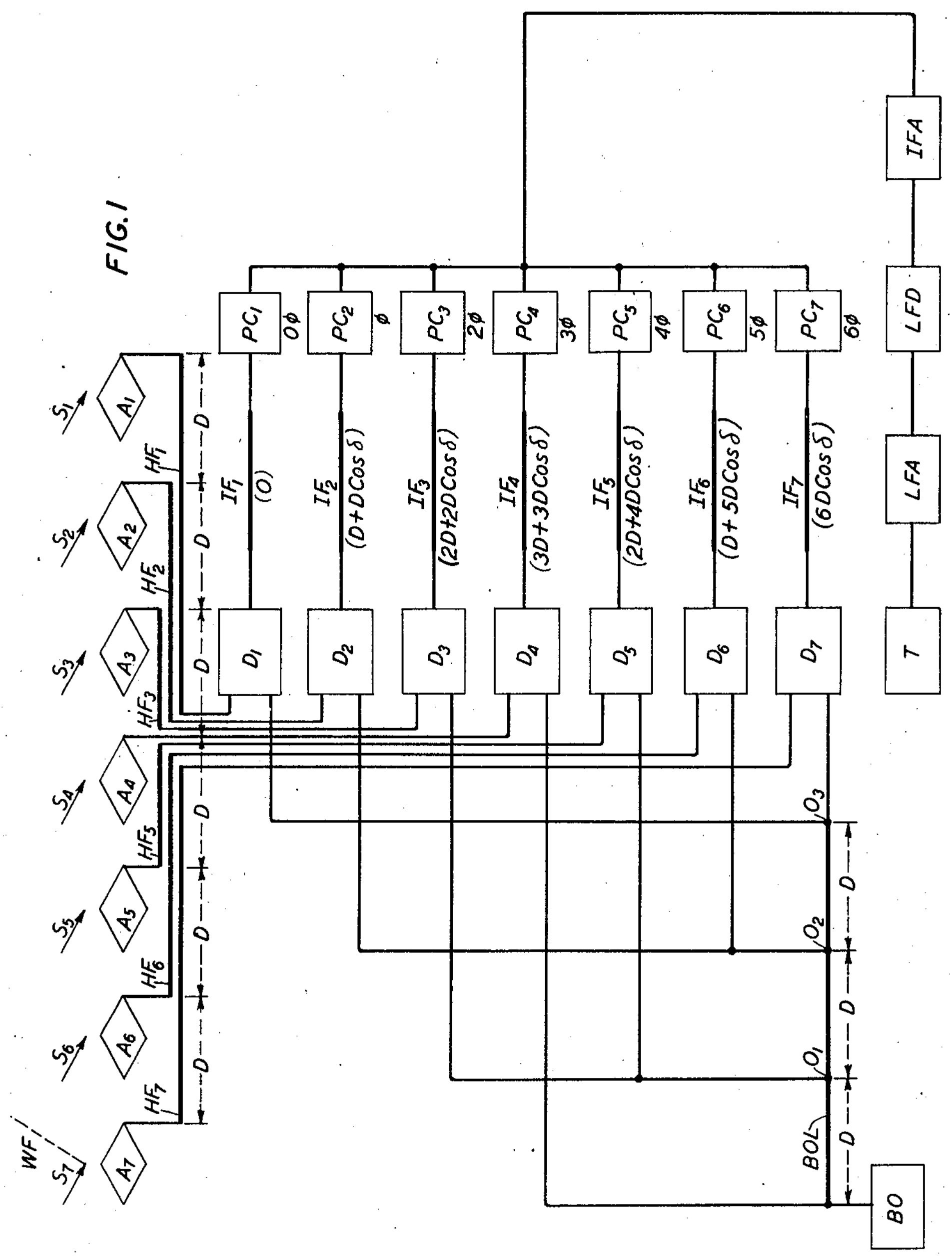
Dec. 24, 1940. D. H. RING 2,225,928

MULTIPLE UNIT STEERABLE ANTENNA SYSTEM

Filed July 14, 1939 2 Sheets-Sheet 1

FIG. 1



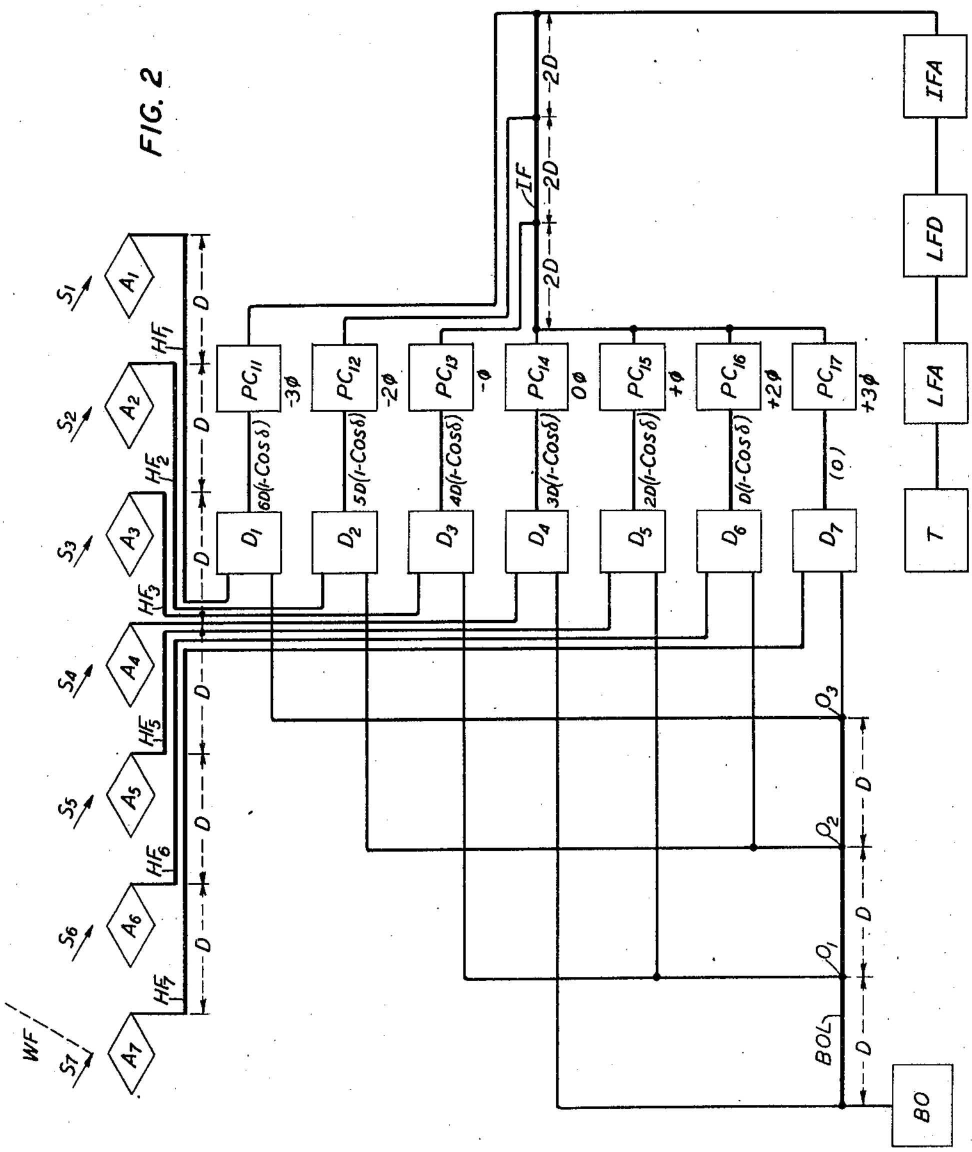
INVENTOR
D. H. RING
BY E. V. Griggs
ATTORNEY

Dec. 24, 1940. D. H. RING 2,225,928

MULTIPLE UNIT STEERABLE ANTENNA SYSTEM

Filed July 14, 1939 2 Sheets-Sheet 2

FIG. 2



INVENTOR
D. H. RING

BY E. V. Griggs

ATTORNEY

Patented Dec. 24, 1940 2,225,928

UNITED STATES PATENT OFFICE

2,225,928

MULTIPLE UNIT STEERABLE ANTENNA SYSTEM

Douglas H. Ring, Red Bank, N. J., assignor to Bell Telephone Laboratories, Incorporated, New York, N. Y., a corporation of New York

Application July 14, 1939, Serial No. 284,400

11 Claims. (Cl. 250—11)

This invention relates to radio communication systems, and more particularly to methods and means for controlling and improving the quality of either reception or transmission or both in a multiple unit steerable antenna system.

The invention is particularly concerned with multiple unit antenna systems generally of the type disclosed in Patent 2,041,600 of H. T. Friis, issued May 19, 1936.

One of the objects of the invention is to effect band width compensation in order to secure a maximum output over a theoretically infinite band of frequencies when the maximum lobe of a multiple unit antenna array is steered to coincide with the average incoming wave path or angle of the incoming carrier wave.

Another object of the invention is to provide a method and means for permitting the steering of the maximum lobe of the multiple unit array at different operating frequencies without altering the relative positions of the phase changers for each operating frequency when the lengths of the high frequency lines to the antennas are unequal, as in the case of a system where the receiver is located at a point intermediate the array, and do not vary progressively in a simple ratio.

Another object of the invention is to effect a saving in the amount of high frequency transmission line required between the antenna units and the receiving station by locating the station at the middle, or at any other convenient intermediate point between the ends, of a long antenna array.

Other objects and features will appear hereinafter in connection with the description of the preferred embodiments of the invention.

A multiple unit steerable antenna array, such as that disclosed in the above-mentioned Friis patent, is an end-on system and is designed to receive waves having a direction of arrival included in the vertical plane of the array, and ordinarily making an angle less than forty degrees with the horizontal. In order to secure a maximum effect at the receiver for a given incoming direction, as, for example, a horizontal direction, the out-of-phase wave components absorbed by the various antenna units must be rendered in phase at the receiver by means of phase shifters included between the antennas and receiver. To secure the maximum output at the receiver, the arrangement should be such that the various antenna units deliver to the receiver an in-phase resultant for each of the simultaneously received frequencies included in a side-band of the incoming signal at which the maximum lobe of the array is steered. If the unit antennas of the array are connected to the receiver or phase changers by lines of equal length, the various wave components will traverse paths of different lengths, for the reason that the paths in space from a given wave front corresponding to a given incoming wave direction are not equal.

The delay or time consumed by a wave component at a given frequency in traveling through the space path and thence through the line path to the receiver is directly proportional to the length of the particular path traversed; and for the paths of different lengths, the delays suffered in transmission over the different length paths will be unequal. For a given single frequency, correction or compensation for the difference in path lengths can be made by means of phase shifters. One of the problems toward the solution of which the present invention is directed is that of compensating for all of the several frequencies that constitute the carrier and its side-bands, and thus securing maximum output over a very wide and theoretically infinite band of frequencies.

Assuming a path of given length and several frequencies applied thereto, the phase at the output end of the line for each frequency will depend on the length of the line. If at a particular frequency the phase at the output end agrees with that at the input end, at another different frequency simultaneously transmitted over the path, the corresponding phases at the ends of the path will be different, and the rate of change in the phase shift will increase with frequency. That is, the delay or phase characteristic of the line is proportional to the line length. Hence, if several frequencies are supplied to two paths of different lengths, the phase relation or difference at one frequency of the waves at the far ends of the paths will differ from the phase relation, at another frequency, of the waves at the ends of the other paths. If the outputs of the two paths are combined, at some particular frequency the combined output will be a maximum, whereas at some other particular frequency the combined output will be a minimum.

In order to secure a maximum combined output at all frequencies, the delay, here defined as the rate of phase change with frequency, must be equal in the two paths. Since space and line paths have linear delay or phase-frequency characteristics, it is only necessary to make the over-all characteristics the same for all paths. In accordance with the present invention, the total electrical lengths of the several paths to the receiver, each of which paths comprises a space portion and line portions, are made equal. Thus the delays in all paths are the same, and at all frequencies in-phase addition occurs at the receiver.

Specifically, in the preferred embodiment of the invention herein disclosed this result is accomplished by the inclusion in each path of compensating intermediate frequency lines of such length or delay characteristics as to make all of the paths equal in effective length to the longest path for an assumed average incoming wave path or angle. This insures that the relative phase relations of the waves on all paths to the receiver shall be the same, and therefore that in-phase combination shall occur at the receiver.

The steering or directing of the maximum lobe of a multiple unit antenna array is a matter which involves the changing of the absolute phase of the signals received. For a given desired direction of reception the adjustment of the phase shifters differs with frequency; that is, if the reception of a wave of one frequency at a given steering angle is accomplished by a progressive adjustment of phase shifters by a certain number of degrees differential between them, the reception of a different frequency at the same steering angle will require the adjustment of the phase shifters at a different number of degrees differential between them. If the lines from the antennas to the receiver are of equal length or differ in length in accordance with a simple ratio, the phase changers may be driven through gears having the ratio 1, 2, 3, etc. for steering purposes. But if the lines are unequal and do not vary in such simple ratio, the phases of the wave components effective at the phase changers do not correspond with the phases at the antennas, and the steering control of the array is impaired.

In accordance with another feature of the present invention, whatever phase changes are introduced by dissimilar antenna spacing and corresponding differences in the lengths of the high frequency lines connecting each antenna to the associated first detector are balanced or eliminated by establishing a certain relationship between the lengths of the beat oscillator lines and the corresponding antenna high frequency lines extending to the first detectors of the various antenna units; as by making each beat oscillator line that extends to a certain detector equal in length to the high frequency line that extends from the antenna to that same detector. With this relationship established, upon a change in beat oscillator frequency, in the process of tuning to a different incoming frequency and at the same time maintaining the intermediate frequency constant, the same absolute frequency change occurs in the beat oscillator line frequency as occurs in the frequency that is coming in over the high frequency line. This has the effect of changing the phases equally. Since the beat oscillator is common to all detectors, the intermediate frequency currents have the same relative phases at the new frequency as they had at the original frequency. Signal wave delay is not affected since the line from the beat oscillator does not convey the signal currents.

The invention will be more readily understood from the following detailed description, when taken in connection with the accompanying drawings in which:

Fig. 1 illustrates one embodiment of the invention, in which the receiving station is located intermediate the ends of the antenna array, in which the irregularities in the lengths of the paths are equalized by the introduction of compensating delay means in the intermediate frequency portions of the paths, and in which steering compensation for tuning changes is effected by proportioning the lengths of the beat oscillator paths to the lengths of the corresponding high frequency antenna lines; and

Fig. 2 illustrates a modification in which the compensating delay means are introduced in a common portion, instead of in individual portions, of the intermediate frequency lines, and the steering is lined up on an intermediate instead of the rear antenna unit.

Referring to Fig. 1, reference characters A_1 to A_7 designate an array of horizontal rhombic receiving antennas assumed to extend in the plane of the great circle including the distant cooperating station with which communication is desired. The antenna units are not necessarily of the rhombic type, but may be any type of directive unit. The assumed direction of the incoming wave is indicated by any of the arrows S_1 to S_7. The wave direction may be included in the vertical plane containing the longitudinal array axis, or in a vertical plane angularly related to the axis, that is, the angle between the wave front and the array axis may be in any vertical plane or in a horizontal plane.

Each of the antenna units excepting A_4, which is at the receiving station, is connected along the array by a corresponding high frequency line HF_1 to HF_7, usually a coaxial line, with its corresponding modulator or first detector D_1 to D_7. Each of the first detectors is connected with a corresponding phase changer PC_1 to PC_7 by way of the corresponding intermediate frequency lines IF_1 to IF_7. The combined outputs of the branches controlled by the phase changers pass by way of intermediate frequency amplifier IFA, low frequency detector LFD and low frequency amplifier LFA to the translation device T, which, in the present intance, is assumed to be a radio signal receiver.

At each of the first detectors D_1 to D_7 the incoming energy from the corresponding antenna units is intermodulated with the energy of a high frequency wave supplied by the beat oscillator BO over the beat oscillator line BOL and its various branches. The beat oscillator and its line, as shown, are assumed to be located at the receiving station.

The circuit interconnections between the various elements are represented in part by light lines and in part by heavy lines. The light lines represent portions of the interconnections in which the transmission delay over the circuit is either inconsequential or is the same for all paths. The heavy lines represent portions of the interconnections having transmission delays which constitute factors in the equalization toward which the present invention is particularly directed.

Assuming first that the direction of reception is at zero angle, that is, a wave arriving in the horizontal plane of the antenna array and in a direction coinciding with the array axis, it is evident that the wave front, which in the assumed case is vertical, reaches the antenna A_7

first and passes the successive antennas of the array, finally passing antenna A_1.

With the antennas spaced apart by intervals D, which may be assumed to be equal, the length traversed by the wave in its passage from antenna A_7 to antenna A_1 is equal to 6D. Considering antenna A_7, as the reference point, the length of the space path to antenna A_6 is D, to A_5 is 2D, to A_4 is 3D, to A_3 is 4D, to A_2 is 5D and to antenna A_1 is 6D. If the angular direction of approach of the wave is greater than the zero angle, the lengths of the various space paths to the successive antennas of the array, represented by S_1 to S_7 for the various units, are diminished over the horizontal spacing intervals D according to the cosine of the angle between the wave direction and the array axis. Multiple unit steerable antenna arrays of this character are ordinarily designed to be steered at any angle between zero and approximately forty degrees.

The transmission path from the advancing wave front through each antenna to the corresponding phase changer is made up of a space portion, a high frequency transmission line portion, and an intermediate frequency transmission line portion. The condition that must be satisfied in order that the relative phases at the outputs of all of the paths shall remain fixed for all frequencies and shall therefore add properly at the receiver, is that the effective or electrical lengths of all of the paths from the advancing wave front by way of the antenna units to the receiver shall be equal. In the arrangement shown in Fig. 1, there is a wide diversity in the lengths of the respective paths from the advancing wave front, shown as the broken line WF intersecting the antenna A_7, to the corresponding first detectors. The length of the space portion of the path from the advancing wave front to antenna A_1 is 6D cosine δ and the high frequency line portion of the path by way of HF_1 has a length of 3D. Proceeding along the line of the array each succeeding space path is diminished by D cosine δ until at antenna A_7 the length of the space path is zero. On account of the central disposition of the receiving station with respect to the antenna array, in the embodiment of the invention shown, the length of the high frequency line becomes 2D for antenna A_2, D for antenna A_3, zero for antenna A_4, D for antenna A_5, 2D for antenna A_6 and 3D for antenna A_7. Therefore, the length of the paths as far as the first detectors may be represented as follows:

Antenna	Space	High frequency
A_1	6D cos. δ	3D
A_2	5D cos. δ	2D
A_3	4D cos. δ	D
A_4	3D cos. δ	O
A_5	2D cos. δ	D
A_6	D cos. δ	2D
A_7	0	3D

Space paths and transmission lines have linear delay or phase-frequency characteristics; that is, the phase shift is a linear function of frequency, and the delay or rate of change of phase shift with frequency is proportional to the length of the path or line, which, in the system under consideration, includes both space portions and transmission line portions. With paths of diverse lengths as indicated above, it is obvious that if several frequencies are being transmitted over the paths the phase shifts on the two paths will differ at all, except possibly one, of the transmitted frequencies whereby while complete phase agreement may result at the above-mentioned frequency when the line outputs are combined, phase disagreement of varying degree obtains at the remaining frequencies and at some particular frequency the outputs are 180 degrees out of phase. Consequently, the outputs from the various lines cannot be combined in phase for all frequencies unless the lengths of the path are made effectively equal.

As shown in the system of Fig. 1, this is accomplished by the inclusion in each path of compensating intermediate frequency lines of such length that all the paths from the various antennas of the array are made equal in length or delay to the longest path for the average assumed incoming wave direction or angle. In other words, the over-all delays in all of the paths are made equal.

By reference to the preceding tabulation, it will be seen that the longest path is that by way of antenna A_1, the space portion having a length of 6D cosine δ and the high frequency transmission line portion having a length of 3D. Therefore, to make the effective lengths of all the paths the same, there is added to the path in each of the intermediate frequency lines IF_1 to IF_7, sufficient length of line or its delay equivalent to bring the total for each path up to 3D+6D cosine δ. The path lengths thus added in the various intermediate frequency lines are indicated on Fig. 1, and are as follows:

$$IF_1=0$$
$$IF_2=D+D\cos.\delta$$
$$IF_3=2D+2D\cos.\delta$$
$$IF_4=3D+3D\cos.\delta$$
$$IF_5=2D+4D\cos.\delta$$
$$IF_6=D+5D\cos.\delta$$
$$IF_7=6D\cos.\delta$$

When the additions indicated above have been made in the various intermediate frequency lines, the effective lengths and delays of all of the paths become equal, the phases at each of the component frequencies are the same at the output terminals of the various paths and at each frequency the combined output energies produce a maximum resultant, and the width of the frequency band is theoretically infinite.

This is the relation which holds with respect to the particular angle of incidence δ that is chosen. When the maximum lobe of the array is steered at a different angle of incidence, the lengths of the space paths from the wave front to the various units of the array are altered proportionately to the cosine of the new angle; and slight alterations of the D cosine δ additions to the various intermediate frequency lines become necessary in order to maintain an exact in-phase relationship between the output energies of the various paths. But in practice it is sufficient to proportion the intermediate frequency line additions to the mean or weighted average angle of reception. When this is done the effect of variations in the steering angle upon the proper phase relations at the output terminals of the paths is minimized, and substantially in-phase combinations over a broad band of frequencies are maintained.

The ratio of the velocity of transmission through space to the transmission velocity over the high frequency lines and the ratio of the velocity in space to the transmission velocity over the intermediate frequency lines are factors entering into the determination of the exact values of the additions in the intermediate frequency lines to equalize the delays in all of the paths. For high frequency and intermediate frequency lines ordinarily employed in receiving systems these ratios are each equal to 0.933.

The conditions for infinite band width at any angle of incidence in the general case have been derived and are expressed in the following equation:

$$D \cos. \delta = V_s(L_{s2} - L_{s1}) + V_i(L_{i2} - L_{i1})$$

where

D=antenna spacing in meters

δ=between the array axis and the wave direction for which efficient operation over an infinite band width is desired

V_s=ratio of space velocity to high frequency line velocity

V_i=ratio of space velocity to intermediate frequency line velocity

L_{s1}=length of high frequency signal line to antenna 1 in meters

L_{s2}=length of high frequency line to antenna 2 in meters

L_{i1}=length of intermediate frequency line in antenna 1 path in meters

L_{i2}=length of intermediate frequency line in antenna 2 path in meters

The above equation shows that for any arbitrary lengths of L_{s1} and L_{s2} the conditions for theoretically infinite band widths for any angle of incidence may be fulfilled by correctly adjusting the difference $(L_{i2} - L_{i1})$.

The steering of the maximum lobe or lobes of a multiple unit steerable antenna system is a matter which involves the changing of the absolute phases of the various paths at the point where the outputs are combined. For the reception of any given frequency the steering of the maximum lobe requires only the relative setting of all phases correctly, regardless of the path delays. When the relative phases of the outputs of all the paths are correctly set for the proper steering angle at a particular frequency, the delays in the system determine the breadth of the band of frequencies that can be received without altering the relative positions of the phase changing units.

In a system in which the high frequency lines from the antennas to the first detectors are equal, steering may be accomplished by gearing the phase shifters together in a 1, 2, 3, etc. ratio, and it will not be necessary to alter the relative phase changer settings when the system is tuned to a new frequency. Also, if the high frequency lines from the antennas to the first detectors vary in any multiple of the gear ratios, compensation may be effected by turning the master control, and the relative phase changer settings will not need to be altered for changes in the frequency of the incoming carrier. An example of such a multiple unit array with uniformly spaced units and uniformly graded gear control of the phase changers is presented in the previously mentioned patent to Friis.

Where, as in the present case, this simple relationship of antenna unit spacing and high frequency line ratios does not exist, means must be provided for compensating for the departure from uniformly progressive phase differentials at the phase changers that is consequent upon dissimilar antenna spacing and dissimilar variation in the relative lengths of the high frequency lines.

Assuming that the frequency in the intermediate frequency lines is to be maintained constant, the frequency of the beat oscillator BO must be changed for each different high frequency carrier for which the system is tuned. The change in the frequency supplied by the beat oscillator must correspond to and be the same as the frequency difference between the carriers in tuning from one to another. Thus, if we assume a fixed frequency of one megacycle for the intermediate frequency, and a beat oscillator frequency of eleven megacycles for a ten-megacycle carrier, then to tune to a twenty-megacycle carrier the beat oscillator frequency, assumed in this case to be kept above the carrier frequency and its band, must be increased to twenty-one megacycles. This means that in changing the tuning of the system from one carrier frequency to another, the absolute change in frequency over the high frequency line is the same as the absolute change in frequency over the line that extends to the first detectors from the beat oscillator. The change in phase shift on any line of given length, however, is proportional to the absolute change in frequency and to the length of the line. Hence it is possible to add lengths of line to the beat oscillator paths to compensate for the changes that take place in the signal carrier phases over the irregularly related lengths of high frequency line when the tuning of the system is altered from one signal carrier frequency to another. More specifically by making the two lines from each detector, one to the antenna and the other to the beat oscillator, equal in length the phases of the beat oscillator waves supplied to the detectors have the same relation, at any tuning frequency, as the phase shifts introduced by the high frequency lines in the currents supplied to the detectors; and the output currents of the detectors have the same phase relation as the components absorbed by the antenna units. Stated differently, the phase shift in each beat oscillator-detector line nullifies the phase shift introduced by the associated antenna-detector line whereby the first detectors are in effect positioned at the terminals of the antenna units and directly connected thereto, and upon a change in tuning frequency steering may be accomplished without calibrating the phase shifters.

Such an arrangement is illustrated in Fig. 1 in which the effective lengths of the paths from the beat oscillator BO to the various first detectors D_1 to D_7 are made equal in each case to the length of high frequency line that extends from each particular first detector to the corresponding antenna of the array. In Fig. 1 it may be assumed that the length of beat oscillator line from the oscillator to the point O_1 is a length D, that the length of line from the beat oscillator to the point O_2 is 2D, and that the length from the oscillator to point O_3 is 3D. The connections from point O_1 are made to the two detectors D_3 and D_5, each one of which is connected with its corresponding antenna by a length D of high frequency line; from the point O_2 of the oscillator line BOL connection is made with the two detectors D_2 and D_6, each of which is connected with its corresponding antenna by a length 2D of high frequency line; and from the point O_3 of beat oscillator line connection is made with the two detectors D_1 and D_7, each of which is connected with its corresponding antenna over a length 3D of high frequency line. The connection of the beat oscillator with the detector D_4 is by means of a connection which is directly from the oscillator and is assumed to be of zero length to match the zero length of high frequency line which is assumed to connect detector D_4 with its corresponding antenna. Thus, the beat oscillator is connected with the detectors over beat oscillator lines the lengths of which in each case are equal to the lengths of the corresponding lines from the detectors to the antenna units of the array. When compensation for irregular phase change with tuning change has been effected as described above, the phase changers may be geared together in a 1, 2, 3, etc. ratio and all operated from a single drive shaft without adjustment upon a change in tuning frequency.

The relationships that must be established in order to satisfy this condition have been derived and are expressed in the following equation:

$$V_s(L_{s1}-L_{s2})+V_o(L_{o2}-L_{o1}=AD$$

where

L_{s1}=length of high frequency line to antenna 1 in meters

L_{s2}=length of high frequency line to antenna 2 in meters

L_{o1}=length of beat oscillator line to detector 1 in meters

L_{o2}=length of beat oscillator line to detector 2 in meters

V_s=ratio of space velocity to high frequency line velocity

V_o=ratio of space velocity to beat oscillator line velocity

A=any constant, including O

D=antenna spacing in meters

When the values of the different factors are so chosen that the constants A have the same value for each and every pair of units in the array, it is not necessary to alter the positions of the various phase shifters when the system is tuned to a new frequency. With beat oscillator lines to the detectors having the lengths shown and described in the system of Fig. 1, the conditions are such that the constant A of the above equation for each and every pair of units has the value of zero.

In Fig. 2 is shown a modified arrangement in which the intermediate frequency line for equalizing the effective lengths or delays of all of the branches is made common to all of the paths by being introduced beyond the phase changers, instead of ahead of them, as is done in the system illustrated in Fig. 1. The system of Fig. 2 is generally the same as that of Fig. 1, with the exception of the features that will be described, and reference characters the same as those of Fig. 1, are used for all elements illustrated excepting those which differ from the elements of Fig. 1.

In the system of Fig. 2 each of the first detectors or modulators D_1 to D_7 is directly connected with its associated phase changer PC_{11} to PC_{17}. The outputs of all but PC_{11} of the phase changers are connected with the common intermediate frequency amplifier IFA through part or all of the compensating intermediate frequency line IF. Each of the three sections of the line IF has a delay equal to 2D. The longest path, that by way of antenna A_1, detector D_1 and phase changer PC_{11} is connected directly with the intermediate frequency amplifier IFA, and has no delay in this portion of the intermediate frequency circuit. The path from antenna A_2 through detector D_2 and phase changer PC_{12} is so connected with the intermediate frequency delay path that it suffers a compensating delay of 2D. As shown, the path from antenna A_3 is delayed 4D in the intermediate frequency path, and the branches from antennas A_4 to A_7 each include the entire length of the intermediate frequency path IF and are each delayed 6D. For zero angle of arrival of the signal wave the over-all lengths of all of the paths are thus equalized, and the condition for in-phase combination for maximum output over a theoretically infinite band of frequencies is established.

Where the angle of arrival of the signal wave is greater than zero, exact compensation may be effected by introducing additional small delays, as by short pieces of intermediate frequency line, in the conductors connecting each of the first detectors D_1 to D_7 with its corresponding phase changer. The proper values for such additional delays may, for instance, be secured by zero addition in the connection from detector D_7 to phase changer PC_{17}, $D(1-\cos.\delta)$ in the connection from detector D_6 to phase changer PC_{16}, and progressively graded increments of 2, 3, 4, 5 and 6 times this value for the connections associated with detectors D_5, D_4, D_3, D_2 and D_1, respectively, as indicated in Fig. 2. These values may receive such slight modification as may be necessary also to compensate for the ratio of space velocity to line velocity.

Another respect in which the system of Fig. 2 differs from that of Fig. 1 is that in the Fig. 2 system the steering is lined up on the middle antenna unit A_4 instead of the rear antenna unit A_1, and the phase changers are arranged in two separate groups. One group includes phase changers PC_{11}, PC_{12} and PC_{13} and the other group includes phase changers PC_{15}, PC_{16} and PC_{17}. The phase changer PC_{14} associated with the first detector of the middle antenna A_4 of the array is in a sense a dummy, as this antenna, being the reference with respect to which the phases of the other two groups of antenna paths are shifted, requires no shifting of phase in the steering operation. Each of the groups of phase changers is driven by a separate shaft having uniformly graded gear connections with a 1, 2, 3 ratio, as indicated in the drawing. The common driving mechanism is arranged to drive the two groups of phase changers in opposite directions.

If it were assumed that the beat oscillator BO were connected with the series of first detectors by measn of paths of equal length, it would be necessary in changing the tuning of the system from one signal carrier frequency to another to mechanically disconnect the shafts of the two groups of phase changers from each other, rotate one or the other of the shafts until the energy contributions of the two groups were in phase with each other, and then again recouple the shafts in the readjusted position. But by virtue of the beat oscillator tuning compensation for diversity in length of the high frequency transmission lines between each antenna and its associated first detector, as described in connection with the system of Fig. 1, no relative adjustment of the two groups of phase changers is required when the tuning is changed from one signal carrier frequency to another. This is true as long as the beat oscillator frequency remains either above or below the carrier frequency for all tuning adjustments. If for any reason it should become desirable to change the beat oscillator frequency from one side of the carrier frequencies to the other, then the provision of a clutch between the groups of phase changers would permit a relative readjustment of the two groups to establish the new relationship required by the change in the side of the beat oscillator frequency with reference to the carrier.

It will be understood that delay networks or artificial lines constructed to have delay characteristics equivalent to those of the compensating intermediate frequency lines or to the compensating oscillator lines may be substituted for such lines if desired. It will also be understood that the principles of the invention may be utilized in an array designed for horizontal and/or vertical steering of the directional characteristic and that antennas designed for utilization of vertically polarized components instead of antennas designed to employ horizontally polarized components may be used.

What is claimed is:

1. In a radio system, an antenna array comprising a plurality of antenna units, a translation device, separate lines connecting said translation device to each antenna unit and each having a wave velocity differing from the wave velocity in space, and means included in certain of said lines for compensating for the difference in said line and space velocities, whereby the paths traversed by the wave components intercepting said units and extending from a desired wave front to the translation device are substantially equal in electrical length and have the same delay or phase-frequency characteristic.

2. In a radio system, an antenna array comprising a plurality of antenna units, a translation device located at a point intermediate the ends of the array, separate lines each including an intermediate frequency portion and a high frequency portion connecting said translation device to each antenna suit, the intermediate frequency portions of certain of said lines having lengths such that the phase-frequency characteristics of the paths traversed by the wave components intercepting said units and extending from the received wave front to the translation device are substantially the same.

3. In a radio system, an antenna array comprising a plurality of antenna units positioned to receive a desired wave end on, a modulator and a phase changer for each unit at a terminal station located intermediate the ends of said array, a translation device at said station, a transmission line for each unit consisting of a high frequency portion connecting the unit to the corresponding modulator and an intermediate frequency portion connecting the modulator to the corresponding phase changer, and a common intermediate frequency line extending to said translation device, said phase changers being connected to said intermediate frequency line at points such that the paths traversed by the wave components intercepting said units and extending from the wave front to the translation device are substantially equal in electrical length.

4. In a radio system, an antenna array comprising a plurality of antenna units, a modulator connected to each unit, a beat frequency oscillator connected to said modulators, the transmission lines extending from each modulator to the associated antenna unit and from each modulator to the beat oscillator being substantially equal in length, a separate phase changer connected to the output terminals of each modulator, and a translation device connected to said phase changers.

5. In a radio system, an antenna array comprising a plurality of antenna units, a translation device at a terminal station located intermediate the ends of said array, a plurality of modulators at said terminal station one for each of said units, a beat frequency oscillator at said station connected with each of said modulators, the transmission lines extending from each modulator to the corresponding antenna unit and from each modulator to the beat frequency oscillator being substantially equal in length, and a separate phase changer connected between each modulator output and said translation device.

6. In a radio system, an antenna array comprising a plurality of antenna units, a terminal station located at a point intermediate the ends of the array, a plurality of modulators at said terminal station one for each of said units, a line connecting each unit with its modulator, a translation device at said station, a beat frequency oscillator connected to said modulators, each modulator being connected to said oscillator through a length of transmission line such that the difference between the lengths of the lines connecting successive pairs of units with their modulators taken pair by pair in one direction along the array plus the difference between the lengths of transmission lines connecting the oscillator to the modulators of successive corresponding pairs of units taken in the other direction along the array shall equal a constant having the same value for all the successive pairs of units along the array, a connection between each modulator output and said translation device, and a separate phase changer included in each of said connections.

7. In a radio system, an antenna array comprising a plurality of antenna units positioned to receive a desired wave end on, a translation device at a terminal station located intermediate the ends of said array, a modulator at said station for each unit and having connection with such unit, the paths traversed by the wave components intercepting said units and extending from the received wave front to the translation device by way of said modulators being substantially equal in length, a beat frequency oscillator connected to said modulators, the transmission lines extending from each modulator to the associated antenna unit and from each modulator to the beat oscillator being substantially equal in length, and a separate phase changer connected between each modulator output and said translation device.

8. The method of steering compensation for deviations from uniformity of spacing with respect to the terminal station of the antenna units of a multiple unit array, which consists in conducting to the terminal station the signal frequencies received at the various units, modulating each signal frequency with a beating oscillator frequency conveyed over a transmission path equal in length in each case to the length of transmission path from the corresponding unit to produce intermediate frequencies of uniformly related phase differences, and controlling the phases of the intermediate frequencies for combination in-phase at a receiver.

9. In a radio system, an array comprising at least two antenna units connected to a translation device by separate lines of different physical length, the wave velocity on said lines being different from the wave velocity in space, said physical length difference being related to the angle between the array axis and the desired wave direction and to the difference in said velocities, whereby the paths extending from the desired wave front to said device and each including an antenna unit and associated line have equal electrical lengths and equal phase-frequency or delay characteristics.

10. In a radio system, a linear array comprising a plurality of antenna units connected by separate lines to a translation device, the angle between the array axis and the desired direction of radiation or reception being acute, the line and space velocities being different, the lines connected to adjacent units being adjusted to differ in actual length an amount dependent upon said angle and the difference between said velocities.

11. A method of obtaining at a receiver in-phase currents at each frequency in a large band of frequencies from a signal wave intercepting the antenna units of a linear array and having a given direction, utilizing separate lines for connecting said units to said receiver, which comprises ascertaining the differences in line length required to render equal in physical length the paths traversed by the wave components and extending to the receiver from the wave front at the unit first intercepted, ascertaining the length correction necessary to compensate for the difference in line and space velocities and connecting lines having the ascertained lengths between said units and receiver.

DOUGLAS H. RING.